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Effects of Environmental Regulation on Economic Activity and Pollution in Commercial Agriculture

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Effects of Environmental Regulation on Economic Activity and Pollution in Commercial Agriculture*

Stacy E. Sneeringer

Abstract

Research empirically estimating the effects of regulation on economic activity is largely focused on manufacturing, while generally overlooking one of the major polluters in the U.S. – commercial agriculture. Further, the prior literature generally does not estimate the pollution effects associated with regulation, making it difficult to assess the relative social costs and benefits of government action. This article considers a specific set of state policies to examine the results of environmental regulations in the agricultural sector, providing estimates of the magnitude of effects on production as well as pollution. During the 1990's, North Carolina's hog production more than tripled after passage of welcoming state legislation. I find that North Carolina's laws led to an additional 11% increase per year in pork industry presence in North Carolina relative to the rest of the U.S., as well as a 10% increase per county per year in ambient air pollution. Through a series of falsification tests and examinations of alternative hypotheses, I conclude that the air pollution is attributable to the industry; a doubling of production yields a 92% increase in ambient air pollution. The magnitude of the changes in air pollution is large enough to result in significant public health effects, totaling in cost to at least 12% of North Carolina's hog production revenue.

KEYWORDS: livestock, externality, regulation, public health

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The goal of environmental regulation is reduction of pollution externalities, but such legislation may increase the cost of business. The benefits of pollution mitigation may therefore come at the expense of lost jobs and decreased industrial activity. The prior empirical literature examining environmental regulation's effect on economic activity is mostly concerned with manufacturing and generally overlooks commercial agriculture, despite this industry's considerable contributions to air and water pollution. Without the iconic smokestack, agriculture is not normally viewed as a major polluter; however, the U.S. Environmental Protection Agency (EPA) judges agriculture to be one of the most significant contributors to impairments of rivers and streams (USEPA, 2002), one of the largest emitters in the country of certain greenhouse gases (USEPA, 2000a), and a cause of coastal "dead zones" where fish cannot live (USEPA, 2000b). Further, the prior literature generally does not estimate pollution changes associated with regulation, hindering comparisons of government action's relative costs and benefits.[1] This paper considers a specific set of state policies to examine the results of environmental regulations in the agricultural sector, providing estimates of the magnitude of effects on production as well as pollution. In doing so, it provides calculations of some of the industry's environmental externalities, pertinent to current debates concerning the regulation of this sector under the Clean Air Act. The use of quasi-experimental identification strategies to estimate effects bolsters the argument of a causal mechanism and further extends the use of these methods in both the agricultural and environmental economics fields (Greenstone and Gayer, 2007).

Between 1991 and 1997 the number of hogs in North Carolina nearly tripled, making it the second-largest pork-producing state in the country (Fig.1). A distinct trend break in North Carolina's hog numbers coincided with policy changes enacted in part by Senator Wendell Murphy, a prominent hog farmer and state politician. In 1991, Murphy helped create exemptions from environmental fees and freedom from local zoning ordinances, encouraging the state's hog production industry. Coupled with this growth in the state's tax base came a succession of harmful environmental events associated with the industry. A number of manure storage ponds leaked, emitting millions of gallons of liquid slurry. Following these pollution spills and a series of Pulitzer Prize-winning negative press reports, the state enacted a moratorium on new swine operations in 1997, yielding a second distinct trend break in the industry's presence in the state.

Concurrent to these events, the industry has been increasingly implicated in air pollution. Contrasted with the idyllic fresh air of the family farm, the current style of livestock production is increasingly shown to emit toxic gases

[1] Important exceptions include Greenstone (2003 and 2004). However, many articles examine regulatory effects on public health and other outcomes associated with pollution, rather than the pollution itself (for example, Chay and Greenstone, 2003 and 2005).

(USEPA, 2000). However, little is understood about the extent of the pollution at a regional level, the effects on ambient levels pertinent to public health, or the amount that should be spent on regulation. In a partial attempt to fill these gaps in knowledge, the EPA is currently in an agreement with livestock operations for air emissions self-monitoring data in exchange for absolution from past pollution violations (USEPA, 2006). However, the U.S. General Accounting Office has stated that data gathered via this method may be of questionable scientific significance (USGAO, 2008), suggesting a need for estimates from alternative sources.

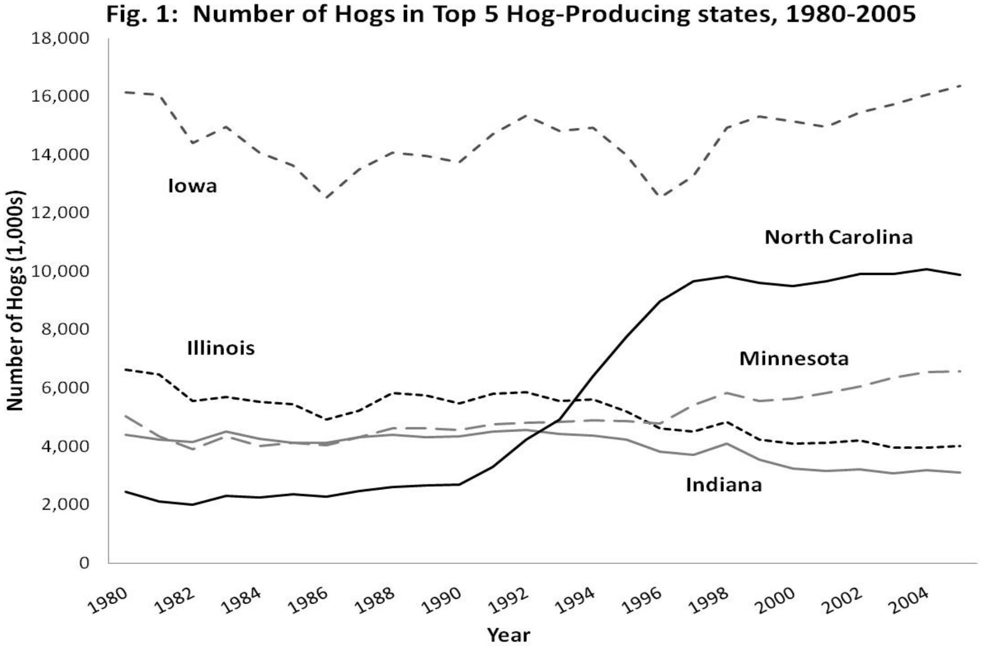
In this article I examine three primary questions using county-level annual data for the entire U.S. between 1980 and 2005 on ambient air quality and hog production. First, to what extent did North Carolina's 1991 policies forbidding county zoning of agriculture and exempting livestock operations from environmental fees increase industry presence in the state? I estimate effects using both differences-in-differences models as well as spline models that control for trends prior to regulatory changes. These estimation strategies overcome many of the problems with causal inference in the prior empirical literature on regulatory effects on livestock location, which either use only cross-sectional data or state-level aggregated longitudinal data without information on levels prior to regulation. I find that the legislation of 1991 induced an additional 11% increase per year in industry presence in North Carolina, controlling for a variety of observed and unobserved potential confounders. The 1997 moratorium then exerted a strong control on the industry's growth in the state. This evidence of two pieces of environmental legislation affecting location and growth helps to document the idea that regulation plays a significant role in agriculture.

The second question is whether the two pieces of legislation impacted environmental quality. In this sense I go beyond most of the literature on environmental regulation's results by actually documenting the effect of legislation on ambient pollution. I use the same models described above and find that the 1991 legislation induced an additional 10% increase in air pollution each year that it pertained in North Carolina, relative to the rest of the U.S. This effect is net of fixed characteristics of counties, multiple county- and time-varying confounders, changes in six other industries, trends in North Carolina prior to 1991, and trend breaks in other states in 1991. Further, relative air pollution growth levels off at the same time as the state moratorium on large-scale swine operations.

Finally, I ask the size of the industry's effect on ambient air pollution. This question is pertinent to current and often heated debates surrounding regulation of the industry under the Clean Air Act. Knowing the magnitude of the externality associated with hog production is necessary to understand the amount the industry should spend on abatement costs, but assessments are lacking. Cross-sectional estimates may yield biased results, as producers may locate based on factors likely correlated with air quality, such as low population density. Hence, any resulting correlation (or lack thereof) between ambient air quality and livestock production may be due to location choice, rather than the actual effect of livestock on air pollution. Because the 1991 legislation does not concern air quality, its implementation and the change it induces in livestock numbers provides a shock in hog production that is arguably exogenous to ambient air pollution. The strength of the identification strategy, a series of falsification tests, and examination of alternative hypotheses strongly point toward hog production as the culprit. Examination of other factors that could cause the increase in air pollution (like energy consumption and vehicular traffic) show that these do not change in the same way as pork production in the state. The use of measured ambient air quality avoids concerns related to modeled emissions. I estimate that a doubling of hog production leads to a 92% increase in certain measures of ambient air pollution.

