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Production Quotas, Competition and Farm Values: A Chronicle of the Swine Industry in North Carolina

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North Carolina imposed a moratorium on the construction and expansion of swine farms in 1997. Existing facilities were granted production permits tied to specific properties, but the quota contributed to the consolidation of pork processors and stifled competition in the market for live hogs. Theory predicts that production permits should be a source of quasi-rents to farmers but that the market power of processors would reduce their value. Using a hedonic model of farm sales from 1994 to 2010 we find that the value of production permits dropped from 55% of the average farm price to 49%, costing farmers on average $68 thousand.

Key words: agricultural policy, hedonic models, oligopsony, production permits, scarcity rents

Introduction

The US pork industry underwent a “revolution" in the 1980s and 1990s (Southard and Reed, 1995). Hog farming shifted from being a traditionally supplemental agricultural enterprise to larger and more specialized operations. Between 1982 and 1992, for example, while the number of hogs sold increased by 17%, the number of swine farmers declined by 42% (Furuseth, 2001). During this period of realignment, the hog population in North Carolina burgeoned. In the 10-year period from 1988 to 1997, the hog population in the state grew from around 2.6 million to over 9 million and North Carolina went from seventh in pork production to ranking second, behind only Iowa. The number of swine farms in North Carolina, meanwhile, fell from nearly 11,000 in 1982 to around 2,300 in 1997. These trends were accompanied by two major forces: the transition to a vertically integrated corporate model and the rapidly increasing market concentration among integrators/ processors, which eroded the competition in the market for live hogs.

Following a lagoon overflow, which resulted in 20 million gallons of hog waste entering the New River, human health and environmental degradation concerns led North Carolina to enact The Clean Water Responsibility and Environmentally Sound Policy Act of 1997. This legislation effectively placed a moratorium on the construction or expansion of swine farms in North Carolina. Along with the moratorium, North Carolina implemented increased farm monitoring and regulation. Existing farms were freely allocated permits in the form of Certificates of Coverage that defined both farm type and production capacity. As a result, the location and amount of live hog production in the state has been permanently restricted since 1997.

Increasing demand for pork—combined with the permanent moratorium on expansion, freely allocated permits, and the spatial concentration of farms in southeastern North Carolina—creates a unique opportunity to evaluate the effects of an increasing market concentration among pork processors on quota values, capitalized into farm values. When evaluating one of the largest

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acquisitions in the swine industry, Smithfield's purchase of Murphy Farms in 2007, the US Justice Department determined that the transaction was not likely to harm competition, consumers, or farmers. In our theoretical framework, however, we postulate that the allocated production permits—tied to specific farms—are expected to produce preservable rents to farmers that should be capitalized into farm values. Helped by the imposed moratorium on the construction of new hog farms, which effectively served as a barrier to entry, we predict that processor market power would increase, harming competition, and the value of permits would decrease, hurting farmers.

This article connects several major threads of economics literature. First, our work considers the impact of production controls (quotas) on production and profits. Second, we investigate the effects of market power in agricultural input markets. Third, we examine how income streams and rents are capitalized into property values. Finally, we contribute to the hedonic literature by exploring how economic policies and market competition impact property values. Both the impact of production control measures on firm profits and the effects of increased regional concentration in livestock procurement have been extensively studied since the 1980s. This article is different because it combines these two branches of the literature by estimating the impact of increased concentration on competition and on the value of rents in a regulated industry where an aggregate production quota is binding.

It is well known that production controls lead to producer gains at the cost of consumer and societal losses (Wallace, 1962). These regulations—which have been used in tobacco, peanut, dairy, and fishing markets—transfer income from consumers to producers through reduced quantities and increased prices (Rucker and Thurman, 1990; Wilson and Sumner, 2004; Grafton, Squires, and Fox, 2000). In addition, the rate of return on quota ownership is typically much higher than it is on comparable market assets and has been tied to increased revenues and preservable rents (Sumner, Alston, and Glauber, 2010; Stavins, 2011). This outcome has previously been demonstrated in tobacco, dairy, and fishery markets (Seagraves, 1969; Moschini and Meilke, 1988; Grafton, Squires, and Fox, 2000). In fact, it has been argued that a high proportion of farmer wealth is attached to production quotas (Wilson and Sumner, 2004). Price signals in quota markets, therefore, are an essential source of information about the expected profitability and economic health of farms (Newell, Papps, and Sanchirico, 2007).

There has been an increased emphasis on the effects of vertical integration and market power in agricultural markets (Sexton, 2013). Theoretical models of both monopsonistic and oligopsonistic processors suggest that deadweight losses are small but that the distributional effects may be large because market intermediaries capture large shares of farmer rents (Perry, 1978; Sexton, 2013). While market concentration continues to increase in food-manufacturing industries, the empirical literature has yet to clearly establish adverse effects (Shames, 2009; Wise and Trist, 2010). Empirical price results are sensitive to underlying assumptions and have been mixed (see, e.g., Murray, 1995; Muth and Wohlgenant, 1999, on pulpwood and sawlog inputs and beef processing, respectively). Two articles have attempted to evaluate processor market power in the swine industry. Inoue and Vukina (2006) did not find statistical evidence of market power in the production contract settlement data, but Zheng and Vukina (2009) found that the presence of contracts (captive supplies) facilitates the exertion of processor market power on the spot market for live hogs.

The present value model contends that land values in equilibrium should be equal to the discounted stream of future profits derived from that land. Consequently, to the extent that various economic policies or government programs contribute to the profitability of an enterprise suitable to be carried out on the land, the value of that property should be enhanced by those programs. Corresponding literature has demonstrated that income from agricultural support programs (Weersink et al., 1999; Goodwin, Mishra, and Ortalo-Magné, 2003; Ifft, Kuethe, and Morehart, 2015), conservation reserve programs (Wu and Lin, 2010), production control programs like tobacco allotments (Vantreese, Reed, and Skees, 1989), and even hunting leases (Henderson and Moore, 2006) are capitalized into land values.

Table 1. US Swine Industry Concentration Measures

	2019	2011	2010	2000	1999	1994
C(4) = top 4 firms	0.2812	0.2218	0.2820	0.1930	0.1768	0.0652
C(8) = top 8 firms	0.3917	0.3236	0.3727	0.2560	0.2393	0.1032
C(20) = top 20 firms	0.5599	0.4336	0.4847	0.3578	0.3347	0.1365
Total no. of US sows	6,398,447	5,776,970	5,741,150	6,182,550	6,237,990	7,393,320

Notes: Market concentration rates are measured in sow ownership. Firm-level data (numerator) were extracted from *Successful Farming Magazine*'s "Pork Powerhouse" rankings. Total industry sows (denominator) was obtained from the USDA December issue of the Quarterly Hogs and Pigs report.

Last, Rosen's (1974) hedonic model has been used to estimate the effect of external property features on prices. A majority of the literature has focused on residential properties and, less frequently, on agricultural settings. Palmquist (1989) developed one of the first agricultural hedonic models to consider how agricultural policy impacts differentiated factors of production. Economists, applying the hedonic model to agriculture, have identified the impact of parcel size, regional scarcity, soil productivity, potential erosivity, alternative land uses, and distance to large cities (Palmquist and Danielson, 1989; Huang et al., 2006; Bergstrom and Ready, 2009).

Utilizing a proprietary dataset of farm sales between 1994 and 2010, along with state permitting information and pork processor market concentrations, we investigate the effect of the increasing market power of processors on farm rents and farm values. The empirical results show that, in line with our theoretical predictions, the production-controlling Certificates of Coverage are capitalized into land values and the value of these certificates declined as processor market power increased. For the entire period covered by the data, the value of the permits dropped from 55% of the average farm price to 49%, representing a loss of about $68 thousand per farm.

