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

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Abstract

Research on environmental regulation's effects on economic activity has largely focused on manufacturing, ignoring one of the major polluters in the U.S. – commercial agriculture. As livestock production has become increasingly mobile, regulation has become an important criterion in firm location. This article extends the literature on environmental regulation's economic effects to commercial agriculture by exploiting a series of regulations adopted in North Carolina in the 1990s. During this time, the state's hog production more than tripled as a consequence of welcoming state legislation. This sudden growth creates an opportunity to study how environmental regulation affects the location of economic activity, the externality costs of legislation aimed at economic growth, and the effects of swine on air pollution. The last of these foci is of particular importance to upcoming federal regulation of large-scale livestock production under the Clean Air Act. By exploiting the distinct trend breaks in hog production in North Carolina, I am able to non-parametrically control for trends in the rest of the country as well as trends in North Carolina prior to the enactment of the lax regulations. I find that the laws led to an additional 11% increase per year in hog production 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 hogs; 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 20% of North Carolina's hog production revenue.

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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. International trade research has examined this in the pollution haven literature, while research on variation in domestic regulation has shown it to be a significant factor in firm location. The prior literature is largely focused on manufacturing, while ignoring one of the major polluters in the U.S. – commercial agriculture. Without the iconic smokestack, agriculture is not normally viewed as a major polluter; however, the Environmental Protection Agency (EPA) judges agriculture to be one of the most significant contributors to impairments of rivers and streams, one of the largest emitters in the country of certain gases, and a cause of coastal "dead zones" where fish cannot live. This article extends the literature on environmental regulation's effects on economic activity to commercial agriculture while overcoming many obstacles hampering causal inference in prior empirical research. Because new technologies have enabled livestock production's increasing mobility, the industry is now able to locate in regions not traditionally conducive to production, creating the opportunity to study legislative effects on location. This paper considers a specific set of state policies to examine the effects of environmental regulations in the agricultural sector.

In the 1990s the number of hogs in North Carolina more than tripled, making it the second-largest swine-producing state in the country. A distinct trend break in North Carolina's hog numbers coincided with policy changes enacted by Senator Wendell Murphy, a prominent hog farmer and state politician. During the 1990s, Murphy created tax breaks, exemptions from environmental fees, and freedom from local zoning ordinances in order to encourage the state's hog production. Coupled with this growth in the state's tax base came a succession of environmental disasters associated with hog operations. 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, the state enacted a moratorium on new swine operations, yielding a second distinct trend break in North Carolina's hog production.

Concurrent to North Carolina's growth in hog prominence, the industry has been increasingly implicated in air pollution. At present, the EPA is collecting data from livestock operations in order to regulate them under the federal Clean Air Act (CAA). However, relatively little is understood about the extent of the pollution, or the amount that should be spent on regulation.

In this article I examine three primary questions using county-level annual data between 1980 and 2005 on ambient air quality and hog production. First, to what extent did Murphy's policies increase hog production in North Carolina? I estimate effects using both differences-in-differences and spline models that control for levels and trends prior to regulatory changes. The estimation strategies overcome many of the problems with causal inference in the prior literature. I find that the legislation adopted in 1991 induced an additional 11% increase per year in hog production per county in North Carolina, controlling for a variety of observed and unobserved confounders. The 1997 moratorium exerted a strong control on the industry's growth in the state. This evidence of environmental legislation affecting location of economic activity documents that regulation plays a significant role in agriculture.

The second question is whether the regulation impacted environmental quality. In this sense I go beyond most of the pollution haven literature by actually documenting the effect of (anti-) regulation on pollution. I use the same models described above and find that the legislation induced an additional 10% increase in air pollution per year 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 6 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 what the effect of swine production is on ambient air pollution. The size of the externality associated with hog production is necessary to understand the amount that should be spent regulating this industry, but assessments are lacking. Cross-sectional estimates may yield biased results, as producers may locate based on factors correlated with air quality. Hence, any resulting correlation between air pollution and livestock production may be due to location choice, versus the actual effect of livestock on air pollution. Because Murphy's legislation is not concerning air quality, its implementation and the change it induces in livestock numbers provides a shock in hog production that is arguably exogenous to air pollution. The strength of the identification strategy, a series falsification tests, and examination of alternative hypotheses strongly point toward hog production as the culprit. I estimate that a doubling of production leads to a 92% increase in ambient air pollution. This finding is pertinent to current debates surrounding regulation of the industry under the Clean Air Act.

The magnitude of the air pollution resulting from Murphy's laws is large enough to yield significant public health consequences. In terms of economic impacts from livestock operation pollution, I find that hogs are responsible for at least $2.45 million (2005$) in health externality costs per county per year. This amounts to 20% of the industry's revenues, and suggests that significant gains in social welfare can be had via regulating hog production in North Carolina and nationally.

Background on Changes in Hog Production and Effects on Air Pollution

Hog production has witnessed significant changes in the last several decades. New technologies in the ability to raise swine in close proximity have enabled capturing economies of scale. These changes have also facilitated geographic shifts to areas not previously conducive to swine production (Rhodes, 1995; Hubbell and Welsh, 1998). In the move to new regions, factors important to location include input costs, experience with contract marketing arrangements, and transportation time to finishing stations.

In the context of these shifts, hog production has become geographically focused, carrying with it the spatial concentration of 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 and by preference for man-made fertilizers. To dispose of the waste, facility operators may over-apply it to land, leading to nutrient run-off. Further, lagoons may leak or overflow, particularly during storms or floods.

Because of this manure, livestock production has become one of the largest contributors to water pollution in the nation (EPA, 2002). This has occurred despite regulation of large-scale livestock operations under the 1972 Clean Water Act, which designated operations above a certain number of head as "point sources" of pollution (Copeland and Zinn, 1998). Regulatory efforts to limit pollution from livestock have continued since that time, but livestock remain a major polluter. In a majority of regions in the U.S., livestock waste contributes more to river impairment than municipal storm sewers or industrial sources (EPA, 1993). It is also a major contributor to coastal water impairment, creating vast "dead zones" where fish cannot live due to nutrient overload.