The magnitude of the changes resulting from the 1991 laws is large enough to yield significant public health consequences. In terms of economic impacts from livestock operation pollution, I find that the industry is responsible for at least $140 million (2005$) in health externality costs in the state per year. This amounts to 12% of the industry's revenues, and suggests that significant gains in social welfare can be had by regulating hog production in North Carolina and nationally.

Fig. 1: Number of Hogs in Top 5 Hog-Producing states, 1980-2005



1. Background on Hog Production and Air Pollution

Livestock production has witnessed significant changes in the last several decades (Rhodes, 1995; Hubbell and Welsh, 1998; Drabenstott, 1998). Sub-therapeutic antibiotic use, unique confinement strategies, and new manure management techniques have enabled raising swine in close proximity, promoting the increasing size of operations and permitting capture of economies of scale. Vertical integration between hog growers and meat processors has led to geographic concentration, often in areas not previously conducive to swine production. The Cornbelt states once produced a large majority of the nation's pork, but non-traditional areas like the Southeast and Mountain regions have seen rapid increases in the past several decades. In the move to new regions, factors important to location as cited in the literature include input costs, environmental amenities such as temperature and precipitation, experience with contract marketing arrangements, transportation time to finishing stations, and relative stringency of regulatory environments.

As hog production has become spatially concentrated in certain areas, so has its major byproduct -- manure. Swine waste is often kept in vast open-air holding ponds called "lagoons," where it is allowed to decompose. Manure is periodically pumped from these lagoons and spread onto fields. However, the use of manure as a soil amendment has been limited by availability of land, use of man-made fertilizers, and transportation costs of moving manure to cropland. To dispose of the waste, facility operators may over-apply it to land, and lagoons may leak or overflow.

Despite regulation of large-scale livestock operations under the 1972 Clean Water Act (CWA), the industry is one of the largest contributors to water pollution in the nation (USEPA, 2002). The 1972 CWA required operations above a certain number of head to file National Pollution Discharge Elimination System (NPDES) permits (Copeland and Zinn, 1998). While federal regulation creates guidelines on how livestock operators dispose of manure, each state can adopt its own regulations, leading to differing stringency levels (Metcalfe, 2000). Beyond direct water quality regulations, states may employ myriad types of laws related to livestock externalities; these include zoning policies, right-to-farm statutes, manure disposal guidelines, and corporate farming rules.

While the industry has long been considered a source of water pollution, it is now increasingly recognized as a source of air pollution. Numerous scientific and engineering studies largely from individual operations or modeled results have estimated emissions of a number of pollutants at different types of livestock facilities (for extensive reviews see National Research Council, 2003, and Iowa State University and The University of Iowa Study Group, 2002). The air pollutants from hog production of most public health concern include hydrogen sulfide (H2S) and ammonia (NH3); at high levels these toxic gases can lead to death. These air pollutants arise from decomposition of manure, spray application of slurry to land, and from the animals themselves. The effects of gases on facility employees and individuals in the vicinities of the hog operations are increasingly documented (Sneeringer, 2009a; Donham, 2000; Thu et al., 1997; Cole et al., 2000).

While studies from individual operations have documented emissions from these sources, the National Research Council (2003) notes a general paucity of research on many aspects of livestock operations' effect on air pollution. Participants from Iowa State University and The University of Iowa (2002) conclude their rigorous study with a call for more monitoring of air pollution in the vicinity of livestock facilities (rather than directly at the sites) and the weighing of externality costs to health and environment in relation to costs of mitigation. While research on individual farms provides much-needed detailed analysis of emissions, its applicability to broader-scale settings and federal policy is less clear; emissions estimates from individual farms may yield very different ambient levels, depending on temperature, precipitation, manure management practices, and geological features. In general, quantitative estimates of the environmental impacts of agriculture are rare; those that exist rely on modeling methods that have been criticized as being irrelevant for ambient pollution levels pertinent to policy making (Lichtenberg, 2002). An exception is Sneeringer (2009b), who finds a significant relationship between hog production and measured ambient air pollution at the national level. Sneeringer uses individual monitor-level data for air pollutants coupled with county-level hog density between 1980 and 2002 and finds a significant positive relationship between hog production and ambient air pollution, even after controlling for emissions from other sources.

The lack of knowledge is often used as a reason for not regulating the industry (NPPC, 2005); as such, livestock operations exert little direct control of air pollution. Having recognized the research gaps (USEPA, 2001 and 2005), the EPA asked the industry to collect its own emissions data in exchange for clemency from past air pollution violations (USEPA, 2006). However, the U.S. General Accounting Office notes that the resulting information may not provide "scientific and statistically valid data" (2008).

Any proposed increase in regulation of livestock operations has important implications for the location of the industry. If firms locate to maximize profit, variation in regulation and mobility of production suggests that livestock operations may locate or grow in regions with lax regulations. Little research empirically estimates the effect of environmental regulation on location decisions of livestock producers. Some consider but do not estimate the part environmental regulation may play in livestock location nationally (Zering, 1997); the few articles econometrically examining this question yield inconclusive results. Studies employing cross-sectional estimation (Roe et al., 2002; Weersink and Eveland, 2006; Park et al., 2002) may suffer from omitted variable bias and inconsistent estimation based on potential endogeneity between production level and regulatory stringency. Specifically, greater regulatory stringency may be adopted in locations with higher concentrations or faster growth of livestock production. In attempts to mitigate potential endogeneity, Metcalfe (2001) and Herath et al. (2005) both use state-level longitudinal data and instrumental variable approaches. Using data for two time periods, Metcalfe instruments for both his outcome variable and the variable of interest, and then finds no effects between the two predicted values. Herath and coauthors construct a longitudinal regulatory stringency variable from dissimilar indices for 1975 to 2000. They instrument for regulatory stringency with lagged measures of livestock production growth, population, and income. They find that increased severity of environmental regulations is correlated with lower production in the hog sector.

The empirical issues in the above literature are echoed in the broader research on the effects of environmental regulation on economic activity, which is particularly concerned with omitted variables and endogeneity in providing causal inference. One method used to mitigate these concerns is to non-parametrically control for unobserved heterogeneity through fixed effects with panel data covering both regulated and unregulated regions in periods covering times prior to any regulation as well as those after. The methods employed in the prior literature will guide the empirical section later in this article.

2. North Carolina's Explosion in Hog Production

North Carolina's experiences provide an opportunity to explore regulatory effects on industry location and environmental quality in agriculture, as well as to estimate the industry's effects on air pollution. To replace its declining tobacco industry, North Carolina welcomed contract hog production. A rapid expansion in the 1990s led to the state producing 16.3% of the nation's hogs by 2002, second only to Iowa. Figure 1 shows the number of hogs in North Carolina compared to other top pork-producing states between 1980 and 2005. Unlike other major producers, North Carolina saw a strong trend break in its hog inventory starting in 1991, and again after 1997. These differential trends coincided with legislative changes.

In 1991, Wendell Murphy, a prominent hog farmer and North Carolina state senator, helped enact a set of bills favorable to hog operations. The bills affected all areas of the state and exempted swine operation from county zoning restrictions and environmental penalties (General Assembly of North Carolina, 1991a).[2] According to the local press, county managers unaware of the state law changes later tried to zone against hog operations but were blocked from doing so (Stith et al., 1995). Environmentalists in the state had been arguing to rescind prior amendments that stopped the state from adopting environmental regulations more strict than federal ones. In 1991, the amendments were repealed; however, Murphy added a clause exempting livestock and poultry facilities from any such restrictions (General Assembly of North Carolina, 1991b).[3]

This welcoming regulatory environment correlates with a steep rise in the state's hog production and the choice by Smithfield Foods of North Carolina as the location for the world's largest slaughterhouse (Center on Globalization, Governance, and Competitiveness, 2007). The slaughterhouse opened in 1992 in Bladen County, an area in the Southeastern portion of the state. Hog production grew most in the counties surrounding Bladen.

The growth in the state's hog production coupled with relatively lax environmental regulations was followed by a series of destructive environmental events. In 1995, a manure lagoon burst, leaking 20 million gallons of urine and feces into North Carolina's New River. Four other manure holding ponds also leaked that year, prompting fish deaths and warnings to boaters to avoid contact with water (Martin and Zering, 1997). A series of negative press followed. North Carolina's *The News and Observer* won a Pulitzer Prize for its 1995 articles detailing the legislation and the environmental consequences of hog production (Stith et al., 1995).