Background

Swine Industry Dynamics, Structure, and Organization

In 1994, *Successful Farming Magazine* published its first edition of "Pork Powerhouses," its rankings of the largest pork companies in the United States. The findings surprised many people: The survey showed that the top 30 largest companies produced about one-quarter of all hogs marketed in the United States. Two firms from North Carolina, Murphy Family Farms with 180,000 sows and Carroll's Foods with 110,000 sows, topped the list of the 30 largest companies in the country. Perhaps the only thing more astonishing than the size of these companies was the speed of their growth. Carroll's Foods, for example, had 20 times as many sows as they had had 10 years prior, and third-ranked Premium Standard Farms from Missouri went from 0 to 97,000 sows in 5 years. Despite this rapid growth, the hog industry was still not highly concentrated. As seen in Table 1, measured by the number of sows, the concentration ratio of the top four firms in 1994 was 6.5%, the top eight firms controlled 10.3%, and the top 20 firms controlled only 13.7% of the market.[1]

The mid-1990s clearly mark the beginning of the strategic emphasis on expansion and vertical integration for Smithfield Foods, originally a meat packer headquartered in Smithfield, Virginia, and the industry's future most dominant player. By that time, Smithfield had already opened the world's largest processing plant in Tar Heel, North Carolina (in 1992), formed long-term contractual relationships with three North Carolina hog companies (Murphy, Carroll's, and Prestage), and begun producing their own hogs through Brown's of Carolina and Smithfield–Carroll's joint hog

[1] The concentration ratios were calculated relative to industry totals obtained from the USDA December issue of the Quarterly Hogs and Pigs report, table "Hogs and Pigs Inventory by Class, Weight Group and Quarter - United States," September 1 inventory for the category "Kept for breeding." To account for boars, the numbers were adjusted downward by 1% for the years 1994–2004 and by 0.5% for the years 2005–2019.

production arrangement. After a year in which hog prices fell to $8/cwt and producers of all sizes were losing money, on September 1, 1999, word came that Smithfield would acquire Murphy Family Farms and its 325,000 sows. Just prior to acquiring Murphy, Smithfield had made other large acquisitions. It bought Western Pork Production in Colorado (12,000 sows) and J&K Farms (15,000 sows) and Carroll's Foods (180,000 sows), both from North Carolina. In 1994, Smithfield had only 65,000 sows. Over the next 5 years, mainly through mergers and acquisitions, Smithfield grew to become the number one vertically integrated US pork packer–producer, with 675,000 sows in 1999. In this 5-year period, the industry concentration increased considerably. The C(4) concentration index grew to 17.7%, C(8) grew to 23.9%, and C(20) grew to 33.5% (Table 1).

In the first decade of the 21st century, hog industry concentration continued to grow, albeit at a slower rate. In September 2006, Smithfield announced its intent to buy Premium Standard Farms, another vertically integrated company and its main rival. In 2005, the last year in which Premium Standard appears on the "Pork Powerhouses" list, with its 225,000 sows in production, it was ranked second in the country. After that purchase, Smithfield's breeding stock in 2007 climbed to 1.23 million sows and its individual market share grew to almost 20% of the national breeding stock. The US Justice Department launched an investigation into this deal but determined that this transaction was not likely to harm competition, consumers, or farmers. By the end of the decade, the swine industry breeding stock had fallen by about 7% relative to its peak in 2007. Smithfield also reduced its breeding stock, both in absolute terms and as a percentage of the national total, such that its market share dropped to only about 15%. For the decade as a whole, however, the concentration ratios of the industry's top four firms grew from 19.3% in 2000 to 28.2% in 2010, the concentration ratio top eight firms grew from 25.6% to 37.3%, and the concentration ratio of the top 20 firms increased from 35.8% to 48.5%.

The most important event of the second decade for the US swine industry occurred on May 29, 2013, when WH Group, then known as Shuanghui Group, the largest meat producer in China, announced the purchase of Smithfield Foods for $4.72 billion. At the time of the deal, China was one of the largest importers of US pork, although it had 475 million swine of its own, roughly 60% of the global total (Palmer, 2013). When WH Group took over Smithfield's market share, its percentage of the total number of sows still stood at 15% and this percentage has remained largely unchanged until the present. The industry as a whole, however, continued its trend toward higher concentration at even slower pace than that achieved in the previous decade. C(4) increased from 22.2% in 2011 to 28.1% in 2019, C(8) increased from 32.4% to 39.2%, and C(20) increased from 43.4% to 56%.

The competitive landscape in North Carolina generally followed national trends, with some important differences. The 1994 "Pork Powerhouses" survey shows that among the top 31 companies, eight of them were headquartered in North Carolina (Murphy, Carroll's, Prestage, Goldsboro, N.G. Purvis, J.C. Howard, J&K Farms, and Coharie Mill and Supply Co.) and an additional six had production base (sows) in the state, for a total presence of 14 firms. This large presence of hog companies in the state reflects tremendous industry growth, which brought North Carolina to being the second-ranked hog-producing state in the nation (after Iowa), up from seventh as recently as 1988.

Only 5 years later, the 1999 industry survey of the largest pork companies in the United States shows a somewhat different picture. This period is characterized by the beginning of the Smithfield's acquisition spree: Some of North Carolina's important players (Murphy, Carroll's, J&K Farms) had already been swallowed by their powerful competitor. Interestingly, the 1999 survey shows that the number of companies headquartered in North Carolina actually increased to 10 and that six other companies maintained a production base in the state, for a total of 16 firms involved in North Carolina's swine production. Despite the significant increase in industry concentration nationally, and the fact that three important players in the state had been acquired, the competitive environment in North Carolina during this 5-year period did not deteriorate appreciably.

If we fast forward through the next decade, we find a dramatically different competitive environment in 2010. Nationally, as shown in Table 1, the industry continued its path toward

consolidation and concentration. In the case of North Carolina, the national trend was even more pronounced. The US "Pork Powerhouse" 2010 survey shows the presence of only four companies with a production base in the state, down from 16 a decade prior.[2] The reason for this amplified industry concentration in North Carolina relative to the national trend is unambiguously the consequence of the 1997 moratorium on the construction of new hog facilities (to be discussed later), which effectively served as the barrier to entry and therefore stifled competition.

In addition to its growth and size, the North Carolina swine industry owes its fame to the fact that it became the cradle for the model of vertical integration and production contracts. A production contract is an agreement between an integrator company and a farmer (grower) that binds the farmer to specific husbandry practices in exchange for monetary compensation, free of market price volatilities. Different stages of the production of animals are typically covered by different contracts, and farmers generally specialize in the production of animals under one contract. The most frequently observed contracts in the swine industry are contracts for a single production stage (e.g., farrowing contracts, nursery contracts, and especially finishing contracts). Some integrators, however, offer contracts that combine several production stages. These are known as farrow-to-finish or wean-to-finish contracts. The division of responsibility for providing inputs between the two parties is such that growers provide land, housing facilities, utilities (electricity and water), and labor and are also responsible for manure management and disposing of dead animals. An integrator company provides animals, feed, and veterinary services. Integrators commonly own and operate feed mills and provide transportation for feed and live animals. Some companies are completely vertically integrated into slaughter and processing, while others specialize only in live production and typically have marketing agreements with pork processors.[3] The concept of production contracts was originally developed in the poultry sector (i.e., broilers and turkeys) and was successfully transplanted into the swine industry, where it gradually became the dominant mode of organizing live production, replacing traditional operations and spot (cash) market. Contracts covered 68.1% of hog production in 2008, up from 34.2% in 1996–1997 and 62.5% in 2002–2003 (MacDonald and Korb, 2011).

Figure 1 presents an organizational flowchart of the swine industry. As seen from the chart, hog farmers (producers) can participate as independent producers (entrepreneurs) or as contract farmers providing animal husbandry services in the different stages of the live production process. The shaded shapes and arrows indicate the vertically integrated segment of the industry. Integrators offer contracts in single stages of the production process (e.g., feeder-to-finish) or combine several production stages under one contract (e.g. wean-to-finish). Traditionally, independent producers engage in all stages of production from farrowing to finishing.

The reliance on production contracts for live hogs raises an important question about whether integrators/processors, when contracting for grower services, have the capacity to engage in some type of noncompetitive (oligopsony) behavior. In the livestock industries context, multiple reasons might explain the absence of perfectly competitive contract grower markets (Inoue and Vukina, 2006, see). Most relevant for this study is the fact that different geographical areas, or the same geographical areas at different time periods, could experience different levels of competition for grower services based on the different number of integrators (buyers). The fact that transporting bulky inputs and live animals over long distances is very costly creates opportunities for the emergence of persistent market (monopsony) power, even in cases where the larger national market could be perfectly competitive. From 1994 to 2010, with the percentage of production covered by

[2] Because "Pork Powerhouse" rankings in the 1990s did not capture companies involved in contracting with fewer than 10 thousand sows and due to certain ambiguities in the definitions of the headquarters and the production base, the data for North Carolina are not entirely reliable. An industry expert estimates that 22 firms were involved in swine contracting in North Carolina in 1994, nine in 2010, and only five in 2024 (personal communication with Dr. Todd Sea, Professor and Head, Department of Animal Science, North Carolina State University).