While the industry has long been recognized for water pollution, it is now increasingly acknowledged as a source of air pollution. Numerous scientific and engineering studies have measured the levels of emissions at different types of livestock facilities and recorded specific emission levels for a number of pollutants (for extensive reviews see National Research Council 2003, and Iowa State University and The University of Iowa Study Group 2002). These finding arise largely from individual farm-level studies, or the model farm method.[1]

The major air pollutants of concern from hog producers include hydrogen sulfide (H2S) and ammonia (NH4). These are both toxic gases that can lead to respiratory problems and, at high levels, death. While other gases are associated with swine production, these are the two that are most linked to public health concerns. These air pollutants arise from decomposition of manure, spray application

[1] The model farm construct estimates total emissions using emissions from different steps of production. A model farm is an entity only on paper, and does not represent an actual operation.

of slurry to land, and from the animals themselves. Numerous popular press articles report health effects from livestock facilities (for example, Lee, 2003; Teitz, 2006), and these have been supported by peer-reviewed research (for example, Sneeringer, forthcoming; Cole, Todd, and Wing, 2000). In contrast to minor nuisances, the amounts of gases emitted at livestock facilities are increasingly shown to be significant. Livestock production is the top emitter of ammonia in the country (EPA, 2000), and the levels of hydrogen sulfide emitted at hog operations are also shown to be significant; by one estimate the hog facilities of North Carolina emit more H2S than the fertilizer and paper producers in the state combined (Schliesser, 2003).

While research has shown that livestock production pollutes the air, understanding the extent of effects and identifying possible regulatory methods has remained elusive. 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. As noted by the National Research Council, emissions estimates from individual farms may yield very different ambient levels, depending on temperature, precipitation, manure management practices, and geological features. This suggests a need for generalized estimates from non-laboratory settings.

Despite regulators' desire for more information on livestock facilities' effect on air pollution, little research has assessed the part these operations play in national contributions to air quality. An exception to this is Sneeringer (2008), who finds a significant relationship between hog production and measured ambient air pollution. Sneeringer uses individual monitor-level data for air pollutants coupled with county-level hog density between 1980 and 2002 and finds a significant relationship between hog production and ambient air pollution, even after controlling for emissions from other sources.

Given the lack of knowledge, there is little direct regulation of air pollution from livestock operations. The first occurred in 2004 in Southern California, when the regional air quality control board for metropolitan Los Angeles began requiring dairies to obtain air quality permits (South Coast Air Quality Management District, 2004). While many states have adopted odor regulations the concern with stench concerns not so much health as it does nuisance and property value. Air pollution can have detrimental effects even if it cannot be smelled. Having recognized the research gaps limiting knowledge of air emissions from livestock production (EPA, 2001 and 2005), the EPA asked the industry to collect its own emissions data in exchange for clemency from past air pollution violations (EPA, 2006).

The future increase in regulation of livestock operations has important implications for the location of the industry. Water quality regulation, while federally mandated, is enforced by states, leading to differential application. Further, states can adopt their own regulations, leading to even more variation in regulatory stringency. 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.

Research on whether environmental regulations play a role in location decisions of livestock producers has used different methodologies with mixed results. Martin and Zering (1997) and Sullivan, Vasavada, and Smith (2000) describe the effect that environmental regulations could have in the hog sector, but do not provide evidence of causal effects. Roe, Irwin, and Sharpe (2002) and Isik (2004) both use environmental stringency indices to cross-sectionally explore the relationship between manure management regulation and prevalence of livestock operations. While Roe, Irwin, and Sharpe find a significant, negative relationship between regulatory stringency and hog production, and Isik finds one for dairy, the use of cross-sectional data seriously hampers any ability of causal inference. While these authors show negative relationships, the estimated effects may be understated due to endogeneity.

Specifically, regulatory stringency may be greater in locations with higher concentrations of livestock. Metcalfe (2001) uses state-level longitudinal data to examine effects of water quality regulation costs on hog production locations, but without data on time periods prior to regulation, he too encounters endogeneity. He attempts to mitigate this using an instrumental variable approach, but offers no evidence that his instrument is valid or strong. He finds no effects. Herath, Weersink, and Carpentier (2005) also use longitudinal data and an instrumental variable approach. However, the environmental stringency measure employed combines a number of separate indices for different factors. Further, this work suffers from the same issues with instrumental variables as Metcalfe. The authors find that increased severity of environmental regulations leads to lower production in the hog sector.

The empirical problems in the above literature are echoed in the broader research on the effects of environmental regulation on economic activity. An expansive literature has considered whether international trade in the context of differential environmental regulations leads to polluting industries fleeing to countries with lower compliance costs (see, for example, Levinson and Taylor, 2008; Eskeland and Harrison, 2003; List, McHone, and Millimet, 2004). The research regarding effects of pollution regulation on economic activity in the U.S. has also found significant effects (see, for example, Becker and Henderson, 2000; Greenstone, 2002). The prior literature is particularly concerned with omitted variables and endogeneity in providing causal inference. One worry is that any association between laxness of environmental regulation and heightened economic activity is due to some third factor (like inexpensive labor) which is correlated with lax environmental regulation; without including this factor, then estimated effects are inconsistent. The second primary concern is endogeneity; regulation may be stricter in areas with more economic activity. One method to overcome omitted variables is to non-parametrically control unobserved heterogeneity through fixed effects with panel data covering both regulated and unregulated regions. To mitigate endogeneity, authors have examined data on regions before and after regulation, controlling for secular effects in untreated areas.

The methods employed in the prior literature will guide the empirical section later in this article.