The state government responded by strengthening environmental regulation of hog production under a bill that went into effect in 1997 (General Assembly of North Carolina, 1995). In that year, the state also enacted a 2-year moratorium on the building of new large-scale livestock operations and partially re-instated county zoning abilities (General Assembly of North Carolina, 1997). The moratorium was renewed in 1999 and 2003 (Center on Globalization, Governance, and Competitiveness, 2008). The legislation grandfathered the

[2] The 1991 bill concerning zoning clarified a statute related to "bona fide farms." Prior to that year, individual North Carolina counties had zoning rights, with the exception of zoning related to "bona fide farms"; however, his term was not defined, so if a county board did not consider an industrial hog operation such an entity, the county could zone against it (Stith et al., 1995). Counties in other states have since attempted to use this type of argument to overcome agricultural exemptions from local zoning rights in order to bar the construction of large-scale hog operations (Grossman, 1999). The 1991 bill explicitly exempted livestock operations from county-level zoning (General Assembly of North Carolina, 1991a).

[3] The text of bill reads, "Except as required by federal law or regulations, the [North Carolina Environmental Management] Commission may not adopt effluent standards or limitations applicable to animal and poultry feeding operations." The local press reports that environmental lobbyists allowed this concession in order to get the bill passed (Stith et al., 1995).

large-scale hog producers already operating in the state, so the moratorium prevented new operations but did not force existing ones to leave.

The regulations and accompanying trend breaks in industry presence create an opportunity to study the effects of this legislation. First, they enable the estimation of how production in the state changed before and after the legislative changes. Since the legislation is so specific to the livestock production industry (as opposed to general environmental regulations), changes in production levels are more likely attributable to it. Second, since the legislation does not focus on air pollution, changes in air quality after its adoption are likely the result of whatever changed with the regulation. Finally, the abrupt nature of the changes in North Carolina's hog inventory creates a "natural experiment" with which to estimate effects of hogs on air pollution. Since swine producers were moving to North Carolina in response to factors other than air quality, and since regulation of air pollution from hog operations was overlooked until recently, the location changes are arguably exogenous to ambient air pollution changes.

This method of identifying effects of the industry on air pollution is strengthened when considering that other legislative changes surrounding air pollution do not coincide with those for the industry. The 1990 Amendments to the Clean Air Act, which focused on reducing sulfur dioxide and acid rain, were not implemented until 1995. Hence, even if North Carolina experienced this regulation differently than the rest of the U.S., effects would not appear before 1995. Finally, livestock agriculture was the only industry exempt from North Carolina's 1991 heightened regulatory stringency, hence resulting pollution increases are more likely due to this sector.

3. EMPIRICAL STRATEGY

The empirical strategy focuses on providing unbiased estimates of the effect of environmental regulation on production levels and externalities. I consider two types of models to estimate effects, one based on differential means between counties affected versus unaffected by North Carolina's legislation and one based on differential trends. Together these models can elucidate not only how environmental regulations shift levels, but also how they affect growth.

The differences-in-differences (DD) approach is one method commonly used in economics to estimate effects of regulations. Panel data of both North Carolina and non-North Carolina counties over time allow two sources of variation that can be used to control for unobserved covariates. First, North Carolina counties are observed both before and after implementation of the laws, hence aspects of individual counties that are fixed over time can be "factored out." Second, in any year both North Carolina and other states are observed, allowing for cross-sectional variation. Thus characteristics affecting all states in a certain time period can be factored out of the effect of the 1991 North Carolina legislation. Restricting the sample to the periods 1980 to 1990 and 1997 to 2005 (thereby removing the period in which the most industry-friendly legislation was in effect), the regression equation is:

$$(1) \qquad Y_{it} = \alpha + \lambda(Post_t \times NC_i) + X_{it}'\beta + \gamma_i + \gamma_t + e_{it}$$

The outcome variable (Y_{it}) refers to industry presence or the ambient air pollution level. The subscript i denotes county, while t indexes the year. An indicator variable NC_i is equal to one if the county is in North Carolina, and $Post_t$ is an indicator variable equal to one if the time period is between 1997 and 2005. A vector X_{it} denotes county- and time-varying potentially endogenous covariates. Vectors of indicator variables for each county and year are γ_i and γ_t, respectively. If no unobserved changes affect the outcome variable in North Carolina without affecting anywhere else at the same time, then λ provides an unbiased estimate of effects. Because we witness North Carolina (and all other states) both before and after the legislation, causal inference is strengthened, and because this strategy controls for unobserved unchanging characteristics of counties, potential omitted variable bias is mitigated.

An important consideration in analyses of policy effects is endogeneity, which would occur if regulation is adopted in response to the outcome. If this is the case, then coefficients resulting from regressing the outcome on legislation would be biased. The assumption of the legislation's exogeneity to the outcome variable is more or less plausible depending on the outcome. It is highly unlikely that air pollution will cause the adoption of legislation exempting hog operations from regulation. During the early 1990s, hog operations were generally not considered of regulatory concern for ambient air pollution, and the legislation adopted did not pertain to air pollution. Endogeneity is more plausible when considering whether hog production level led to the adoption of the laws, but such endogeneity would occur in the opposite direction as that described in the prior literature. Specifically, the usual concern is that high levels or rapid growth of the industry encourage stricter regulation; the case here is one of relatively high levels of production and reduced regulation.[4] I use a second empirical strategy to control for trends in years prior to legislation adoption, so that trends post-legislation can more plausibly be attributed to the legislation changes.

The differences-in-differences model provides an estimate of the mean shift in the outcome variable attributable to the legislation in North Carolina. The

[4] Even prior to the 1991 legislation, North Carolina was the 5th-highest hog producing state in the country.

approach provides a relatively straightforward estimate and is also useful when considering one-time effects. Fig.1 suggests that the differences-in-differences approach is valid for the changes in hog production when comparing the pre-1991 and post-1997 time periods. However, a differential mean shift may be found if North Carolina experiences a different trend from other states in the outcome variable. For example, if North Carolina's growth in hog production is occurring at a much faster pace than other states, but no state experiences trend breaks at the time of legislation, then this appears as a larger mean shift in North Carolina than in other states. It would be incorrect to attribute the shift to the legislation. Further, modeling the distinct pattern in hog production in North Carolina and then estimating whether air pollution follows a similar pattern allows for an even stronger method of identification of effects on air pollution. If air pollution exhibits the same direction of trend breaks as those in hogs, the changes in air pollution are more plausibly attributed to hog production. The second type of model therefore estimates different periods of growth in North Carolina versus other states.

Consider three periods characterizing North Carolina's legislative history between 1980 and 2005: pre-1991, 1991-1996, and 1997-onward. To characterize these three periods and control for possible secular trend-breaks occurring in other states, I construct a set of interacted splines. The spline allows for trend breaks over time in the predicted outcome, but it restricts the function to be piecewise continuous. A description of the development of the model along with a visual schematic is found in Appendix C. For ease of description, the equation here is written:

$$(2) \qquad Y_{it} = (\beta_0 P0_t + \beta_1 d_{1t} P1_t + \beta_2 d_{2t} P2_t) + NC_i(\lambda_0 P0_t + \lambda_1 d_{1t} P1_t + \lambda_2 d_{2t} P2_t) + X_{it}^{'}\alpha + \gamma_i + e_{it}$$

where i denotes county and t indexes year. Restricted linear trends in the three periods are denoted $P0$, $P1$, and $P2$. The dummy variables d_{1t} and d_{2t} denote whether the year is greater than 1990 or 1996, respectively. The trends are therefore additive; for example, the predicted outcome in a non-North Carolina county in 1992 is

$$(3) \qquad E(Y_{i,1992}) = (\beta_0 + \beta_1)(1992) + X'_{i,1992}\alpha + \gamma_i$$

and the predicted outcome in a North Carolina county in 1992 is

$$(4) \qquad E(Y_{i,1992}) = (\beta_0 + \beta_1 + \lambda_0 + \lambda_1)(1992) + X'_{i,1992}\alpha + \gamma_i \,.$$

In Equation(2), the primary coefficients of interest are λ_1 and λ_2, where λ_1 denotes the estimated difference in trends between North Carolina and all other counties between 1991 and 1996. A significant value of λ_1 indicates that the trend in North Carolina counties post-1990 is different from the non-North Carolina counties post-1990. The model controls for an event occurring in 1991 that affects trends in both North Carolina and all other counties. The coefficient λ_2 is the estimated difference in trend between North Carolina and all other counties after 1996. With hog production as the outcome variable, I expect λ_1 to be positive and λ_2 to be negative. With air pollution as the outcome variable, findings of a positive λ_1 and a negative λ_2 will provide strong evidence that hog production is the mechanism, as other sources of air pollution are unlikely to exhibit the same distinct pattern as hog production in North Carolina. Further, if the industry presence changes are induced by legislation and not by some other factor affecting air pollution, trends in air pollution coinciding with legislative changes are more plausibly due to the hog industry.