[3] Throughout this article, we use the term *integrators* to refer to companies involved only in organizing the production of live hogs for slaughter (processing). The term *processors* refers to either fully integrated companies with live production and processing or with processing alone. The terms *producers* and *growers* are used interchangeably to refer to hog farmers.

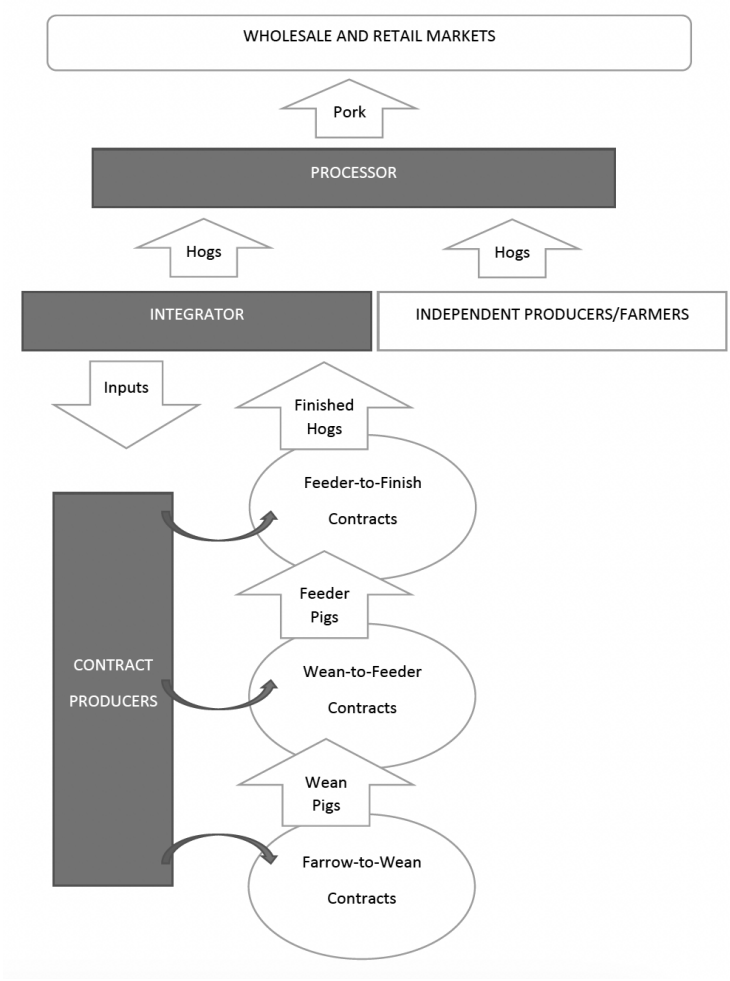

Figure 1. Organization of the Swine Industry

contracts at nearly 100%, the national market concentration more than tripled, and the number of firms located in North Carolina decreased by 60%. Changes to the swine industry structure indicate that, over the years, competition in the sector has clearly deteriorated, providing favorable conditions for noncompetitive types of business practices.

Swine Industry Regulation and Litigation

In June 1995, over 20 million gallons of hog waste spilled from an 8-acre lagoon in Onslow County, North Carolina, and entered the New River. Within a month, the North Carolina Senate passed the Swine Farm Siting Act, restricting the location of new swine houses and lagoons (North Carolina House of Representatives, 1995). Soon after, in March 1997, the General Assembly of North Carolina enacted The Clean Water Responsibility and Environmentally Sound Policy Act, establishing a 2-year moratorium on the construction or expansion of hog farms, lagoons, and swine waste management systems (North Carolina House of Representatives, 1997). The moratorium was originally established to allow counties time to adopt zoning ordinances and for the completion, receipt, and response to existing studies. This legislation was renewed for 2 years prior to the 1999 hurricane season and extended by the North Carolina General Assembly twice more before finally becoming permanent in 2007.

In addition to the moratorium, state officials under political pressure from environmental groups and the general public vowed to do more to solve the problem of hog waste storage in open-air lagoons. On July 25, 2000, the centerpiece agreement was signed with Smithfield Foods, who agreed to finance research into alternatives to the lagoons and to install, within 3 years, whatever system emerged as environmentally effective and economically viable. In place of open-air lagoons should have been a newer, safer system that would have put North Carolina on the cutting edge of commercial agriculture. Smithfield committed to providing a total of $17 million for research at North Carolina State University and to donating an additional $50 million over the next 25 years to programs protecting the state's environment. After years of work, in March 2006researchers presented to the state Environmental Review Commission one technology that met all of the environmental criteria for newly constructed hog farms, but it was too expensive to retrofit existing hog farms. At the time, it would have cost around $400 per 1,000 lb of swine to install, whereas the lagoon system cost only $87, so nothing happened (Buford, 2018).

The imposition of the moratorium and permitting, as well as the Smithfield agreement, did little to reduce the steady stream of legal actions against integrators and contract farmers. It is hard to keep track of the number of lawsuits, complaints, EPA filings, and administrative challenges that have taken place since the vertically integrated model of hog farming started to dominate the state's economy more than 30 years ago. Allegations of racism and environmental injustices have been at the heart of many of those battles. For example, 26 federal nuisance lawsuits have been brought against Murphy-Brown, LLC, alone by more than 500 plaintiffs. Juries in five trials in 2018 and 2019 awarded 36 plaintiffs a total of almost $550 million, a number that was quickly whittled down to about $98 million because of a North Carolina state law that caps punitive damages (Newsome, 2021).

Despite many problems and failed initiatives, robust legislative action has given North Carolina one of the strongest swine facility permit programs in the country (North Carolina Department of Environmental Quality, 2015). Since 1993, each facility has been covered by the North Carolina Swine Waste Management System General Permit, which is renewable and valid for 5 years. The general permit contains required performance standards, annual inspection expectations, production restrictions, and penalty policies. Each permit, for example, includes a Certificate of Coverage that is permit-specific and designates the permitted number and type of swine. Permitted animal operations are also required to have a Certified Animal Waste Management Plan developed by a certified technical specialist. Each certificate specifies the type of swine production and the maximum annual average number of swine that can be produced at that facility. The average weight of swine produced and, consequently, the amount of waste generated depend on the type of swine production. The maximum annual number of swine is multiplied by the respective average swine's weight to compute a facility's permitted Steady State Live Weight (*SSLW*) (Harden, 2015).

As a result of the moratorium, the number, location, and size of swine farms in North Carolina has remained unchanged since 1997. The North Carolina Department of Environmental Quality maintains a list of permitted animal facilities that includes the owner, type, location, and size of each facility. There are currently 2,189 permitted swine facilities covering 61 of North Carolina's 100 counties. These certificates amount to an astounding 9.6 million permitted swine, with 3,694 associated lagoons. The geographic location of the associated lagoons can be seen in Figure 2. A full 46% of all permitted swine are located within Sampson and Duplin Counties in eastern North Carolina, with another 14% in neighboring Wayne and Bladen Counties. Table 2 lists the types and associated number of swine facilities in North Carolina. There are eight production types, but farmers predominantly engage in only one type. Among the 2,189 swine farms in North Carolina, over 92% fall within three main categories. Nearly 15% are farrow-to-wean facilities, 22% are wean-to-feeder, and over 55% are feeder-to-finish facilities.