North Carolina's Explosion in Hog Production

North Carolina's experiences provide a method to explore regulatory effects on industry location and environmental quality in agriculture. In the search to replace its declining tobacco industry, North Carolina found contract hog production. By 2002, North Carolina produced 16.3% of the nation's hogs, second only to Iowa (USDA, 2004). A rapid expansion in the 1990s led to the current situation. Figure 1 shows the number of hogs in North Carolina versus the number in other top hog-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 1983, Wendell Murphy, a prominent hog farmer attributed with the development of pork contract marketing (Roth, 1997), was elected to the North Carolina House of Representatives and helped enact a number of laws welcoming hog production to the state. Between 1983 and 1988, bills were ratified that exempted hog operations from sales tax on building materials and machinery, gas taxes on delivery vehicles, and inspection fees. In 1988, Murphy was elected to the North Carolina Senate, and in 1991 the state adopted another set of bills favorable to hog operations. The 1991 bills included swine operation exemptions from county zoning restrictions and environmental penalties (General Assembly of North Carolina, 1991a). The state attempted to tighten pollution standards in 1991 when it allowed state-level environmental regulations to be stricter than federal ones. However, Murphy added an amendment exempting livestock and poultry facilities from any such restrictions (General Assembly of North Carolina, 1991b).[2] This welcoming regulatory environment heralded a steep rise in the state's hog production and enabled Smithfield Foods to choose North Carolina as the location

[2] 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."

for the world's largest slaughterhouse (Center on Globalization, Governance, and Competitiveness, 2007).[3]

The explosion in the state's hog production coupled with lax environmental regulations had noticeable consequences. Despite 1993 state rules which forbade livestock operations to directly discharge wastes into surface water (EPA, 1997), the state came last in a 1994 state ranking of manure management stringency (Metcalfe, 2000). 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). Environmental debates and a series of negative press followed. North Carolina's *The News and Observer* won a Pulitzer Prize for its 1995 articles detailing Murphy's laws and the environmental consequences of hog production (Stith, Warrick, and Sill, 1995).

The state government responded by strengthening environmental regulation of hog production under Senate Bill 1217. This bill called for "nondischarge" permits, twice-yearly inspections, lagoon set-back requirements, an increase in penalty fees, and written notice to neighbors of future large-scale hog operations (General Assembly of North Carolina, 1995). The bill went into effect in 1997; in that year, the state also enacted a 2-year moratorium on the building of new large-scale livestock operations, partially re-instated county zoning restrictions on hog operations,[4] and instituted further setbacks (General Assembly of North Carolina, 1997). The moratorium was renewed in 1999 and again in 2003 (Center on Globalization, Governance, and Competitiveness, 2008). Hog production growth in the state leveled off after 1997, but did not drop. The legislation grandfathered the large-scale hog producers already operating in the state, so the moratorium prevented new operations but did not force existing ones to leave.

[3] The slaughterhouse opened in 1992.
[4] Counties were allowed zoning in the cases of hog operations with 600,000 lbs. of steady-state live weight. However, counties were not allowed to prohibit the existence of already present facilities, or to be so strict as to run the current operations out of business.

The distinct trend breaks in North Carolina's hog production create an opportunity to study the effects of Murphy's 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 regulations do not focus on air pollution, changes in air quality before and after the regulation are likely the result of the regulation. Finally, because the changes in North Carolina's hog inventory are so abrupt, this creates a so-called "natural experiment" with which to estimate effects of hogs on air pollution. Since swine producers were not moving to North Carolina in response to poor air quality, and since air pollution from hog operations was overlooked until recently, the location changes are arguably exogenous to air pollution changes.

This method of identifying effects of hogs on air pollution is strengthened when considering that other legislative changes surrounding air pollution do not coincide with those for hogs. 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. Further, because North Carolina does not regulate swine facilities for air pollution, movement of hogs is likely exogenous to air pollution.[5] Finally, livestock operations were the only industry exempt from heightened regulatory stringency enacted in 1991 in North Carolina, hence resulting pollution changes are more likely the result of hog operations.

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 *levels* between counties affected versus unaffected by Murphy's laws and one

[5] North Carolina started regulating odor from swine facilities in 1999 (NCDENR, 2002).

based on differential *trends*. Together these models can elucidate not only how environmental regulations shift levels, but also how they affect trends.

Begin by considering a cross-sectional regression model of the effect of Murphy's laws on an outcome variable. Allow the time period to be post-adoption of Murphy's laws.

(1) $$Y_i = \alpha + \lambda(NC_i) + X_i'\beta + e_i$$

The outcome variable (Y_i) refers to the number of hogs or the ambient air pollution level. The subscript *i* denotes county, NC_i is an indicator variable equal to one if the county is in North Carolina, and X_i denotes a vector of county-varying confounders that are correlated with features of North Carolina as well as the outcome. The coefficient λ will provide an estimate of the correlation between being in North Carolina and hog production or air pollution, and if the time period is post-adoption of Murphy's laws, then one might interpret this as an effect of Murphy's legislation. However, the coefficient would only provide a consistent estimate for these effects if $E(e_i \mid X_i, NC_i) = 0$.

One way in which this stipulation would be violated is in the case of omitted variable bias. For example, North Carolina may always have higher or lower air pollution due to naturally-occurring factors; if one does not include a confounder for every variable associated with air pollution and correlated with the features of the state, then λ will be biased. Further, if the goal is to estimate an effect of Murphy's laws, then it will be incorrect to attribute λ to the laws. The first method of reducing potential omitted variable bias is by including all confounders. Barring observable data on all X variables, one can turn to non-parametric methods.

One method of non-parametrically controlling for county-level time-invariant and time-specific county-invariant effects is the differences-in-differences model. Consider panel data of counties over time. The data allows two sources of variation which can be used to control for unobserved confounders. First, North Carolina counties are observed both before and after implementation of

Murphy's 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 factors that are common for all states for a specific time period can be factored out of the effect of Murphy on the outcome variable.

This "differences-in-differences" approach provides an estimate of the effect of Murphy on the outcome variable comparing North Carolina pre- and post-adoption (the first difference), while factoring out secular changes occurring in the same time periods in counties outside of North Carolina (the second difference). With county-level panel data, the equation is mathematically the same as a model with fixed effects for county and year:

(2) $$Y_{it} = \alpha + \lambda(Post - Murphy_t * NC_i) + X'_{it}\beta + \gamma_i + \gamma_t + e_{it}$$

In equation (2) *t* indexes the year, and $Post - Murphy$ is an indicator variable for whether the year is after the adoption of Murphy's legislation. γ_i is a vector of indicator variables for each county, while γ_t is a vector of indicators for each year. If there are no unobserved changes that affect the outcome variable occurring in North Carolina but nowhere else at the same time as Murphy's legislation, 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, omitted variable bias is mitigated.