The methods outlined above compare eventually-“treated” counties to never-“treated” counties over time. The “treatments” are the pieces of North Carolina legislation in 1991 and 1997, which both cover multiple influences on hog production; the 1991 legislation includes both zoning and freedom from environmental fees, while the 1997 legislation includes the moratorium as well as a number of other factors. Yet the methods outlined above cannot show which type of regulation had more of an influence on production (or pollution). To answer this type of question would require variation in the type of regulation (i.e. lack of local zoning power without freedom from environmental fees), which would entail full legislative histories of all laws pertaining to livestock in multiple states. While I do consider certain laws pertaining to agriculture as they relate to the identification strategy, one treatment here should be understood as the combined set of legislation occurring in 1991 and the other treatment is the combined legislation of 1997 in North Carolina.

Another aspect of the identification strategies is the comparison of outcomes in North Carolina with a pertinent “control group.” This control group is used to represent what could have been North Carolina’s experience without the legislation, and it controls for secular trends in all areas regardless of treatment. Using multiple states allows for the “averaging out” of variables that are unobserved, including the potential myriad other regulations and levels of enforcement in other states, which are arguably pertinent to production but not necessarily to pollution. I start by using all counties in the U.S. but outside of North Carolina as the control group; this approach is the most agnostic when considering what variables would most likely lead to such regulation, and it allows results to be interpreted as effects compared to the rest of the U.S. I also consider a number of other control groups based on factors indicated in the literature as pertinent to livestock production location to test whether these sample restrictions affect results.

Explicit consideration of the 1992 opening of the Bladen County slaughterhouse is pertinent in the identification strategy for two reasons. First, the slaughterhouse may threaten the validity of identifying effects of regulation on production; one may be concerned that the processing facility induced the increase in hog production, rather than the regulation. Reports that county managers would have used their zoning power were they allowed indicate that this legislation was necessary for production growth in the state, which was in turn necessary for the opening of the slaughterhouse; therefore the anti-zoning regulation appears a necessary precursor to the slaughterhouse. The timing of the trend break in North Carolina's hog inventories can be used to test whether the slaughterhouse motivated the growth; if North Carolina's relative growth starts prior to the slaughterhouse opening, it would suggest that the growth was due to the regulation. Second, the validity of attributing air pollution changes to hogs via the strategies described above requires no other air pollution source changes in the same manner as relative hog inventories. If the slaughterhouse causes significant air pollution, then changes in air quality might be attributable to it instead of the individual hog production facilities. The 1997 regulations can be used to test this hypothesis; since inventory growth is curbed at that time but the slaughterhouse does not close, a finding of slower changes in air pollution in 1997 would suggest that producers were the source (rather than the slaughterhouse). Finally, even if the slaughterhouse contributed to air pollution, it would likely only affect Bladen County's air quality. Since the data includes multiple counties, a single county is unlikely to create statistically significant effects.

A final word in the empirical strategy concerns the standard errors on the coefficients. Variables for a county may be correlated over time. To correct for unspecified heteroscedasticity, I cluster standard errors at the level of the county.

4. Data and Summary Statistics

I compile a data set of county-year observations between 1980 and 2005 on number of hogs, air pollution levels, as well as a number of time- and county-varying controls including covariates for 6 other industries.

A. Data on Hog Production

Data on county-level hog inventories between 1980 and 2005 come from the National Agricultural Statistics Service (NASS), part of the U.S. Department of

Agriculture. Not every county has hog data in an individual year due to confidentiality purposes; in these cases values are imputed. See Appendix A for the imputation procedure.

B. Data on Air Pollutants

While hog production has been primarily implicated in hydrogen sulfide (H2S) and ammonia (NH3) pollution, ambient levels of these pollutants are not monitored on a consistent, nationwide basis over time. The EPA at present only collects ambient measures for six “criteria” air pollutants, using fixed monitors. Two of these criteria pollutants, sulfur dioxide (SO2) and particulate matter (PM), are both directly and indirectly implicated in air pollution from livestock facilities. SO2 is formed when H2S oxidizes (ATSDR, 2006; Finlay-Pitts and Pits, 2000) and is also a direct (albeit minor) emission at swine facilities (Thorne, 2002; Lim et al., 2003). I therefore use ambient SO2 to estimate not just direct changes in this pollutant, but changes in SO2 resulting from changes in H2S and other sulfur-related emissions from hog facilities.

While using SO2 as a proxy for H2S is relatively straightforward, measuring effects on PM is more complex. Particulate matter arises from livestock facilities in many forms, mainly through dust and via the conversion of ammonia to fine particulate matter.[5] Measured PM is comprised of many elements and the same level can be achieved via emissions of different gases. Based on data availability, I only examine the period 1987 to 2005 for PM10 (particulate matter of 10 microns in diameter).

The data on ambient SO2 and PM10 come from the EPA’s AirData system. This system contains data from individual monitors, as well as the location of these monitors. The observations are average monthly levels by monitor, which I then average by county. Not all counties have monitors; while monitors are fixed, they are generally placed in more populated areas. When examining effects on hog production, I show results for the entire U.S. as well as for the samples with air pollution data in order to ascertain the effects of this sample restriction.[6]

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[5] Ammonia is associated with particulate matter of 2.5 microns in size (PM2.5). While the EPA currently monitors PM2.5, it did not begin to do so until 1998; the data for PM2.5 can therefore not be used in the estimation strategies employed here. Instead, I examine data for particulate matter of 10 microns in size. PM2.5 is a non-constant subset of PM10, so changes in PM2.5 should be reflected in changes in PM10.

[6] Regressions of whether or not a county has a monitor for a specific pollutant on hog inventory show negative coefficients (see Appendix Table B.1); this result is unsurprising given that monitors are generally in more populated areas and that hog production generally occurs in more rural areas.

C. Data on Controls

I garner data on time- and county-varying controls from a variety of sources. The controls are variables that are conceivably correlated with livestock or air pollution as well as the adoption of the 1991 legislation. Many of the factors that are implicated in hog production may also influence air pollution, thus the confounders in models with either outcome variable overlap. The prior literature has found that hog production location is based in part on proximity to inputs and end markets, historical setting, and environmental amenities. Many of these are also correlated with air pollution. For example, proximity to corn production (hogs' major feed source) may mean that livestock facilities locate in more rural settings that have fewer people and therefore lower air pollution.

In models for all outcomes, I include county- and time-varying covariates for per capita income (logged and in 2005$), population density, temperature, precipitation, the percentage of the population over age 65, the unemployment rate, the natural log of population, poverty rate, and the number of residential housing building permits.[7] The variables for per capita income, unemployment rate, population growth, and population age control for economic setting, which influence both air pollution and industry presence. For example, state legislators may encourage pork production if unemployment rates are high, and unemployment may be related to lower vehicle use and air pollution. Population density and size as well as number of building permits control for aspects of the built environment, which may impact pollution levels and be correlated with availability of land on which to produce livestock. Temperature and precipitation influence air pollution levels and where livestock producers operate. Detailed descriptions of sources of data appear in the Appendix Table B.2.

Other industries may be correlated both with hog production and air pollution. While the literature on livestock production location decisions does not mention any other specific industry as particularly correlated with the livestock agriculture, the possibility remains if hog production's growth encourages other business. I therefore control for 6 of these using data from the County Business Patterns, focusing on industries most plausibly contributing to pollution.[8] See Appendix A for further description of variables for other industries.

Other confounders aside from those included are conceivably related to either hog production or air pollution; however, I limit the covariates to be the same in models estimating effects on both air pollution and hog inventories in order to use the estimated coefficients to calculate effects of hog production on

[7] NPDES permits are differentially applied by state. They are generally required for livestock operations over a certain size and are meant to deter water pollution.
[8] These include mining, manufacturing, transportation, utilities, construction, and wholesale trade.

pollution. Further tests adding more confounders to either of the models show that such additions do not affect results.[9]

D. Summary Statistics

Table 1 provides summary statistics for North Carolina and other states for the two main outcomes of interest in the three time periods. The increase in the number of hogs per county in North Carolina is evident, as is the slow decline in the rest of the country. Noticeably, SO2 declines in the rest of the country as North Carolina's level remains constant; the difference between the state's SO2 levels in the first and third time periods is not statistically significant, suggesting that lenient regulation's effect in North Carolina is a slow-down in the decline in air pollution. This same type of effect occurs for PM10. North Carolina moves from being a relatively cleaner state before the increase in hog production to one that is no different from other states after the hog influx.

Appendix Tables B.3 and B.4 provide evidence as to whether the counties in the states outside of North Carolina serve as legitimate controls for North Carolina counties. The tables show levels and trends in the period before the initial 1991 regulation (1980-1990), during the period of (lenient) regulation in North Carolina (1991-1996), and the period after the initial moratorium (1997-2005). Comparison of levels is useful for the difference-in-differences estimates, while the trends are more pertinent for the splines. Prior to 1991, North Carolina is not statistically different from the other states in levels of population size or poverty rate, nor in construction, utilities, wholesale trade, or transportation employment. Trend differences in the number of residential building permits and construction employment present some concern, as trends in these variables are not statistically different between North Carolina and the rest of the U.S. in the pre-period but are in the second period and are not in the third. Given the similarities between North Carolina and the other state averages, regulation is likely to be uncorrelated with unobservables. However, given the dissimilarities, the econometric methods described above can be used to control for possible unobserved characteristics that may introduce bias.