Despite the presence of the production quota system, the sell side of the live hogs market remained perfectly competitive, as indicated by the presence of 2,189 permitted producers (farms). Table 3 summarizes the ownership of permitted farms in 2020. The single largest owner of hog farms

Table 2. Swine Facilities in North Carolina

	Farms	Avg. No. of Swine	Min.	Max.	Avg. Lbs	Avg. SSLW
Boar/stud	12	411	130	809		
Farrow-to-feeder	27	1,081	18	4,800	522	564,282
Farrow-to-finish	23	402	100	1,250	1,417	569,634
Farrow-to-wean	315	2,835	20	10,800	433	1,227,555
Feeder-to-finish	1220	4,617	150	64,680	135	623,295
Gilts	34	1,216	70	7,200	150	182,400
Wean-to-feeder	482	4,932	180	32,000	30	147,960
Wean-to-finish	76	8,275	1,033	60,000	115	951,625
All farms	2,189	2,971	18	64,680		

Notes: Data on all 2,189 permitted swine facilities come from the NC Department of Environmental Quality (NCDEQ). Farrow pigs are weaned near the 4-week mark, are feeder pigs when they reach around 8 weeks and reach market weight (finish) in 6 months. A gilt is a female hog that has not yet produced a litter of piglets. The average facility-type weight is set by the NC Department of Environmental Quality (NCDEQ) and is multiplied by the facility's maximum allowable count to calculate each facility's steady state live weight (SSLW).

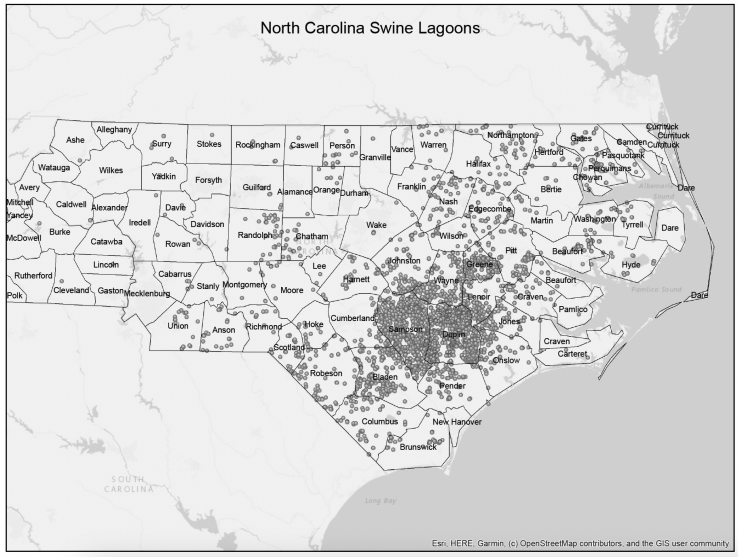

Figure 2. Locations of the 3,694 North Carolina Swine Lagoons

is Murphy Brown, which owns about 6.5% of all hog farms in the state. Given that Murphy Brown is a part of the vertically integrated chain (Smithfield Foods - WH Group), these animals were most likely moved from the live side to processing using some form of intrafirm transfer pricing and are usually referred to as the industry's captive supplies. Nevertheless, the sell side remains highly competitive. Using NCDEQ data on farm ownership, we computed the Herfindahl–Hirschman Index (HHI) to be extremely low, 57.81 (on the 10,000 scale). Taking into consideration that a market with an HHI of less than 1,500 is considered competitive, and contrasting it with only several companies on the buy side (see footnote 2), the competitive asymmetry of the live hog market in North Carolina market is obvious.

Table 3. Ownership of Permitted Hog Farms in North Carolina in 2020

Owner	No. of Owners	Farms per Owner	Total Farms
Murphy Brown	1	143	143
Prestage	1	39	39
Maxwell	1	32	32
Ironside	1	22	22
Kronseder	1	15	15
Coharie	1	12	12
N.G. Purvis	1	11	11
	2	8	16
	5	7	35
	3	6	18
	11	5	55
	24	4	96
	75	3	225
	223	2	446
	1,024	1	1,024
Total			2,189

Notes: Data on all 2,189 permitted swine facilities come from the NC Department of Environmental Quality (NCDEQ). While the NCDEQ does not keep historical records, this data demonstrates that as recently as 2020, the market landscape of hog producers remained competitive.

Theoretical Framework

Our theoretical model is based on the stylized facts describing the swine industry in North Carolina, where vertically integrated firms (processors or integrators) compete against each other for the procurement of live hogs. The production of live animals can be carried out by independent producers or contract operators. Under an independent scenario, the farmer is the residual claimant on the entire profit, from buying inputs, growing, and selling live hogs. Under a contract scenario, integrators contract the production of live hogs with individual farmers; because they control the critical inputs (feed and swine), contract growers are compensated for renting their housing facilities, manure disposal, and husbandry services. Under either scenario, farmer equilibrium profits are inclusive of the return on the scarce quota. The relevant price under the independent scenario is the price of live hogs per pound of live weight; under the contract scenario, the relevant price is grower compensation per pound of live weight.

There are two main ingredients to the model structure. First, we investigate the increased market concentration of integrators/processors coupled with the restricted supply of hogs. We illustrate this in two different ways. We begin by graphical presentation of a partial equilibrium model with a production quota and a monopsony buyer. The model demonstrates that the monopsonistic processor will extract all quasi-rents (the farmer's expected windfall) and that the presence of the quota may actually drive live hog prices (farmer profits) below those expected under pure monopsony; farmers may be worse off under the quota regimen than they would be under monopsony alone. Next, we relax the monopsony assumption to consider a more realistic Cournot oligopsony in the market for live hogs. In this model, we demonstrate that the price farmers receive for their hogs decreases as the number of Cournot buyers gets smaller.

Second, we use a hedonic model to explore how hog farm certificates are capitalized into farm values. Each certificate specifies the production capacity of the farm; therefore, the value of the certificate should be equal to the present value of expected future profits (quasi-rents). Since each certificate is tied directly to an existing farm, the value of the certificate should be fully capitalized

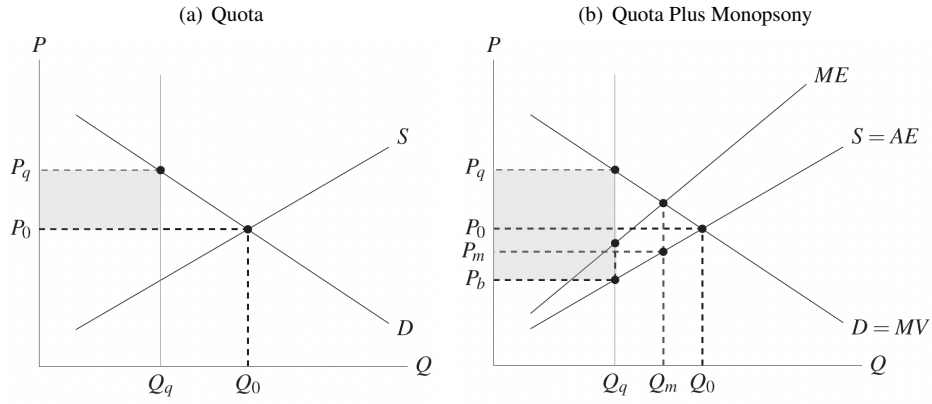

Figure 3. The Market for Live Hogs

into the value of the farm. Notice that the equilibrium value of the manure quota should be the same regardless of whether the hog farm in question belongs to an independent producer or a contract operator. Also, because certificates are not tradable without buying or selling the entire farm, a separate market for quotas does not exist. The only way to elicit its value is by using a hedonic model setting.

A Monopsonistic Processor

Consider the case of a production quota coupled with a monopsonistic processor. Figure 3a demonstrates the effect of the binding quota on existing farmers in an otherwise perfectly competitive environment. Only certificate owners are allowed to produce swine, and because the restricted market price exceeds the marginal cost of production, the certificate is valuable. The quota increases prices from P_0 to P_q, resulting in quota rents to farmers of $(P_q - P_0) \times Q_q$. This is because the market never reached the equilibrium at Q_0 because the rapid expansion of the industry was abruptly stalled by the imposition of the moratorium. Had the market begun at Q_0, then the production quota would have created a change in the producer surplus that would require the subtraction of the triangle above the supply function and below P_0, between Q_q and Q_0. But this is not case, as underscored by the fact that all hog growers that existed at the point in time when quota was introduced were grandfathered into the program.