The possibility of endogeneity is more or less plausible depending on the outcome variable. It is highly unlikely that air pollution will cause the adoption of legislation exempting hog operations from regulation. During the 1990s, hog operations were generally not considered of regulatory concern for 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. An argument against this is that other states produced more hogs and yet did not adopt such (anti-) regulation. However, the question of endogeneity provides a reason for turning to the second estimation strategy.

The differences-in-differences model provides an estimate of the mean shift in the outcome variable attributable to the legislation in North Carolina. The approach provides a relatively straightforward estimate, and is also useful when considering one-time effects. 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 Murphy. To overcome this potential problems, one can instead examine difference in differences in trends to control not only for the trend in North Carolina prior to the legislation but also any trend breaks in other states at the same time as the legislation. This method, by focusing on trends, also mitigates endogenous regulation adoption due to production levels. Using the trend breaks in hogs allows for an even stronger method of identification of effects on air pollution. Specifically, if air pollution exhibits the same direction of trend breaks at the same time 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 the rest of the U.S.

To understand this alternative estimation method, begin by considering three periods characterizing North Carolina's legislative history between 1980 and 2005. The pre-1991 (1980-1990) period can be characterized as "pre-Murphy", the 1991-1996 period is when Murphy's laws were in effect, and the 1997-onward period follows the first moratorium. To characterize these three periods and control for possible secular trend-breaks occurring in other states, I construct a set of interacted splines with "knots" at the years when different regulations were adopted. To non-parametrically "difference out" trends that occur in each of the three time periods requires two splines: one for North Carolina and one for the rest of the states.

Allow t_1^* and t_2^* to refer to the "knots" at which different line segments are forced to meet. Let $t_1^* = 1991$ and $t_2^* = 1997$. The indicators d_1 and d_2 are dummy variables equal to one if the year is greater than or equal to t_1^* or t_2^*, respectively. The regression model is written:

(3) $$Y_{it} = \beta_0 Year_t + d_{1t}\beta_1 (Year - t_1^*)_t + d_{2t}\beta_2 (Year - t_2^*)_t$$
$$+\beta_3 (Year_t \times NC_i) + d_{1t}\beta_4[(Year - t_1^*)_t \times NC_i] + d_{2t}\beta_5[(Year - t_2^*)_t \times NC_i]$$
$$+X_{it}^{'}\alpha + \gamma_i + e_{it}$$

$Year_t$ denotes the year in time *t*. In equation (3), the estimated β_0 denotes the estimated increase in the outcome variable in all counties in the years prior to 1991. $\beta_0 + \beta_3$ provides the trend in the outcome variable for North Carolina counties prior to 1991. β_3 denotes the estimated difference in trends between North Carolina and all other counties prior to 1990. $\beta_0 + \beta_1$ is the trend for all U.S. counties in years between 1991 and 1996. $\beta_0 + \beta_1 + \beta_3 + \beta_4$ provides the trend in North Carolina counties between 1991 and 1996. β_4 denotes the estimated difference in trends between North Carolina and all other counties between 1991 and 1996. If β_4 is significant, this 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. $\beta_0 + \beta_1 + \beta_2$ is the estimated trend for all U.S. counties in years after 1996. $\beta_0 + \beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5$ provides the trend in North Carolina counties after 1996. β_5 denotes the estimated difference in trend between North Carolina and all other counties after 1996.

In this estimation strategy, the primary coefficients of interest are β_4 and β_5. With hog production as the outcome variable, I expect β_4 to be positive and β_5 to be negative. With air pollution as the outcome variable, findings of a positive β_4 and a negative β_5 will provide strong evidence that hog production is the mechanism. This is because other sources of air pollution are unlikely to exhibit the same distinct pattern as hog production in North Carolina. Further, because the hog 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 hogs.

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 (see Bertrand, Duflo, and Mullainathan, 2004).

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.[6]

B. Data on Air Pollutants

While hog production has been primarily implicated in hydrogen sulfide and ammonia pollution, ambient levels of these pollutants are not monitored on a consistent, nationwide basis. The EPA at present only collects ambient measures for six "criteria" air pollutants, using fixed monitors. Two of

[6] To do this I make use of the reported values for "Agricultural Statistical Divisions" (ASDs), the "combined county" totals within the ASDs, and the reported values. Rather than report county-level hog numbers when individual operations can be identified, NASS groups these counties with others in a "combined county". Counties with no hogs are also grouped in these combined counties. In order to impute values for individual missing counties, I first find which counties never have a listing for hogs between 1980 and 2005. I assume that these have zero values and discard them. I next exploit the fact that each ASD has one combined county. I discern which counties are missing observations in each year; I then find the ASDs of these counties. Using the ASD-specific combined county totals, I assign an equal portion of the hogs in the combined county to each of the missing counties. I do not assign any zero values.

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) and is also a direct (albeit minor) emission (Thorne, 2002; Lim et al., 2003). I therefore use SO2 as a proxy for 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. Measured PM is comprised of many elements and the same level can be achieved via emissions of different gases. Further, the EPA switched the type of particulate matter monitored in the middle of this article's period of interest (1980-2005).[7] I therefore only examine the period 1990 to 2005 for PM10, using the moratorium adoption as an exogenous source of variation in hog production trends.

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 levels over a year, which I then average by county. Not all counties have monitors; while monitors are fixed, they are generally placed in more populated areas (maps of counties with monitors available from author). I show results for the entire U.S. as well as just the samples with air pollution data in order to ascertain the effects of this sample restriction.

C. Summary Statistics on Hogs and Air Pollution

Table 1 provides summary statistics for North Carolina and other states for the two main outcomes of interest before, during, and after Murphy's legislation. 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. Air pollution has been declining in the U.S. through a variety of mechanisms, regulatory and otherwise. What is noticeable is

[7] In the late 1980s, the EPA switched from monitoring total suspended particulates (TSPs) to particulate matter of 10 microns in size (PM10). PM10 is not a consistent proportion of TSPs. Regression results using EPA data reveal that only 42% of the variance in TSPs can be explained by the variance in PM10 (results not shown).

that 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.