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[9]In the model with hog production as the outcome variable, I add further covariates on feed efficiency (as measured by the amount spent on feed divided by the amount spent on livestock purchases), government payments to farms, and whether the state had an active right-to-farm law. For the air pollution regression I add a covariate for whether or not the county is in non-attainment of the Clean Air Act. In both of these instances the coefficients on the variables of interest are unchanged.

Table 1: Comparison of Hog Production and Air Pollution in North Carolina and Other States in Three Periods Corresponding to North Carolina's Legislation

	1980-1990 (for Hogs, SO2) 1987-1990 (for PM10)	1991-1996	1997-2005
North Carolina			
Hogs	25,491	67,226	103,192
	(50,228)	(207,039)	(312,500)
Change per year	1,140	10,544	266
	(12,570)	(37,856)	(12,767)
SO2 (ppb)	4.7	4.0	4.3
	(2.3)	(1.1)	(1.2)
Change per year	-0.1	0.1	-2.1
	(1.9)	(0.9)	(0.6)
PM10 (μg/m^3)	29.9	23.7	21.6
	(4.0)	(3.7)	(3.3)
Change per year	-0.74	-0.38	-0.63
	(3.4)	(2.5)	(1.6)
All other states			
Hogs	20,588	15,613	13,625
	(40,261)	(32,880)	(37,286)
Change per year	-289	-175	-19
	(4,157)	(6,359)	(5,208)
SO2 (ppb)	7.9	6.2	4.6
	(5.0)	(3.7)	(2.7)
Change per year	-0.2	-0.4	-12.9
	(2.3)	(1.5)	(199.8)
PM10 (μg/m^3)	32.1	24.8	22.2
	(10.6)	(7.2)	(5.9)
Change per year	-1.28	-0.89	-0.19
	(5.5)	(3.8)	(3.4)

Note: Standard deviations shown in parentheses.

5. RESULTS

Tables 2a and 2b show the results of the differences-in-differences estimation. For the hog and SO2 regressions the sample includes 1980-1990 and 1997-2005; the sample for the PM10 regressions includes just 1987-1990 and 1997-2005. Taking the natural log of the outcome variable allows estimated coefficients to be interpreted as percent changes. The results of the non-logged outcomes are also shown. Comparison of results from these two specifications allows for a test of robustness with respect to functional form. Results before and after adjusting for the county- and time-varying variables are also shown as a test for the robustness with respect to the addition of these variables.

Comparing the pre- and post-policy time periods (1980-1990 and 1997-2005) shows that the 1991 policies led to a highly significant 78,505 increase in hogs (45%) and a 3.3ppb increase in SO2 (44%); adjusting for covariates show these results increase to 80,022 hogs (58%) and 3.5ppb (53%). Restriction of the sample to just counties with SO2 data shows very similar percentage change results to the overall sample in terms of changes in hogs (Model (v)); however, the level change in hogs is smaller than in the overall sample, possibly reflecting the fact that air pollution monitors are located in areas with lower hog inventories. The PM10 results are generally not statistically significant, which may be due to the short "pre" period reducing the sample size. [10]

Table 2a: Results of Differences-in-Differences Estimation, Hog Inventory Outcomes

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
	Entire U.S.				Entire U.S. with SO2 data		Entire U.S. with PM10 data	
	ln(Hogs)	ln(Hogs)	Hogs	Hogs	ln(Hogs)	Hogs	ln(Hogs)	Hogs
Post*NC	0.454***	0.579***	78,505***	80,022***	0.564*	24,098**	0.353	35,053*
	(0.160)	(0.16)	(27854)	(29761)	(0.33)	(11175)	(0.35)	(19345)
Other county covariates?[a]	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Other industry variables?[b]	No	Yes	No	Yes	Yes	Yes	Yes	Yes
County fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	43,285	32,326	43,285	32,326	3,966	3,966	2,884	2,884

[10] These differences-in-differences results for both the hogs and air pollution provide a natural opening for an instrumental variable estimate. Using the North Carolina policy adoption as an instrument for hog inventory, the instrumental variable estimate of the effects of number hogs on SO2 air pollution is a 0.145ppb increase in SO2 for every 1,000 hog increase (an elasticity of 0.93). This estimate is statistically significant at the 5% level. The estimate for PM10 is not statistically significant, but shows a 0.032μg/m^3 increase per 1,000 hogs (a 0.05 elasticity).

Table 2b: Results of Differences-in-Differences Estimation, Air Pollution Outcomes

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
	ln(SO2)	ln(SO2)	SO2 (ppb)	SO2 (ppb)	ln(PM10)	ln(PM10)	PM10 ($\mu g/m^3$)	PM10 ($\mu g/m^3$)
Post*NC	0.438***	0.525***	3.256***	3.492***	0.0196	0.0187	1.561*	1.105
	(0.10)	(0.10)	(0.66)	(0.66)	(0.0316)	(0.034)	(0.870)	(0.98)
Other county covariates?[a]	No	Yes	No	Yes	No	Yes	No	Yes
Other industry variables?[b]	No	Yes	No	Yes	No	Yes	No	Yes
County fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,112	3,966	5,112	3,966	3,499	2,884	3,945	2,884

Notes for Tables 2a and 2b: Robust standard errors shown in parentheses. Standard errors clustered by county. *** refers to significance at the 1% level. **refers to significance at the 5% level. * refers to significance at the 10% level. Samples for hog and SO2 regressions include only 1980-1990 and 1997-2005. Samples for PM10 regressions include only 1987-1990 and 1997-2005.

[a]County covariates refers to ln(per capita income), population density, temperature, precipitation, percentage of the county over age 65, number of building permits, ln(population), poverty rate, and unemployment rate.

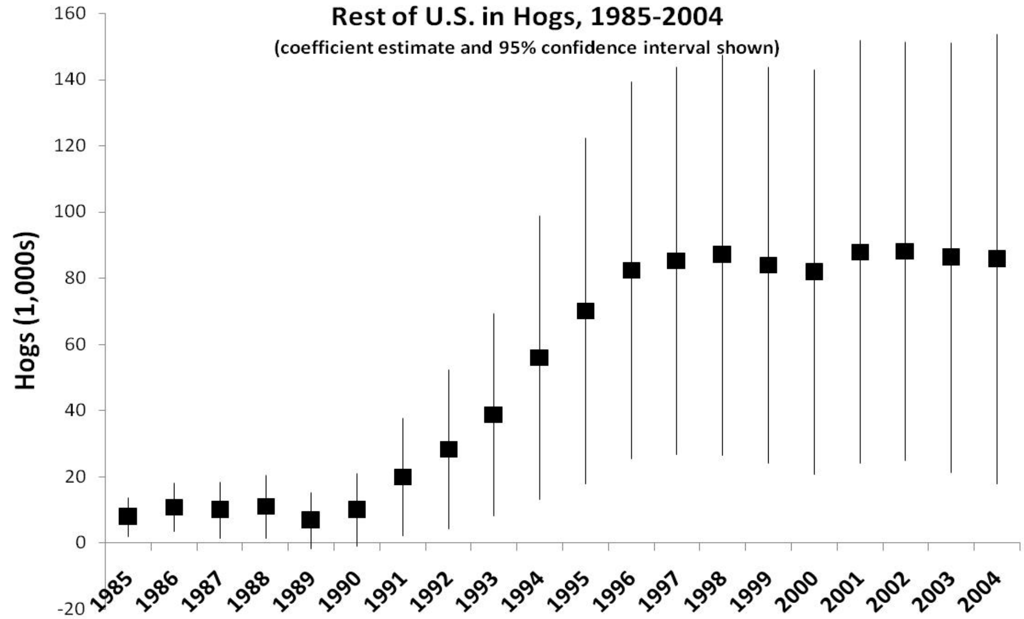
[b]Other industry variables refers to separate variables for ln(employment) in 6 other industries.

As stated earlier, differences-in-differences estimates may only reflect differential but unchanging trends. A first test of whether air pollution follows such a pattern is to examine data for multiple years and examine whether trends differ across the three time periods. I estimate treatment effects for each year between 1985 and 2004 including all covariates and fixed effects, and I plot the estimated coefficients with 95% confidence intervals for the three outcome variables in Figures 2 through 4.[11] Fig. 2 shows that the estimated coefficients for hogs are generally not statistically significant between 1985 and 1990, but are significant after that time. The "leveling off" is also evident in 1997 and after. A comparable figure for SO2 (Fig. 3) shows similar trend breaks in the early and late 1990s. Figure 4 shows a graph for PM10, but only for 1988 to 2004 due to data availability. Trends here are less obvious, but negative trends prior to 1990 and after 1997 and a positive one between 1991 and 1996 may be discerned.