Figure 3b illustrates the combined result of the production quota with a monopsony buyer. Because demand (D) for or the marginal value (MV) of live hogs is above marginal expenditure (ME) on live hogs at Q_q, the processor will purchase the entire quota quantity. Using their market power, the processor pays farmers the price at the intersection of the supply (S) or average expenditure on live hogs (AE) and the quota, namely P_b. In this case, rather than extracting quota rents equal to $(P_q - P_0) \times Q_q$, existing farmers lose $(P_q - P_b) \times Q_q$. Notice that, regardless of the level of the quota, the entirety of quota rents will be extracted by the monopsonist. If $Q_q < Q_m$, as in Figure 3b, then $P_b < P_m$ and existing firms lose even more than they would under monopsony power without the quota. If $Q_m < Q_q < Q_0$, then the quota is not binding and the processor purchases Q_m at the monopsony rate of P_m.

Oligopsonistic Processors

Now we loosen the monopsony restriction from the previous section to consider the case of a Cournot oligopsony among pork processors. Due to the moratorium, each farm supplies a constant quantity of live hogs $q_i = \bar{q}_i$ $(i = 1,2,...,I)$, and thus $\sum_{i=1}^{I} \bar{q}_i = \overline{Q}$, where $\bar{Q}$ denotes aggregate supply of live

hogs established by the imposition of the moratorium. If we let costs be linear in production such that $c(q_i) = cq_i$, where $c > 0$, then farmer profits can be written as $\pi_i = w\bar{q}_i - c\bar{q}_i = (w - c)\bar{q}_i$. We assume that farms were profitable prior to the moratorium, so $w > c$.[4] Suppose there are K identical processors, $(k = 1,2,...,K)$, entry is blocked, and the total amount of hogs available to them to buy is determined by the moratorium: $\sum_{k=1}^{K} q_k = \overline{Q}$. Assume, for the sake of simplicity, that all processors have identical costs equal to the rate the firm pays the farmer, be that the price of live hogs or the contract grower payment per pound of live weight. Further assume that the processing costs and market demand for pork are also linear:

$$g(q_k) = wq_k \quad \forall k \in K \tag{1}$$

and

$$p = a - b\sum_{k=1}^{K} q_k, \tag{2}$$

where $a > 0$, $b > 0$, and $a > p$. Notice that by a suitable choice of units (afforded by the fact that swine processing is a fixed proportion technology), the quantity of live hogs and the quantity of processed pork can be labeled using the same symbol, q. Using equations (1) and (2), profits for firm k are

$$\pi_k = pq_k - wq_k = (a - b\sum_{k=1}^{K} q_k)q_k - wq_k. \tag{3}$$

The Cournot–Nash equilibrium satisfies

$$d\pi_k/dq_k = a - bq_k - b\sum_{k=1}^{K} q_k - w = 0 \tag{4}$$

or

$$bq_k = a - b\sum_{k=1}^{K} q_k - w, \tag{5}$$

which is independent of firm k; hence, each firm's output level is the same and equal to the common output level, $\bar{q}$:

$$\bar{q} = (a - w)/b(K + 1). \tag{6}$$

Respecting that the aggregate moratorium-imposed quota constraint is regionally binding (i.e., $\sum_{i=1}^{I} q_i = \sum_{k=1}^{K} \bar{q}_k = \bar{Q}$) and assuming no imports of live hogs form outside the region, such that the aggregate quota is also binding on demand, then

$$\bar{Q} = \sum_{k=1}^{K} \bar{q} = K(a - w)/b(K + 1). \tag{7}$$

Solving for the price farmers receive, w, as a function of the number of processing firms,

$$w = a - \bar{Q}b(K + 1)/K, \tag{8}$$

it can be easily seen that w is an increasing function of K. This means that as the number of processing firms decreases, the price farmers receive for their services (either by selling live hogs or by selling contract grower services) decreases. Two polar cases are the pure monopsony considered before, where $K = 1$ and equation (8) reduces to $w = a - 2\bar{Q}b$, and perfect competition, where $K \to \infty$ and $w = a - \bar{Q}b$.

[4] Here we refer to profitability in an accounting sense (i.e., without taking into consideration the opportunity cost of capital invested in the next best option). In an economic sense, the long-run profits are driven to 0 because the sell side of the market is perfectly competitive.

Market Capitalization

Starting in 1993, hog farms in North Carolina have been required to obtain a state permit and be repermitted every 5 years. In conjunction with the permit, hog farms are issued a Certificate of Coverage stating their permitted annual average swine capacity. A steady state live weight (SSLW) capacity is calculated based on the certificate and the type of farm (e.g., feeder-to-finish, farrow-to-finish) to give a more consistent measure of the amount of pork and waste across farms. Due to the 1997 moratorium, these SSLWs have not changed over time and are tied directly to the property.

The process of obtaining and owning the SSLW quota is the same regardless of whether a hog farmer is an independent producer or a contract operator. However, farmer profits from growing hogs will depend on the marketing channel used. An independent producer's expected profits are going to be larger than those of a contract farmer, but the uncertainty surrounding these profits (the variance) will also be larger. Being more risk averse than an independent farmer, a contract operator will settle for lower profits but also lower year-to-year profit volatility (Zheng, Vukina, and Shin, 2008). The difference between these two streams of profit can be interpreted as the insurance premium the contract operator is willing pay to receive a more stable stream of contract payments rather then being exposed to the lottery of buying and selling inputs and output on the spot markets.[5]

The difference in expected profits would not drive a wedge in the value of the quota between the two channels over and above the risk premium unless there are some other systematic differences in the profitability within and between the two types of farms. If this were true, then excess profit of the inframarginal producer should be regarded as the true opportunity cost of the quota to that producer in the long run. These are quasi-rents accruing to owners of scarce factors, not to entrepreneurs, and constitute the producer surplus in the long-run. The above discussion also explains why, in a perfectly competitive environment, processors would not be able to appropriate quasi-rents from farmers. The perfectly competitive equilibrium value of the quota is whatever it takes to drive profits to 0 in both channels (net of risk premium). Hence, it is the equilibrium price of hogs (or contract grower payments) that determines the rent, and not the other way around. Therefore, the price of the quota in equilibrium is determined by the capitalized value of the discounted expected stream of long-run profits (producer surpluses), which only functioning barriers to entry (property rights) can preserve:

$$PV(SSLW) = \sum_{t=0}^{\infty} \frac{E(\pi(SSLW))}{(1+r)^t}, \tag{9}$$

where PV is the present value. Because production quotas are not individually tradeable, the market for production quotas does not exist. Instead, the $SSLW$ is tied to the farm and only transferable through the sale of the farm. The value of the quota, therefore, can only be revealed by the sale price of the farm,

$$P = f(PV(SSLW), \mathbf{X}), \tag{10}$$

where P is the farm price and $\boldsymbol{X}$ is a vector of farm attributes possibly influencing the value of the farm. The capitalization story allows us to use a hedonic model of farm prices to estimate both the average value of the certificate and the impact of vertical integration and oligopsony power on its behavior over time.

[5] Indeed, Zheng, Vukina, and Shin (2008) have shown that farmers who use production contracts are more risk averse than farmers who use spot markets or marketing contracts. A hypothetical regulation that would force producers to market their hogs in a riskier marketing channel relative to the channel they themselves selected would impose large welfare losses on the affected farmers.

Table 4. Summary Statistics by Farm Types

	Count	Avg. *Acres*	Avg. Building Area (sq. ft.)	Avg. Sale Price	Avg. *SSLW*
Agricultural	350	76	228	136,475	
Farrow-to-finish	17	149	6,090	2,374,624	1,086,449
Farrow-to-feeder	6	72	4,876	2,177,333	1,098,202
Farrow-to-wean	2	199	15,231	2,862,500	4,215,576
Feeder-to-finish	63	114	19,810	967,782	1,808,964
Wean-to-feeder	42	65	13,232	619,552	919,289
All farms	480	83	4,263	404,699	

Notes: Agricultural farms are defined as farms where acreage is used for crop production alone. Buildings area (sq. ft.) is the sum of building square footage on the property. Prices are nominal. *SSLW* denotes steady state live weight.