These means can also provide a differences-in-differences estimate of the effect of Murphy's laws on hog numbers and air pollution. While North Carolina counties gained on average 78,000 hogs eachbetween 1991 and 1996, the counties outside the state lost nearly 7,000 hogs, resulting in a relative gain in North Carolina of nearly 85,000 hogs. Likewise, while the rest of the country's SO2 levels declined by 0.0033ppm, North Carolina's only declined by 0.0004ppm, making the relative difference 0.003ppm. Without controlling for observable confounders, the estimated effect of Murphy's laws on air pollution is 0.003ppm.

As stated earlier, differences-in-differences estimates may only reflect differential trends. A first test of whether this is the case for air pollution is to examine data for multiple years. In order to examine both the possibility of differential but constant trends as well as control for aspects of individual years, I graph the mean difference between North Carolina and the rest of the U.S. in SO2 level between 1980 and 2005 (Figure 2). The 95% confidence interval of the difference in each year is shown, and levels are normalized so that the difference in 1980 is equal to zero. If North Carolina and the rest of the U.S. were experiencing different but constant trends, then this graph would show a straight line. Instead, this figure shows trend breaks in the early and late 1990s, similar in timing to those for hogs. Figure 3 shows a similar graph for PM10, but only for 1990 to 2005 due to data availability. Here again we see that the difference between North Carolina and the rest of the U.S. is non-constant, and further is not decreasing or increasing constantly. While a definite negative trend occurs after the late-1990s, the trend prior is less clear.

These means provide suggestive evidence of hog production's effect on air pollution. However, more rigorous econometric analysis can control for a variety of measures that may also be affecting both hog location and air pollution. Ideally, one would like averages for North Carolina to be the same as those for the rest of the country except for the hog production in order to attribute any changes in air pollution to the hog production. While it is possible to compare (and control for) observables, there is still the worry that unobservable variables will be correlated with legislative changes in North Carolina and therefore a correlation between legislation and the outcome may be the result of the unobservable. In order to mitigate this possibility, we can look first at observable characteristics. If observables are the same for North Carolina and all other counties, then we are more likely to have orthogonality among the unobservables.

D. 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 Murphy's 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. Hog production location is based on agglomeration economies, proximity to inputs, historical setting, and environmental amenities. Many of these are also correlated with air pollution.

In models for both outcome variables, I include confounders for per capita income (logged and in 2005$), population density, temperature, precipitation, the percentage of the population over age 65, the unemployment rate, population size, poverty rate, and the number of residential housing building permits. The variables for per capita income, unemployment rate, population size, and population age control for economic setting, which influences both air pollution and hog production. Population density and size and 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. The data come from various government sources; see Appendix Table 1 for detailed descriptions.

I compile data on 6 other industries from annual County Business Pattern from 1980 to 2005.[8] While the literature on hog production location decisions does not mention any other specific industry as particularly correlated with the hog industry, the possibility remains. Other industries may be correlated both with hog production and air pollution. I therefore control for these. As a measure of another industry's influence in the area, I use the number of people employed in it. Tests using the number of establishments in the industry reveal the same results.

Other confounders are conceivably related to either hog production or air pollution; however, I limit the confounders to be the same in both models in order to provide consistent results. Further tests adding additional confounders to either of the models show that they do not affect results.[9]

E. Summary Statistics for Controls

Tables 2a and 2b 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 Murphy (1980-1990), during the period of (anti-) 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 interacted splines. In terms of levels in the pre-Murphy period, North Carolina is not statistically different from the other states in any period in population size or poverty rate, nor in construction, utilities, wholesale trade, or transportation employment. In terms of trend differences in the three periods, the variables of most concern are the

[8] The County Business Patterns gather data on industries by Standard Industrial Classification (SIC) code before 1987 and North American Industry Classification System (NAICS) after 1987. Therefore, constructing a coherent series for 1980 to 2005 requires converting pre-1987 data from SICs to NAICs. This was done using the Census Bureau's SIC to NAIC correspondence tables. In the cases where individual SIC categories are not entirely assigned to a single NAICS, this correspondence table provides the percentage of the SIC that was assigned to individual NAICS codes.

[9] In the model with hog production as the outcome variable, I add further confounders on feed efficiency (as measured by the amount spent on feed divided by the amount spent on livestock purchases) and government payments to farms. For the air pollution regression I add a confounder 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. Estimated emissions (as compared to ambient levels) are only available for 1990-2002, so I do not include them; Sneeringer (2008) has also found that addition of emissions variables to regressions of ambient levels on hog production does not change the coefficient on hog production.

number of building permits, construction employment, and population growth. Trends in these three 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. This suggests that growth in North Carolina occurred more rapidly than in the rest of the U.S. during between 1991 and 1996, and creates a possible alternative as to causes of air pollution. Given the similarities between North Carolina and the other state averages, there is a higher likelihood that regulation is uncorrelated with unobservables. However, given the dissimilarities, it is necessary to use the econometric methods described above to control for possible unobservables that may bias results.

Results

Because estimation of effects on PM10 uses a different time period, I first present results for hogs and SO2 using the entire time period (1980-2005), and then turn to the results for PM10. In Table 3, I examine the robustness of the unconditional differences-in-differences estimates from Table 1 to the addition of various confounders. The results show that the confounders do not greatly change the estimates of the effect of Murphy on both hog numbers and SO2. Comparing the pre- and post-Murphy time periods (1980-1990 and 1997-2005) shows that Murphy's laws led to a highly significant 80,022 increase in hogs (58%) and a 0.003ppm increase in SO2 (53%), findings very similar to the unconditional results. Results for logged outcome variables show robustness with respect to functional form, as well as provide an estimate of percentage differences. Restriction of the sample to just counties with SO2 data shows very similar results to the overall sample in terms of changes in hogs.

Table 4 provides the results of estimating the interacted spline models with hogs as the outcome variable. Models (i) through (iii) show robustness of estimated trends to the addition of confounders, revealing that estimates do not change. The estimated coefficients representing β_4 and β_5 from Equation (3) are in bold. Post-1990, North Carolina counties see an average 10,401 (10.2%) increase 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 confounders. The post-1996 trend shows a negative value, reflecting the leveling off of the increase in hogs. Model (v) shows this result to be similar in the sample including just SO2 data (an 11.1% increase), suggesting that findings for air pollution will be externally valid to the larger sample.