[11] The years 1980-1984 and 2005 are excluded to avoid perfect collinearity.

Fig. 2: Predicted Difference between North Carolina and Rest of U.S. in Hogs, 1985-2004

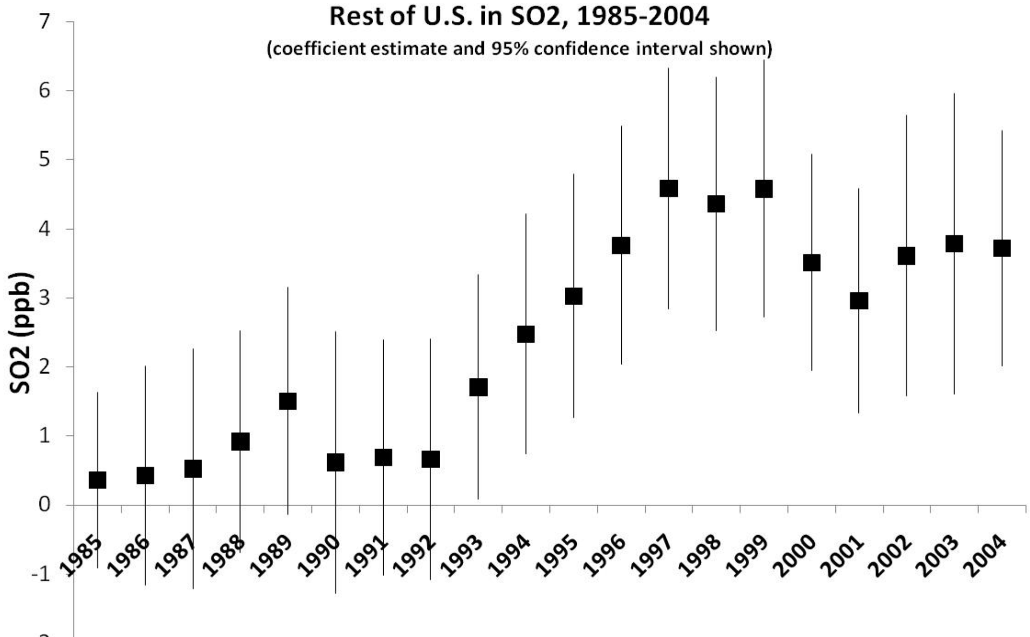
(coefficient estimate and 95% confidence interval shown)



Note: Includes controls for all county and state covariates and county fixed effects.

Fig. 3: Predicted Difference between North Carolina and Rest of U.S. in SO2, 1985-2004

(coefficient estimate and 95% confidence interval shown)



Note: Includes controls for all county and state covariates and county fixed effects.

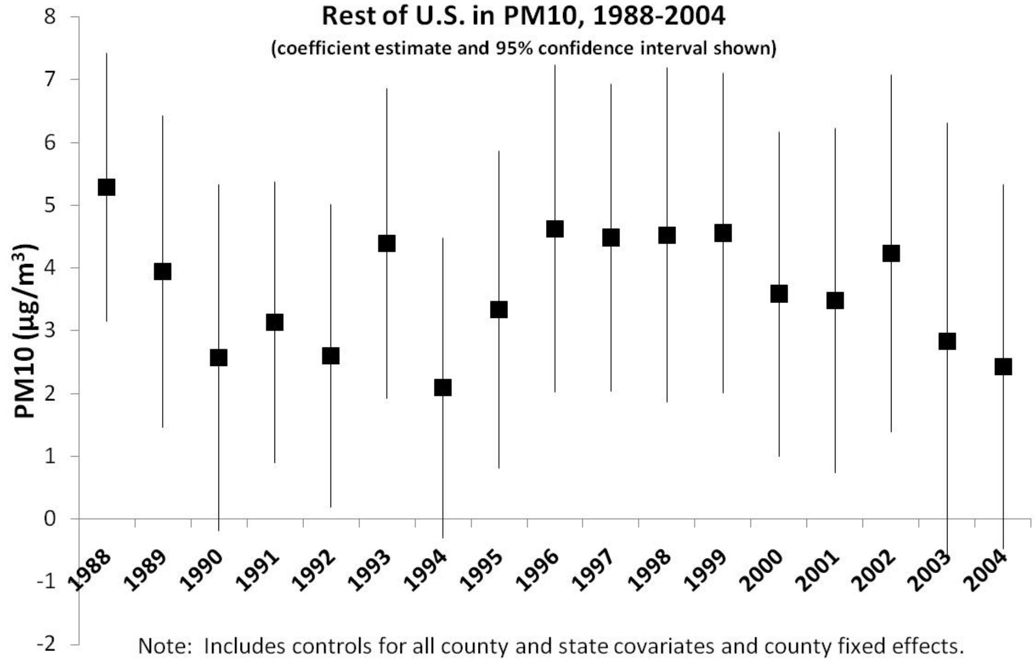


Fig. 4: Predicted Difference between North Carolina and Rest of U.S. in PM10, 1988-2004

(coefficient estimate and 95% confidence interval shown)

Note: Includes controls for all county and state covariates and county fixed effects.

While these graphs can provide a visual representation of effects over time, the spline models can provide coefficient estimates for the trend changes and provide an alternative specification test. Table 3 provides the results of estimating the interacted spline models with county-level number of hogs as the outcome variable. Models (i) and (ii) show robustness of estimated trends to the addition of confounders, revealing that estimates do not change. The coefficients representing λ_1 and λ_2 from Equation (2) are in bold. Post-1990, North Carolina sees a 10,401 (10.2%) increase per county per year in hogs, net of the pre-1991 trend in North Carolina, trends in the rest of the U.S., county fixed effects, and multiple covariates. The post-1996 trend shows a negative value, reflecting less increase in hogs. Models (iv) and (v) show this result to be similar in the sample including just SO2 data (an 11.1% increase), suggesting that findings using SO2 as the outcome variable are valid for areas outside of the sample with SO2 monitors. The last two columns of Table 3 show that results are statistically significant and similar for the sample with PM10 monitors, but only in the linear model.

Results for air pollution using the interacted splines are shown in Table 4. Regressions with SO2 as the outcome show that the estimates are robust with respect to the addition of confounders, and they display a similar pattern as effects of the 1991 policies on hogs. Post-1990, North Carolina saw a 0.5ppb (10.2%) per county per year increase in sulfur dioxide compared to the rest of the U.S., net of the various confounders and existing trends. Sulfur dioxide changes in North Carolina versus the rest of the U.S. also level off in the years when hog increases do the same. This finding suggests that the state-level hog inventory separate from the state's slaughter capacity had an effect on air pollution. The results for PM10 also suggest that this air pollution measure follows a trend similar to that of hogs. During North Carolina's period of rapid hog production expansion, PM10 increased at a rate 0.88μg/m^3 (4%) per year compared to other states. After the moratorium, North Carolina's levels decreased. The findings for PM10 support those for SO2 and provide further evidence that the hogs are driving the changes in air pollution.

The effects of North Carolina's legislation on production and pollution reveal that legislation can have strong effects in agribusiness. The fact that results are largely robust with respect to the addition of confounders strengthens the case that the identification strategies are valid, and that results are unbiased. The parallel results for hog production and air pollution using a restrictive empirical design provide strong evidence that hogs are causing the air pollution. In order to cement this claim, I perform further analysis and falsification tests and examine alternative hypotheses.

Using just the counties in North Carolina can provide an even more detailed examination of whether the changes in pollution are due to the hogs. Production growth in North Carolina occurred largely in the Eastern counties near the Bladen slaughterhouse. I therefore consider just the Eastern counties of North Carolina as the treatment group and use the Western counties as the control. While the small sample size restricts the ability to add covariates while still estimating effects with any precision, results (Appendix Table B.5) are statistically significant and somewhat larger than the main results. Compared to the Western counties, the Eastern counties increased hog inventories by 15.6% per year between 1991 and 1996, and increased ambient SO2 by 15.0%. The results for PM10 are not precisely estimated.