Farm Sales Data

To estimate the impact of the moratorium-established production quota and pork processor industry concentration on farm values in North Carolina, we digitized a proprietary dataset of real estate transactions from Cape Fear Farm Credit Services. Cape Fear Farm Credit Services serves southeastern North Carolina and specializes in loan services to North Carolina farmers. The market area served by Cape Fear Farm Credit Services covers over 70% of all swine farms in the state. Because Cape Fear Farm Credit Services is part of the national Farm Credit system, the USDA-Farm Service Agency is a preferred lender and alone serves the major hog-producing counties. This dataset is expected to include a majority of hog farm sales during this period. The dataset contains 480 North Carolina farm transactions between 1994 and 2010, accounting for nearly 9% of the total number of hog farms in the market region. Only 2.9% of farm sales (14 farms) took place in the 3-year prior to the 1997 moratorium, and the first hog farm in the dataset was sold in 1998. There are only 14 repeat sales during this period;, half of which are hog farm sales. Our average annual transaction rate of over 0.5% is consistent with market expectations and supports the fact that Cape Fear Farm Credit Services captures the majority of hog farm sales in the region.[6]

Bank records include multiple pages describing each individual farm at length. In addition to sale price, the documents include the number of swine, location, year, acreage types (e.g., pasture and wooded), farm types (e.g., general agricultural, farrow-to-wean, and farrow-to-feed), the size of exterior buildings, descriptions of equipment, and hand-drawn property maps. For the purpose of this study we use the sale price, number of swine, county, year, acreage, permit type, and the building square footage. The number and type of swine on each farm was multiplied by the NCDEQ-set average facility-type weight to calculate each facility's SSLW. These weights were then verified against NCDEQ permitting data.

Table 4 shows the distribution of farm types and characteristics. A full 73% of farm sales can be categorized as general agricultural land sales (crop production). The remaining sales are distributed among wean-to-feed (9%), feed-to-finish (13%), farrow-to-finish (3%), farrow-to-feed (1%), and farrow-to-wean (<1%) farms. All hog farms are to a certain extent crop farms as well. All of them have significant acreage which is needed to spray the anaerobic lagoon sludge to the land, which is always cultivated with some crops. The reason for including the sales of crop farms in the analysis is to more precisely estimate the contributions of factors common to both types of farms to the value of the farm, such as the size (acres) and infrastructure (buildings).

[6] While about 4% of residential housing units sell each year, farmland markets are much thinner (Bigelow, Borchers, and Hubbs, 2016). For example, in Illinois from 2000 to 2011, less than 1% of acreage was sold per year (Sherrick, 2012).

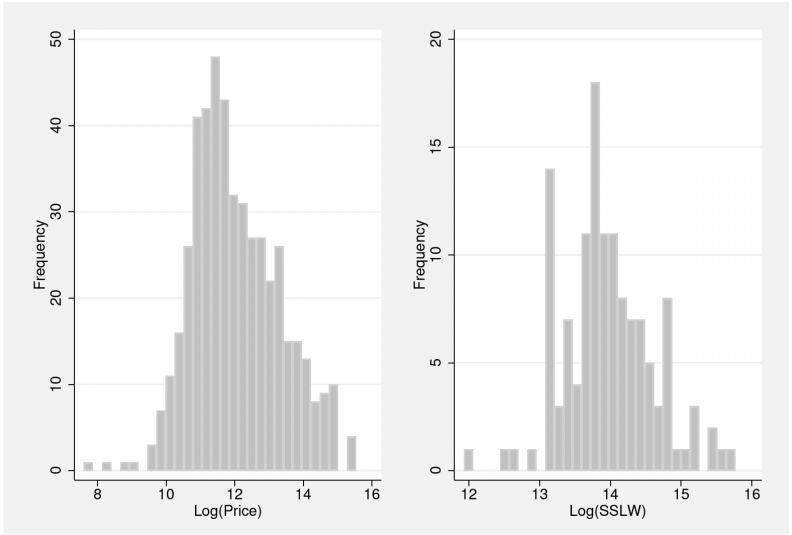

Figure 4. Farm Sales Prices and Permitted Production Capacity, 1994–2010

While the average nominal sale price for all farms in the dataset was just over $400,000, the average hog farm sold for over $1.1 million. Farm prices, during the sample period, increased by 34% per year on average. The farms in our dataset are mostly located in four counties: Sampson (30%), Duplin (27%), Bladen (21%), Pender (15%), and Other (7%). For the most part, the sales data are consistent with the distribution of hog farms (both type and location) in North Carolina. Two exceptions are farrow-to-finish farms, which are overrepresented (13% of farms in our data whereas only about 1% of actual farms), and farrow-to-wean farms, which are underrepresented (2% in our data versus 14% in total). Histograms of the log sale price for all transactions and the log SSLW (permitted production) of hog farms are found in Figure 4. Permitted production, measured in SSLW, averages over 1.4 million lb. per hog farm. The charts clearly show that both price and production quotas are slanted to the right, indicating that larger and more expensive hog farms dominate the sample.

Estimation

As a reduced-form equation, economic theory alone cannot define a hedonic functional form (Halvorsen and Pollakowski, 1981; Palmquist, Roka, and Vukina, 1997). Many authors have argued that linear hedonic functions are inappropriate because they require strong assumptions about divisibility, the shape of the utility function, and complementarities (Rosen, 1974; Freeman, 1992; Bishop et al., 2020). Cropper, Deck, and McConnell (1988) used simulation to test six different forms and found that linear and linear Box–Cox performed best in the presence of omitted variables. In their Monte Carlo study of a large cross-sectional data set, Kuminoff, Parmeter, and Pope (2010) found that a quadratic Box–Cox with spatial fixed effects performed best but that including spatial fixed effects significantly reduced omitted variable bias regardless of functional form. Because the quadratic Box–Cox is computationally intensive and results are difficult to interpret, authors still often use semilog, log–log, and linear Box–Cox models (Cassel and Mendelsohn, 1985; Locke and Blomquist, 2016). We take the resulting approach of most practitioners and use a mix of simple but flexible models with a variable transformation justified by economic theory, including both spatial and temporal fixed effects, verified with goodness-of-fit tests, along with robust standard errors (Palmquist, Roka, and Vukina, 1997; Mahan, Polasky, and Adams, 2000; Bin and Polasky, 2004; Bishop et al., 2020).

In estimating the model in equation (10), we consider three common functional forms: linear, log–log, and Box–Cox. The baseline hedonic model is

$$P_{it} = \alpha_0 + \alpha_1 SSLW_i + \alpha_2 Acres_i + \alpha_3 BuildingSqft_i + \mu_f + \delta_t + \gamma_c + \epsilon_{it} \tag{11}$$

where P_{it} is the recorded price of farm i in year t and ϵ_{it} is a randomly distributed error term. Each regression contains farm type, μ_f (equal to 1 if the farm is a hog farm and 0 otherwise); year, δ_t; and county, γ_c, fixed effects. The farm type dummy is intended to capture any unobserved differences between hog farms and the other agricultural farms, such as for example paved road access or the proximity to a slaughter house or a feed mill. Ideally, farm prices should be adjusted based on the general price changes of land over the period, but since there is no price index for land transactions, we use year fixed effects to capture unobserved annual variations that affect prices. Spatial (county) fixed effects are included and, although the market region is fairly uniform, will capture any differences in unobserved county-level characteristics.

The explanatory variable of interest is *SSLW*, the measure of permitted production capacity of the hog farm. *Ceteris paribus*, higher permitted SSLWs are associated with higher farm values. With a linear model, the implicit (shadow) price of the permit is the coefficient α_1. With a log–log model, the implicit price is the estimated coefficient times the average price divided by the average value for the independent variable, $\alpha_1 \times \overline{P} \times \overline{SSLW}^{-1}$. For a linear Box–Cox model, the implicit price is $\alpha_1 \times \overline{P}^{1-\lambda} \times \overline{SSLW}^{\lambda-1}$, where λ is the Box–Cox transformation parameter. The relative contribution is then the implicit price divided by the total value of the property (Ham et al., 2012; Champ et al., 2003). Two additional explanatory variables are standard in hedonic models. Larger farms (more acres) are associated with higher farm values, and more and larger farm buildings are associated with higher farm prices.

To test our main hypothesis about the impact of industry concentration on the value of the production quota, we need a more complex model. To accomplish this objective, we augment the base model with an interaction term between farm SSLW and the market concentration index from Table 1. The interaction term allows us to control for the implicit prices and capitalization changes due to increases in pork industry concentration. We expect the value of permitted production (*SSLW*) to remain positive and that the coefficient on the interaction of *SSLW* with market concentration will be negative; as market concentration increases, the value of the permit decreases.