If North Carolina is taking hogs away from other states, the effect of Murphy on North Carolina will be overestimated, as it will include both the increases in North Carolina as well as the decreases in the rest of the U.S. To test for this possibility, I exclude the other top four hog production states from the sample (Model (vi)).[10] Estimates are strikingly similar to the full sample, suggesting that Murphy did not take away production from other states.

Results for SO2 (Table 5) using the interacted splines show the estimates are again robust with respect to the addition of confounders and display a similar pattern as effects of Murphy on hogs. Post-1990, North Carolina saw a 0.0005ppm (10.2%) per county per year increase in sulfur dioxide, net of the various confounders and existing trends. Sulfur dioxide also levels off in the years when hog increases do the same. Eliminating the other top hog-producing states (Model (viii)) also does not change results.

The effects of Murphy'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.

These parallel results for hog production and SO2 using a restrictive empirical design provide strong evidence that hogs are causing the air pollution. In order to cement this claim, I perform falsification tests and examine alternative hypotheses. 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

[10] These states include Iowa, Indiana, Illinois, and Missouri.

general.[11] To test both of these ideas, I use two other air pollution measures as dependent variables (Table 5, Models (v) and (vi)). The results show that neither carbon monoxide nor ozone, two pollutants normally associated with vehicles, follow the same trends as sulfur dioxide and hogs. 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.

A second possibility is that another industry is moving in the same pattern as hog production in North Carolina, and it is this industry that is leading to the changes in air pollution. While variables for other industries were included in the regressions above and do not change predictions, I further test this by regressing each of the 6 industries included on the model with all covariates and trends (see Appendix Table 2). None of the other 6 industries exhibit the same patterns as hog production and air pollution, providing evidence that the changes in air pollution are not attributable to another source.[12]

Another hypothesis is that results are due to some upwind state strongly increasing its sulfur dioxide emissions in 1991 and strongly curbing 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. I therefore restrict the sample to just states surrounding North Carolina.[13] The results (Table 5 Model (vii)) show that the estimated coefficients of interest are very similar and are still highly significant.[14]

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[11] 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.

[12] I perform this analysis for all 18 industries listed in the County Business Patterns, and find that none of the industries exhibit the same pattern as hogs. Tests for per capita income, population growth, population density, and building permits also do not exhibit the same pattern.

[13] These include South Carolina, Georgia, Virginia, Tennessee, Alabama, Kentucky, and West Virginia.

[14] In a set of further tests, I include as a confounder the total estimated emissions of SO_2 and 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 A.3, reveal that inclusion of the emissions does not change the estimated coefficients as reported in Table 5.

Finally, I turn to the results for particulate matter. In this analysis I use only the period 1990 to 2005, due to the PM10 data limitations. For this estimation I focus only on one trend break, that in 1997 when the moratorium was declared. The results (Table 6) show that during North Carolina's period of rapid hog production expansion, PM10 declined at a rate 0.3μg/m^3 (2%) per year more slowly than other states. After the moratorium, North Carolina's levels decreased 0.6μg/m^3 (3%) each year, net of the positive increases prior to it. These effects are robust with respect to the addition of covariates (Models (iii)-(v)), as well as sample restrictions (Models (vii)-(viii)). The findings for PM10 support those for SO2 and provide further evidence that the hogs are driving the changes in air pollution.

Discussion

The results show that the events 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 6 other industries, and multiple other confounders. Further, the regulations in 1997 strongly decreased the growth in the state's hog production. Mirroring these trends in hog production are changes in ambient air pollution. Given that the shape and timing of the trends in air pollution echo those for hogs, this provides strong evidence that hog production is responsible. Tests for air pollutants not associated with hog production do not show similar trends. No other industries follow the same pattern as hog production. North Carolina has similar differences when compared to surrounding states, suggesting that regional air quality effects are not responsible.

The rapid increase in swine production may be reasonably attributed to regulation changes if no other factor influencing the state's hog production occurred simultaneously. However, Smithfield Food's construction of the world's largest slaughterhouse in the state a year after the 1991 legislation creates the possibility that continued growth was due to this factor, rather than the legislation. This is pertinent if another state that wishes to encourage the industry's growth wishes to follow North

Carolina's example. The growth might only happen with the legislation and the slaughterhouse, not each by itself.

The increases in ambient air pollution associated with the legislation reveal that Wendell Murphy did create a pollution haven. The differences-in-differences estimator shows that the legislation led to a 0.003ppm increase in sulfur dioxide. The size of this effect is mirrored in the interacted spline models, which show that a 0.0005ppm increase per year, totaling a 0.003ppm increase over the 6 years between 1991 and 1997. This magnitude may not seem large to those unfamiliar with air pollution, so contextualization of its size is necessary. The national ambient air quality standard for SO2 is 0.03ppm; Murphy's laws therefore moved counties 10% closer to violation of federal air quality standards and intensified regulatory stipulations on other industries. Another way of contextualizing 0.003ppm is by considering the actual change in SO2 in North Carolina. As reported in Table 1, North Carolina saw a SO2 decrease of 0.0004ppm between 1991 and 1997; therefore, without the growth in hog production, this would have over eight times as large. Finally, a 0.003ppm increase in SO2 has consequences from a public health perspective; it is correlated with a 1.27% increase in emergency room admissions for asthmatic children (Sunyer et al., 1997), and a 7.8g decrease in average birth weight (Ha et al., 2001).[15]

If the hogs are 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 predicted to be 0.92 and between hogs and PM10 to be 0.29; a doubling of production is predicted to raise sulfur dioxide by 92% and PM10 by 29%.[16] The findings here are larger than those in other research examining the effects of hogs on air pollution. In a national

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[15] Compare this to a 100g decrease in birth weight from passive smoking (Hoffman et al., 2006), or a 200g decrease from active maternal smoking during pregnancy (Walsh, 1994).