Table 3: Effects of North Carolina Legislation on Number of Hogs, Spline Regressions

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
	Entire U.S.			Entire U.S. with SO2 data		Entire U.S. with PM10 data	
	ln(Hogs)	ln(Hogs)	Hogs	ln(Hogs)	Hogs	ln(Hogs)	Hogs
Trend 1980 onward	-0.0240***	-0.00813**	-100.2	-0.000977	-8.544	-0.0247	-494.0**
	(0.0017)	(0.0033)	(97.9)	(0.012)	(189)	(0.015)	(244)
Trend 1991 onward	-0.0502***	-0.0424***	157.7	-0.0677***	-222.6	-0.0485**	316.9
	(0.0047)	(0.0064)	(163)	(0.014)	(169)	(0.023)	(267)
Trend 1997 onward	0.0414***	0.0535***	159.6	0.0640***	196.4	0.0641***	75.60
	(0.0062)	(0.0081)	(133)	(0.020)	(187)	(0.023)	(159)
Trend 1980 onward in North Carolina	-0.00364	0.0131	1685*	0.0165	-1578	0.0733	-3916
	(0.0086)	(0.0090)	(863)	(0.022)	(1935)	(0.100)	(3130)
Trend 1991 onward in North Carolina	**0.109*** **	**0.102*** **	**10,401*** **	**0.111*** **	**13,759***	**-0.0209**	**10,869***
	(0.020)	**(0.021)**	**(3349)**	**(0.038)**	**(7413)**	**(0.12)**	**(6243)**
Trend 1997 onward in North Carolina	**-0.143*** **	**-0.165*** **	**-12,651*** **	**-0.171** **	**-17,396** **	**-0.0910***	**-7,212***
	(0.024)	**(0.026)**	**(3916)**	**(0.071)**	**(7714)**	**(0.049)**	**(4023)**
Other county covariates included?[a]	No	Yes	Yes	Yes	Yes	Yes	Yes
Other industry variables included?[b]	No	Yes	Yes	Yes	Yes	Yes	Yes
County fixed effects included?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	56,819	43,595	43,595	5,269	5,269	4,968	4,968

Notes: Robust standard errors shown in parentheses. Standard errors clustered by county. *** refers to significance at the 1% level. **refers to significance at the 5% level. * refers to significance at the 10% level. Sample including data with PM10 information only includes 1987 onward.

[a]County covariates refers to ln(per capita income), population density, mean temperature, precipitation, percentage of the county over age 65, number of building permits, ln(population), unemployment rate, and poverty rate.

[b]Other industry variables refers to separate variables for ln(employment) in 6 other industries.

Table 4: Effects of North Carolina Legislation on Air Pollution, Spline Regressions

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
	Sample: Entire U.S. with air pollution data							
	ln(SO2)	**ln(SO2)**	**SO2 (ppb)**	**ln(PM10)**	**ln(PM10)**	**PM10 (μg/m^3)**	**ln(carbon monoxide)**	**ln(ozone)**
Trend 1980 onward	-0.0241***	-0.0182***	-0.167***	-0.0538***	-0.0430***	-1.488***	-0.0194***	-0.00149
	(0.0028)	(0.0060)	(0.039)	(0.0035)	(0.0040)	(0.13)	(0.0061)	(0.0013)
Trend 1991 onward	-0.0325***	-0.0353***	-0.207***	0.0249***	0.0134**	0.741***	-0.0347***	0.00875***
	(0.0061)	(0.0075)	(0.058)	(0.0041)	(0.0052)	(0.16)	(0.0079)	(0.0017)
Trend 1997 onward	0.0246***	0.0228***	0.188***	0.0130***	0.00988**	0.271**	-0.00736	-0.0164***
	(0.0067)	(0.0087)	(0.056)	(0.0029)	(0.0041)	(0.11)	(0.0086)	(0.0019)
Trend 1980 onward in North Carolina	-0.00668	0.00207	0.0691	-0.00995	-0.0246***	-0.436*	-0.0306*	0.00684
	(0.020)	(0.021)	(0.12)	(0.0076)	(0.0079)	(0.24)	(0.017)	(0.0054)
Trend 1991 onward in North Carolina	**0.109*** **	**0.102*** *	**0.517*** *	**0.0269*** **	**0.0437*** **	**0.884*** **	**0.0297**	**-0.00544**
	(0.040)	**(0.041)**	**(0.21)**	**(0.010)**	**(0.011)**	**(0.29)**	**(0.020)**	**(0.0067)**
Trend 1997 onward in North Carolina	**-0.144*** **	**-0.145*** **	**-0.712*** **	**-0.0350*** **	**-0.0334*** **	**-0.668*** **	**0.00508**	**-0.00932*** **
	(0.033)	**(0.036)**	**(0.16)**	**(0.0075)**	**(0.0079)**	**(0.18)**	**(0.021)**	**(0.0034)**
Other county covariates included?[a]	No	Yes	Yes	No	Yes	Yes	Yes	Yes
Other industry variables included?[b]	No	Yes	Yes	No	Yes	Yes	Yes	Yes
County fixed effects?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,671	5,269	5,269	5,958	4,968	4,968	3,037	6,789

Notes: Robust standard errors shown in parentheses. Standard errors clustered by county. *** refers to significance at the 1% level. **refers to significance at the 5% level. * refers to significance at the 10% level. Sample for SO2, ozone, and CO regressions includes 1980-2005. Sample for PM10 regressions includes 1987-2005.

[a]County covariates refers to ln(per capita income), population density, mean temperature, precipitation, percentage of the county over age 65, number of building permits, ln(population), unemployment rate, and poverty rate.

[b]Other industry variables refers to separate variables for ln(employment) in 6 other industries.

One may believe that increases in hog production in North Carolina led to more vehicular traffic, which is the cause of the air pollution. Alternatively, the time period could have been associated with lower state environmental standards in general.[12] To test both of these ideas, I use two other air pollution measures as dependent variables (Table 4, Models (vii) and (viii)). The results show that neither carbon monoxide nor ozone, two pollutants normally associated with vehicles, follows the same trends as those in SO2, PM10, and industry presence. If the 1991 through 1996 time period was associated with generally lax environmental legislation, then effects would likely also show up in these other pollutants, which is not the case. [13]

Instead of creating more vehicular traffic, the increased industry presence may have led to more electricity consumption; the increased SO2 levels in North Carolina relative to the rest of the U.S. may therefore be due to electricity, rather than effects from hogs. In particular, the Bladen County slaughterhouse may have created air pollution via the energy consumption involved in refrigeration. North Carolina produces a significant portion of its electricity via coal (Energy Information Administration, 2009). I therefore examine trends in industrial and commercial consumption of electricity produced from coal in North Carolina versus the rest of the U.S (Appendix Figures B.1 and B.2). Results show that coal electricity consumption declines in North Carolina starting in the early 1990s, following a steady increase in prior years. In relation to other states, North Carolina parallels use between 1991 and 1997. The figures show that coal electricity consumption does not exhibit the same pattern as ambient SO2 (Fig.3), suggesting that changes in electricity consumption are not associated with the changes in air pollution.

A further possibility is that another polluting industry is moving in the same pattern as hog production in North Carolina, and that this other industry is leading to the changes in air pollution. While variables for other industries were included in the regressions above and do not change coefficients, I further test this hypothesis by regressing each of the 6 industries included on the model with all covariates and trends (Appendix Table B.7). None of the other 6 industries exhibit the same patterns as pork industry presence and SO2 air pollution,

[12] However, state laws in 1991 also allowed more stringent regulations of all other industries outside of livestock production, hence any accompanying pollution effects would need to arise from emitters outside of regulatory stipulations.

[13] In a set of further tests, I include as covariates the total estimated emissions non-point and point source SO2 and non-point source carbon monoxide in the county. The data on emissions by county come from the EPA's National Emissions Inventory and are only available for the period 1990 to 2002. I therefore restrict the time period and only explore the trend break in 1997. The results, shown in Appendix Table B.6, reveal that inclusion of the emissions does not change the estimated coefficients on the variables of interest.

providing evidence that the changes in air pollution are not attributable to these other potential sources.

Examination of alternate control groups can provide further robustness checks and allow the examination of yet other alternative hypotheses. Appendix Table B.8 shows the results of performing the analyses with other control groups. The first alternative control group includes just the states surrounding North Carolina; these arguably offer the most similarities to North Carolina in terms of end market access and environmental amenities pertinent to hog production and air pollution. Comparing North Carolina to its surrounding states also serves to test an alternative hypothesis with respect to air pollution. Suppose some upwind state strongly increases its sulfur dioxide emissions in 1991 and strongly curbs the increase in 1997. If this were the case, then states around North Carolina would likely exhibit the same patterns as North Carolina, and by comparison the effects in North Carolina would not be significant. The results show that the estimated coefficients of interest are very similar to the main results and are still highly significant.

I use two sets of further comparison groups to provide additional checks of robustness. The first set is chosen based on economic features that may encourage the adoption of laws like those in North Carolina. The first of this type of group includes states with the most hog production in 1987, which may have been more likely to adopt lenient regulation of this industry. A second alternative control group includes states with the lowest agricultural growth between 1982 and 1987, which may have had these states toward wooing pork production. In both cases, results are largely robust and are very similar to the main results.