Finally, it is important to investigate whether there are systematic differences between the two types of farms that can impact the estimate of the value of the quota. In particular, it is highly likely that the original selection into different farm enterprises (i.e., before the moratorium was imposed and the production quota was established) was not random. Farms with better acreages (size and soils) were more likely to select themselves into crop farming and those with inferior acreage into livestock farming. This should be tested by measuring whether, *ceteris paribus*, the price of an acre of land belonging to a crop farm is worth more than an acre of land on a hog farm. If swine farm acres are more valuable, then SSLW and the interaction of *SSLW* with market concentration could capture some of the difference and bias the estimates upward. However, we expect the opposite to be true: acreage in swine production should be less valuable, given that it has fewer alternative uses.

The fully specified hedonic regression model is

$$P_{it} = \beta_0 + \beta_1 SSLW_i + \beta_2 SSLW_i \times C(N) + \beta_3 Acres_i + \beta_4 BuildingSqft_i + \mu_f + \delta_t + \gamma_c + \delta_t * Acres + \epsilon_{it} \tag{12}$$

As in the base model, the coefficients of primary interest are β_1—the value of a pound of Steady State Live Weight—and β_2—the change in the value of *SSLW* as the processors' market concentration changes over time. Based on the theoretical model, we expect the sign of β_1 to be positive and β_2 to be negative. We expect the coefficients on $Acres_i$ and $BuildingSqft_i$ to be positive. Finally, the sign of the interaction term between acreage and farm type should be negative.

Table 5. Hedonic Price Base Model: Exploring Functional Forms (N = 480)

	Linear	Log–Log	Box-Cox
SSLW	0.527***	0.259***	0.304***
	(0.0357)	(0.0812)	(0.0712)
Acres	654.3***	0.628***	1.015***
	(157.5)	(0.0321)	(0.0526)
Building Area (sq. ft.)	−0.242	0.0795***	0.133***
	(1.272)	(0.0174)	(0.0256)
Constant	731,721.0*	6.308***	0.0836
	(416,241.6)	(1.220)	(0.181)
Year fixed effects	yes	yes	yes
County fixed effects	yes	yes	yes
Farm type	yes	yes	yes
R^2	0.669	0.826	0.836
λ			0.0644***
AIC	13,781.19	783.19	12,280.97
BIC	13,885.53	887.53	12,285.15

Notes: Values in parentheses are robust standard errors. Single, double, and triple asterisks indicate significance at the 10%, 5%, and 1% levels, respectively.

Results

An empirical search for the preferred functional form with the base model in equation (11) is presented in Table 5. Notice that in all versions the *SSLW* coefficient is positive and statistically significant. The log–log and Box–Cox models fit the data very well. The Box-Cox specification has slightly higher adjusted R^2. In both the log–log and Box-Cox versions, acreage and building square footage are also positive and significant.

Despite the fact that both the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) favor double log specification, our preferred specification is Box–Cox for two reasons. First, the Box–Cox coefficient is nonzero ($\lambda = 0.0644$) and significantly different from 0. A post-estimation hypothesis test rejected the log–log alternative with a chi-squared value of 10.65. In addition, we ran a Box–Cox transformation using the log-transformed variables. If the log–log specification performs well, then the Box–Cox transformation would return a coefficient near 1. Instead, results return a coefficient of $\lambda = 1.438$. The hypothesis that $\lambda = 1$ was rejected with a χ^2 value of 5.65, further supporting the Box-C-ox specification.

Table 6 reports the Box–Cox results of the main model in equation (12). Each column uses a different market concentration metric.[7] The values of both the AIC and the BIC are too close across three model specifications such that neither of these criteria can be used for meaningful model selection. We give more credence to the C(8) and C(20) models because, according to expert opinion, the number of firms in North Carolina dropped from 22 in 1994 was 22 to nine in 2010 (see footnote 2). In all three versions of the model, the *SSLW* coefficient is positive and statistically significant. As predicted by the theory, the interaction coefficient between permitted quota and the concentration index is negative and statistically significant. As the industry concentration increases, the value (implicit price) of the quota decreases. The comparison across models indicates that the cross-product coefficients are quite similar in magnitude.

[7] The results in Table 5 are based on transforming all continuous variables by the Box–Cox parameter λ from the base model, but the variables used to construct the cross-products (interaction), notably the concentration index, *C(N)*, and farm type dummy, μ_f, are not transformed.

Table 6. Box–Cox Hedonic Price Equation: Full Model with Interactions (N = 480)

	C(4)	C(8)	C(20)
SSLW	0.584***	0.597***	0.637***
	(0.0877)	(0.0891)	(0.0940)
SSLW × *C(N)*	−0.357***	−0.308***	−0.313***
	(0.107)	(0.0929)	(0.0944)
Acres	1.121***	1.120***	1.120***
	(0.0568)	(0.0568)	(0.0568)
Swine Farm × *Acres*	−0.585***	−0.585***	−0.587***
	(0.134)	(0.134)	(0.134)
BuildingSqft	0.106***	0.106***	0.105***
	(0.0250)	(0.0250)	(0.0250)
Constant	0.797***	0.789***	0.759***
	(0.244)	(0.244)	(0.244)
Year fixed effects	yes	yes	yes
County fixed effects	yes	yes	yes
Farm type	yes	yes	yes
R^2	0.845	0.845	0.845
AIC	−1,141.67	−1,141.44	−1,141.47
BIC	−1,028.98	−1,028.75	−1,028.78

Notes: Values in parentheses are robust standard errors in parentheses. Single, double, and triple asterisks indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 6 also summarizes the important findings. First, the coefficients on $Acres_i$ and $BuildingSqft_i$ have expected signs (positive) and are statistically significant. The interaction coefficient between farm type and acres is negative and significant, suggesting, in line with expectations, that the typical swine farm acre is worth less, with a similar value as half of a row-crop acre. Second, based on the C(8) model and evaluated approximately in the middle of the concentration index range (year 2000), the implicit price of *SSLW* was 41.4 cents per pound. The value of the quota accounted for 52.6% of the value of the permitted farm. Given the fact that the average price of the hog farm in the data set is $1,126,839, the value of the quota amounts to $592,932.

These results are consistent with similar studies in the literature. Floyd (1965) estimated that land-restricted production quotas would increase land values by 55%–65%. Vantreese, Reed, and Skees (1989) found that tobacco quotas accounted for up to 39% of land values. Other studies evaluating how government payments are capitalized into land values have provided additional perspective and similar capitalization results. For example, Just and Miranowski (1993) found that government payments were capitalized as 25% of land values. Probably the best proof that government policies can create actual monetary rents was the termination of the tobacco quota program. Under the corporate-tax bill passed by Congress in 2004, owners of tobacco quotas and farmers who produced the crop in the United States received cash payments totaling $10.1 billion as compensation for accepting an end to the tobacco price-support program. Under the buyout bill, quota owners received $7/lb of quota owned and active producers $3/lb of quota on tobacco produced. Most active producers also owned quota, and they received both payments (Pasour, 2005).

Our most interesting and novel result shows the behavior of the quota values over time as the competitive landscape on the market for live hogs deteriorated. Figure 5 illustrates the decline in the value of a pound of *SSLW* over the sample period. The results look similar across all three model specifications. Large drops in *SSLW* values (e.g., the one between 2005 and 2006) are associated

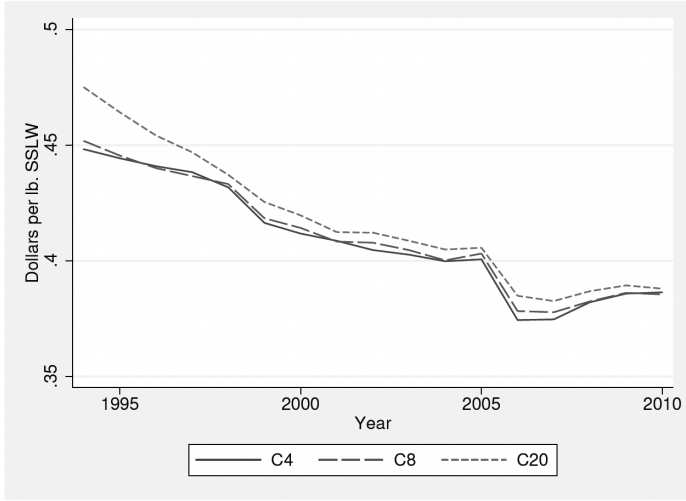

Figure 5. Time Estimates of the Implicit Values of Production Permits

with large increases in industry concentration measures. Based on the C(8) model, the results show that in 1994, when market concentration was lowest and the quota program was still not in place, a pound of *SSLW* would have been worth 45 cents and would have accounted for over 57% of a farm's value. In 1998, at the beginning of the moratorium, a pound of *SSLW* was worth 43 cents, and the permit accounted for 55% of the farm price. By the last period of the data set (2010), the value of the permitted production quotas had decreased even more. A pound of permitted *SSLW* was worth only 39 cents and the total permit accounted for 49% of a farm's value. For the entire period from the first year of the fully implemented moratorium cum quota policy (1998) until the end of our sample (2010), the value of the quota dropped from $620,071, or 55% of the average farm price, to $551,790, or 49% of the farm price, costing farmers $68,281 on average.