[16] 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 elasticites, 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, and for PM10 I use the post-1996 time period, due to the data coverage differences.

sample for the same time period using monitor-level data, Sneeringer (2008) shows a 0.10 elasticity between hog density and sulfur dioxide. The result here of a 0.92 elasticity is much higher, which may reflect a less-biased estimate or circumstances particular to North Carolina. The methods of hog production employed in North Carolina may yield worse air pollution effects than hog production methods in other regions of the country. In terms of levels, a 100 hog increase causes a 0.004ppb increase in ambient SO2 and a 0.001μg/m^3 increase in PM10.[17]

Putting an economic cost on the air pollution externality created by hog production requires making strong assumptions. However, it is worth performing the exercise to get an order of magnitude of the externality. North Carolina counties saw on average a 7.8% increase in hogs per year between 1991 and 1997. This is correlated with a 7.2% increase in sulfur dioxide per year. Sneeringer (forthcoming) has found that livestock production (for all livestock types) influences infant mortality, with strongest evidence for an air pollution mechanism. Using the 0.35 elasticity between air pollution and infant mortality found by Chay and Greenstone (2003), this increase in air pollution results in a 2.5% increase in infant mortality per year in each county in North Carolina. In 1991 North Carolina's infant mortality rate (IMR) was 10.8 deaths per 1,000 births.[18] A 2.5% decrease in this yields an IMR of 10.5. If we assume that the 102,362 births in 1991 the state were evenly distributed among the 100 counties, this yields 1,024 births per county. An IMR of 10.8 yields 11.1 deaths per county, compared to 10.75 deaths per county at an IMR of 10.5. This yields 0.35 deaths that could have been avoided per county per year; using the EPA's value of a statistical life of approximately $7 million (2005$), this yields an externality cost of $2.45 million per county per year attributable to hog production. For the state this totals $245 million or 35 deaths per year.

[17] Converting this to an emissions factor is outside the scope of the paper and would require conversions between emissions and ambient levels and hydrogen sulfide and sulfur dioxide.
[18] In 1991, North Carolina had 1,106 infant deaths and 102,362 births, yielding an IMR of 10.8.

Comparing this externality cost to revenues can provide an indication of social welfare. The 1992 Census of Agriculture reports sales of hogs and pigs in North Carolina totaling $1.23 billion (2005$). Assuming this is divided equally among counties, this yields sales of $12 million per county. Therefore, 20% of revenues are in health externality costs. Externality costs are higher, however, if one includes effects on property values and other types of morbidity and mortality or costs associated with water pollution. While this exercise in estimating health externalities can provide some order of magnitude of the health externality, further research examining whether public health measures change in a similar pattern as hog production in North Carolina would provide a stronger estimate.

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.

References

U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. 2006. *Hydrogen sulfide ToxFAQs*. Atlanta GA, July.

Becker, R., and V. Henderson. 2000. "Effects of Air Quality Regulations on Polluting Industries." *Journal of Political Economy* 103(2):379-421.

Bertrand, M., E. Duflo, and S. Mullainathan. 2004. "How Much Should We Trust Differences-In-Differences Estimates?" *Quarterly Journal of Economics* 119:249-275.

Center on Globalization, Governance, and Competitiveness. 2008. *North Carolina in the Global Economy: Hog Farming.* Online Publication of the Social Science Research Institute. http://www.soc.duke.edu/NC_GlobalEconomy/hog/overview.shtml.

Chay, K., and M. Greenstone. 2000. "The Impact of Air Pollution on Infant Mortality: Evidence From Geographic Variation in Pollution Shocks Induced By a Recession." *Quarterly Journal of Economics* 118(3):1121-1167.

Cole D., L. Todd, and S. Wing. 2000. "Concentrated Swine Feeding Operations and Public Health: A Review of Occupational and Community Health Effects." *Environmental Health Perspectives* 108: 686-699.

Copeland, C., and J. Zinn. Library of Congress. 1998. "Animal Waste Management and the Environment: Background for Current Issues." Congressional Research Service Report 98-451. Washington DC, May.

Eskeland, G.S., and A.E. Harrison. 2003. "Moving to Greener Pastures? Multinationals and the Pollution Haven Hypothesis." *Journal of Development Economics* 75(1):269-301.

General Assembly of North Carolina. 1991a. "An Act to Clarify that the Production of Crops, Fruits, Vegetables, Ornamental and Flowering Plants, etc., is a Bona Fide Farm Purpose in the Zoning Statutes." 1991 Session Ratified Bill, Chapter 69, Senate Bill 148, Section 1. G.S. 153A-340. 6 May.

———. 1991b. “An Act to Amend those Portions of the General Statutes that Limit the Environmental Management Commission to the Adoption of Environmental Rules Regarding Water Quality and Air Quality that are No More Restrictive than Federal Environmental Regulations to Provide that an Evaluation of the Impact of Such Rules be Prepared Before Such Rules are Adopted.” 1991 Session Ratified Bill, Chapter 403, Senate Bill 386, Section 1. G.S. 143-213. 26 June.

———. 1995. “An Act to Implement Recommendations of the Blue Ribbon Study Commission on Agricultural Waste.” Ratified bill, Chapter 626, Senate Bill 1215. 21 June.

———. 1997. “An Act to Enact the Clean Water Responsibility and Environmentally Sound Policy Act, a Comprehensive Program to Protect Water Quality, Public Health, and the Environment. S.L. 1997-458. House Bill 515. 27 August.

Greenstone, M. 2002. “The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures.” *Journal of Political Economy* 110:1175-1219.

Ha, E.H., Y.C. Hong, B.E. Lee, B.H. Woo, J. Schwartz, and D.C. Christiani. 2001. “Is Air Pollution a Risk Factor for Low Birth Weight in Seoul?” *Epidemiology* 12(6):643-648.

Herath, D., A. Weersink, and C.L. Carpentier. 2005. “Spatial Dynamics of the Livestock Sector in the United States: Do Environmental Regulations Matter?” *Journal of Agricultural and Resource Economics* 30(1):45-68.

Hoffman, B., K. Straif, H.E. Wichmann, and K-H Jöckel. 2006. “Gesundheitliche Folgen Des Passivrauchens.” *Umweltmed Forsch Prax* 11(6):1-17.