A second group of alternative controls are chosen on the basis of state-level agricultural laws. One factor influencing livestock production location is regulatory environment. First, I exclude the nine states that had anti-corporate farming laws at any time between 1980 and 2005. States without such laws (like North Carolina) may be more likely to experience the fast growth and contract arrangements witnessed in North Carolina. Second, I exclude states that have NPDES permits for hogs listed in the EPA's Permit Compliance System at any point between 1980 and 2005. States without such permits listed with the EPA (like North Carolina) may be less stringent overall in terms of environmental rules surrounding livestock, and may therefore adopt similar regulation to North Carolina's. Again, results using these control groups mirror the main results.[14] The similarities found when using these different control groups suggests that the

[14] Appendix Table B.8 also shows two further specification tests. First, I include just observations with non-imputed values for hogs. This shows much larger estimates, likely due to the bias toward the null presented via imputation. Second, I limit the time period of inclusion to check for sensitivity to this specification. Findings are similar to the main results.

estimated effects are unbiased with respect to other factors that may not be explicitly included (like other states' regulatory environments).

If North Carolina's production grew, where did it come from? National inventories do not significantly change between 1980 and 2005, but do generally fluctuate in amounts larger than the overall increase in North Carolina between 1991 and 1997. Thus it is difficult to discern what portion of the growth in North Carolina is due to national increases and what part is taken from other states. Examination of two final comparison groups allows for an estimation of how much production North Carolina might have removed from other states. Consider the Western half of the U.S. to supply one market and the Eastern half to supply another.[15] Comparison of North Carolina to each of the groupings can provide an estimate of how much North Carolina took away production from its most likely competitors while still controlling for secular trends. Using the differences-in-differences model for simplicity, the 1991 North Carolina regulations led to a 78,005 increase in hogs per county compared to Western states, but an 83,246 increase compared to Eastern states.[16] The difference between the two values (5,241) provides an estimate of how much production on average each Eastern county outside of North Carolina lost to North Carolina.[17] This amount constitutes on average 28% of 1991 inventories in each Eastern county,[18] suggesting that North Carolina removed nearly a third of inventories from each other state in the Eastern half of the country by enacting lenient regulations.

6. Discussion

The results show that the legislation in North Carolina in 1991 enabled a strong increase in the state's hog production net of prior trends in the state, trends elsewhere in the country, effects of other industries, and multiple other potential confounders. Further, the regulations in 1997 strongly decreased the growth in the state's industry presence. Mirroring these trends in hog production are changes in ambient air pollution. The similar shapes and timings of trends in air pollution and hogs provide strong evidence that the pork industry is responsible. Tests for air pollutants not associated with hog production do not show similar trends. None of the 6 other industries tested follow the same pattern as hog production.

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[15] Here, "Western" states refer to those west of and including Texas and North Dakota.
[16] Results are shown in Appendix Table B.9.
[17] If North Carolina is taking production from Eastern states, than the DD coefficient will capture both the increase in North Carolina and the decrease in other states due to production moving to North Carolina. Since North Carolina is less likely to remove production from Western states, using these states as a control group is less likely to suffer from this sort of effect.
[18] The average number of hogs in Eastern counties outside of North Carolina in 1991 was 18,657.

If this industry is responsible for the air pollution, then the magnitude of the effect is pertinent for policy discussions regulating the industry under the Clean Air Act. Using the Wald estimator, the elasticity between hogs and SO2 is estimated to be 0.92 and between hogs and PM10 to be 0.37; a doubling of production is predicted to raise sulfur dioxide by 92% and PM10 by 37%.[19] In terms of levels, a 100 hog increase is associated with a 0.004ppb increase in ambient SO2 and a 0.009μg/m^3 increase in ambient PM10.

The findings here are larger than those in the one other article examining the effects of hogs on ambient air pollution on a scale wider than the individual operation. In a national sample for roughly the same time period used here, but using monitor-level data, Sneeringer (2009b) shows a 0.10 elasticity between hogs per square mile and sulfur dioxide. The result here of a 0.92 elasticity is much higher, which may due to at least one of three factors. First, the lower elasticity from the national study may be downward biased due to some unobserved confounder that increases (decreases) air pollution but decreases (increases) hog production. While Sneeringer includes a number of covariates as well as fixed effects, measurement error or unobserved confounding may still be present. A second alternative may be differential spacing of air pollution monitors in North Carolina compared to the rest of the U.S. For example, North Carolina is relatively populated compared to other major livestock-producing states. If monitors are located in more populated areas, then it is easier to capture the effects of hogs on air pollution in North Carolina; effects may be better estimated and less likely to capture effects only at the lower end of the distribution of hogs per county. Finally, the different methods of manure management in other parts of the country may yield less pollution than the liquid-based lagoon system common in North Carolina.

The increases in ambient air pollution associated with the legislation reveal significant negative externalities associated with the 1991 policies. The differences-in-differences estimator shows that the legislation led to a 3ppb increase in sulfur dioxide. The size of this effect is mirrored in the spline models, which show a 0.5ppb increase per year, totaling a 3ppb increase over the 6 years between 1991 and 1997. This magnitude may not seem large to those unfamiliar with air pollution, so context is useful. The national ambient air quality standard for annual SO2 is 30ppb; the 1991 legislation therefore moved counties 10% closer to violation of federal air quality standards. Another way of describing

[19] The Wald estimator is similar in concept to the instrumental variable estimator. Its magnitude is calculated by dividing the reduced form estimate (the effect of the legislation on air pollution) by the first stage estimate (the effect of the legislation on hog production). For calculation of elasticities, I use the estimated effect of the legislation on number of hogs in the sample with air pollution data. For SO2 I use the 1991-1996 time period; for PM10 I use 1997-2005 to make use of the statistically significant estimate for ln(hogs) during that period.

3ppb is by considering the actual change in SO2 in North Carolina. As reported in Table 1, North Carolina saw a SO2 decrease of 0.4ppb between 1991 and 1997 (from 4.7ppb to 4.3ppb); therefore, without the growth in hog production, this decline would been have eight times larger. Finally, consider the effect of North Carolina's lax regulatory environment relative to the effect of the attainment/non-attainment designations of the Clean Air Act. Greenstone (2003) finds a 5.2ppb decline in SO2 from CAA non-attainment status in 1987-1992.[20] The change in North Carolina from increased hog production is approximately 60% of this effect, suggesting that leaving the industry unregulated can have effects that are large enough to "undo" the gains from other policies.

Putting an economic cost on the air pollution externality created by hog production requires making strong assumptions, but such an exercise can provide an order of magnitude of the external costs associated with the industry. North Carolina counties saw on average a 7.8% increase in hogs per year between 1991 and 1997. Sneeringer (2009a) has found that livestock production influences infant mortality, with the strongest evidence for an air pollution mechanism; she finds a 7.4% increase in infant mortality correlated with a 100% increase in production, as measured by livestock inventory.[21] The increase in North Carolina hog inventories is therefore predicted to increase infant mortality by 0.53% per year, which, at the state's 1991 infant mortality rate, yields 0.2 deaths per county per year. Using the EPA's value of a statistical life of approximately $7 million (2005$) generates an externality cost of $1.4 million per county per year attributable to hog production.[22] For the state this totals $140 million or 20 deaths per year.

These externality costs can be compared to industry revenues. The 1992 Census of Agriculture reports sales of hogs and pigs in North Carolina totaling $1.23 billion (2005$). Assuming this revenue is divided equally among counties yields sales of $12 million per county. Therefore, 12% of revenues are in health

[20] Greenstone (2003) finds for the 1987-1992 period "non-attainment" status under the CAA yields a decrease in ambient SO2 between 0.0014 and 0.009ppm (p. 605). I use the mean of Greenstone's two estimates for comparison. Greenstone strongly points out that the coefficients estimated are largely not statistically significant.

[21] Since SO2 is a proxy for H2S, and PM is a partial proxy for ammonia, using a dose-response relationship for SO2 or PM10 may not accurately reflect the health effects of these other pollutants. I therefore use the reduced form estimate from Sneeringer (2009), which may capture the pollutants most implicated in hog production. As this estimate of livestock inventory's relationship to infant mortality arises from 1980-1999, it likely reflects the same levels estimated in the article, mitigating concern about capturing heterogeneous pollution level effects.

[22] In 1991 North Carolina's infant mortality rate (IMR) was 10.8 deaths per 1,000 births. A 0.53% decrease in this number yields an IMR of 10.7. Assuming that the 102,362 births in 1991 in the state were evenly distributed among the 100 counties yields 1,024 births per county. An IMR of 10.8 yields 11.1 deaths per county, compared to 10.9 deaths per county at an IMR of 10.7. The difference shows 0.2 deaths that could have been avoided per county per year.

externality costs. Externality costs are higher, however, if one includes effects on property values, other types of morbidity and mortality, water pollution, and recreational amenities. Additionally, analysis estimating the other positive attributes accruing to the state via hog production, such as tax revenue and employment, would provide a better valuation of benefits.

This article reveals that environmental regulations can have important implications for agribusiness and pollution. Given that livestock production is one of the major polluters in the U.S., these findings have important implications for stringency of future federal regulation of agriculture. Further, this article supports the EPA's regulation of livestock operations under the Clean Air Act by showing that hog production is significantly implicated in ambient air pollution and heightened exposure levels for public health.

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