If we extrapolate these results to more recent farm sales, the losses due to the lack of competition in the swine industry continue to be substantial. As an example, for an individually owned large swine farm with a permitted steady state live weight of 3.17 million pounds in Duplin County that sold for $2.84 million in 2019, based on our C(8) model, the value of the quota (permits) would amount to 43 cents per pound. However, because of the continuous deterioration of industry competitiveness (i.e., increase in market concentration), the quota value has declined since the beginning of the moratorium in 1998 by about 12%, which constitutes a loss to the farmer of $187,000.

Robustness Results

Going back to Table 4, recall that both AIC and BIC favored the double-log functional form, as seen from their substantially lower values in comparison to either linear or Box–Cox forms. Yet, we have chosen the Box–Cox specification as our preferred specification for reasons other than AIC and BIC. To investigate how sensitive our results are with respect to the choice of functional form, we re-estimated our main model in the log–log form. The results are presented in Table 7.

First, notice that all of the coefficients remain correctly signed and statistically significant. To make the comparison with the earlier results straightforward, here too we evaluate the effects based on the C(8) model for the concentration index as it was recorded in the year 2000. Based on the double-log model, the implicit price of the permit was 40 cents per pound, which amounts to $569,000 for the average farm or 50.5% of the farm price. Given that our Box–Cox coefficients gave us an estimate for the value of the quota of 41.4 cents a pound, we see that the double-log estimates are about 3% lower.

Table 7. Log–Log Hedonic Price Equation: Full Model with Interactions (N = 480)

	C(4)	C(8)	C(20)
SSLW	0.586***	0.598***	0.632***
	(0.0961)	(0.0970)	(0.1000)
SSLW × *C(N)*	−0.289***	−0.250***	−0.254***
	(0.0840)	(0.0731)	(0.0743)
Acres	0.705***	0.704***	0.705***
	(0.0344)	(0.0344)	(0.0344)
Swine Farm × *Acres*	−0.420***	−0.420***	−0.420***
	(0.0806)	(0.0806)	(0.0806)
BuildingSqft	0.0737***	0.0735***	0.0731***
	(0.0169)	(0.0169)	(0.0169)
Constant	4.371***	4.329***	4.243***
	(1.247)	(1.247)	(1.247)
Year fixed effects	yes	yes	yes
County fixed effects	yes	yes	yes
Farm type	yes	yes	yes
R^2	0.838	0.838	0.838
AIC	750.25	750.47	750.40
BIC	862.94	863.16	863.09

Notes: Values in parentheses are robust standard errors in parentheses. Single, double, and triple asterisks indicate significance at the 10%, 5%, and 1% levels, respectively.

Looking at the entire period from the first year of the fully implemented moratorium (1998) until the end of our sample (2010), we find that production quota in 1998 was worth 43 cents in the Box–Cox model and the permit accounted for 55% of the farm price; by 2010, the value of the quota was 39 cents and the total permit accounted for 49% of a farm's value. In the log–log model the value of the quota in 1998 was 43.6 cents or 55.3% of the farm price, whereas by 2010, the value of the quota dropped to 39.7 cents or 50.5% of the farm. Expressed as a percentage of farm price, the value of the permits dropped on average by 6 percentage points in the Box–Cox model and 4.8 percentage points based on the log–log model. The comparison of two model specifications shows that the results are reasonably close.

Conclusions

This study provides an important contribution to the sparse literature on the effects of industry concentration (market power) on the value of Ricardian-type rents. The empirical stage is provided by the swine industry in North Carolina whose rapid expansion led the state officials to enact the moratorium on the construction of new production facilities to prevent further escalation of environmental problems associated with manure disposal. At the time of the imposition of the moratorium, the existing hog farmers were grandfathered into the program by being issued free-of-charge production permits. Despite its original environmental policy objective, the moratorium effectively served as a barrier to entry into live hog production and significantly contributed to the rapid consolidation of downstream pork processors in the post-moratorium period. At the same time, the upstream live production segment remained competitive despite the quota program.

Given the fact that future expansion of live hog production was blocked, production permits became the scarce factor and the source of future long-run profits (quasi-rents). Excess profit earned by a farmer should be regarded as the true opportunity cost of that permit in the long run. Under

perfect competition, the equilibrium value of this rent would be determined by whatever it takes to drive profits to 0. Hence, the equilibrium price of live hogs would determine the rent, and not the other way around. These quasi-rents would accrue to scarce factor owners (farmers) and not processors or integrators. The presence of the market power of processors on the market for live hogs (or the market for contract grower services) diminishes the value of that quasi-rent below the perfectly competitive case.

Consistent with economic theory, the empirical analysis shows a considerable decline in the value of the quota that is attributable to market concentration among processors. Because these permits are tied to specific properties and are not separately tradable, we used a hedonic model to isolate the baseline permit value as one of the components of the bundle of property attributes. The interaction of the permit variable with various measures of buyers concentration enabled us to estimate the change in the value of the permit as the concentration index changes over time. Using a digitized proprietary dataset of farm sales in North Carolina from 1994 to 2010 and the Box–Cox model specification, we found that production quota in 1998, at the beginning of the moratorium, was worth 43 cents a pound and the permit accounted for 55% of the farm price. By the last period of the dataset (2010), the value of the permitted production quotas was only 39 cents a pound and the total permit accounted for 49% of a farm's value. The results obtained by the double-log model specification are somewhat lower.

The political economy of the moratorium and quota policy are not the topic of this paper, but it is nevertheless interesting. As a policy alternative, the state legislature could have imposed an effluent tax on hog farmers. Assuming for the moment that both policy designs were of Pigouvian type (i.e., imposed at the point where marginal social cost of raising hogs intersects with the marginal benefits of consuming these hogs), they would have been equally efficient in minimizing total cost to society, yet with different short-term effects on welfare distribution. Had the North Carolina legislature opted for a tax on pollution from hog waste, hog farmers (or the industry as a whole) would have paid for the use of the environment thereby earning lower profits. In the production quota case, however, hog producers continue to use the environment free of charge and earn higher profits than under tax policy. In the long run, an effluent tax would incentivize the research and implementation of new pollution control technologies, whereas a quota approach enshrines existing technologies and legal regulations. The fact that the legislature opted for the quota system is an indication that it acted myopically and favored the industry (both farmers and processors) over consumers.

Our results have policy implications for the future of the swine industry in North Carolina, continuously faces significant challenges from regulators and various environmental groups. Given current public sentiment, it seems likely that any enduring solution to hog manure problems will involve replacing the traditional lagoon and spray-field technology with a more environmentally friendly approach. Public and industry acceptance of any solution will depend crucially on the magnitude and incidence of the adoption costs. Second, given that North Carolina hog farmers have already lost significant equity in their farms due to diminished competition among swine integrators and processors, the financial responsibility to address the swine waste problem should not be borne by hog farmers alone. It is important to recognize that the moratorium and permits program came into existence via government regulation. These policies initially created a windfall gain for farmers but later served as a barrier to entry into the swine industry that led to market consolidation and concentration, creating windfall gains for the corporations who exploited their market power to earn above-competitive profits through the entire post-moratorium period.

All of this points to the important role of government regulations in the swine industry over the past 30 years. Going forward, developing new regulations to equitably share the cost burden of changing the industry's waste management practices will likely require new actions by lawmakers. Along with new hog waste regulations, it seems more likely than not that government assistance to farmers in the form of equipment grants, tax breaks, and subsidized loans may be necessary.

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