Hubbell, B.J., and R. Welsh. 1998. “An Examination of Trends in Geographic Concentration in U.S. Hog Production, 1974-96.” *Journal of Agricultural and Applied Economics* 30(2):285-299.

Kliebenstein JB, Lawrence JD. 1995. “Contracting and vertical coordination in the United States pork industry,” *American Journal of Agricultural Economics Proceedings Issue* 77(5), 1213-1218.

Isik, M. 2004. "Environmental regulation and the spatial structure of the U.S. dairy sector." *American Journal of Agricultural Economics* 86(Feb.): 949-962.

Iowa State University and The University of Iowa Study Group. 2002. *Iowa Concentrated Animal Feeding Operations Air Quality Study*. Online publication.

Lee, J.8. 2003. “Neighbors of Vast Hog Farms Say Foul Air Endangers Their Health.” *New York Times,* 11 May, pp. N1-N2.

Levinson, A., and M.S. Taylor. 2008. “Unmasking the Pollution Haven Effect.” *International Economic Review* 49(1):223-254.

Lim, T.T., A.J. Heber, J.Q. Ni, A.L. Sutton, and P. Shao. 2003. “Odor and Gas Release From Anaerobic Treatment Lagoons for Swine Manure.” *Journal of Environmental Quality* 32:406-416.

List, J.A., W.W. McHone, and D.L. Millimet. 2004. “Effects of Environmental Regulation on Foreign and Domestic Plant Births: Is There a Home-Field Advantage?” *Journal of Urban Economics* 56(2): 303-326.

Martin, L., and K. Zering. 1997. “Relationship Between Industrialized Agriculture and Environmental Consequences: The Case of Vertical Coordination in Broilers and Hogs.” *Journal of Agricultural and Applied Economics* 29:45-56.

Metcalfe, M. 2000. “State Legislation Regulating Animal Manure Management.” *Review of Agricultural Economics* 22:519-532.

———. 2001. “U.S. Hog Production and the Influence of State Water Quality Regulation.” *Canadian Journal of Agricultural Economics* 49:37-52.

National Research Council Ad Hoc Committee on Air Emissions from Animal Feeding Operations, Committee on Animal Nutrition. 2003. *Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs.* Washington, DC: National Academies Press.

North Carolina Department of Environment and Natural Resources. 2002. "Controlling Odors From Animal Operations." Online publication.

Rhodes, V.J. 1995. "The Industrialization of Hog Production." *Review of Agricultural Economics* 17(2):107-118.

Roe, B., E.G. Irwin, and J.S. Sharp. 2002. "Pigs in Space: Modeling the Spatial Structure of Hog Production in Traditional and Nontraditional Production Regions." *American Journal of Agricultural Economics* 84:259-278.

Roth, D. 1997. "The Ray Kroc of Pigsties." *Forbes*, 13 October, pp. 115-120.

Schliesser, S. 2003. "Hydrogen sulfide from NC hog farms." Publication of North Carolina State University and North Carolina Division of Air Quality.

Sneeringer S. 2008. "A National, Longitudinal Study of the Effects of Concentrated Hog Production on Ambient Air Pollution," Working paper, Department of Economics, Wellesley College.

Sneeringer, S. 2008. "Does Animal Feeding Operation Pollution Hurt Public Health? A National Longitudinal Study of Health Externalities Identified by Geographic Shifts in Livestock Production." *American Journal of Agricultural Economics* 90:in press.

South Coast Air Quality Management District. 2004. "AQMD Adopts First-Ever Measure to Reduce Dairy Emissions." Diamond Bar CA, August. http://www.aqmd.gov/news1/2004/bs8_06_04.html.

Stith P., J. Warrick, and M. Sill. 1995. "Murphy's Law: For Murphy, Good Government Means Good Business." *The News and Observer,* 22 February. Available online at http://www.pulitzer.org/archives/5897.

Sullivan, J., U. Vasavada, and M. Smith. 2000. "Environmental Regulation and Location of Hog Production." Washington DC: U.S. Department of Agriculture, Economic Research Service. *Agricultural Outlook,* 19-23 September.

Sunyer, J., C. Spix, P. Quenel, A. Ponce-de-Leon, A. Ponka, T. Barumandzadeh, G. Touloumi, L. Bacharova, B. Wojtyniak, J. Vonk, L. Bisanti, J. Schwartz, and K. Katouyanni. 1997. "Urban Air Pollution and Emergency Admissions for Asthma in Four European Cities: The APHEA Project." *Thorax* 52(9):760-765.

Teitz, J. 2006. "Boss Hog." *Rolling Stone*, December 14, pp. 89-139.

Thorne, P.S. 2002. "Air Quality Issues" in *Iowa Concentrated Animal Feeding Operations Air Quality Study*. Iowa State University and The University of Iowa Study Group. Online publication.

U.S. Department of Agriculture. 2004. *2002 Census of Agriculture. United States Summary and State Data. Vol. 1, Geographic Area Series Part 51.* National Agricultural Statistics Service, AC-02-A-51, Washington DC, June.

U.S. Environmental Protection Agency. 1993. *The Report of the EPA/State Feedlot Workgroup.* Office of Wastewater Enforcement and Compliance, Washington, DC, September.

———. 1997. *Animal Waste Disposal Issues.* Office of Inspector General, Pub. No. 7100142, Washington DC, April.

———. 2000. *National Air Pollution Emissions Trends, 1900-1998.* Research Triangle Park NC.

———. 2001. *Emissions from Animal Feeding Operations, Draft*. EPA Contract No. 68-D6-0011 Task 71.

———. 2002. *National Water Quality Inventory, 2000 Report.* Office of Wetlands, Oceans, and Watersheds, Publication EPA-841-R-02-001, Washington DC, September.

———. 2005. *National Emissions Inventory—Ammonia Emissions from Animal Husbandry Operations, Revised Draft Report.* Research Triangle Park NC.

———. 2006. *Animal Feeding Operations Air Agreements.* Washington DC.

Walsh, R.A. 1994. "Effect of Maternal Smoking on Adverse Pregnancy Outcomes: An Examination of the Criteria of Causation." *Human Biology* 66(6):1059-1092.

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

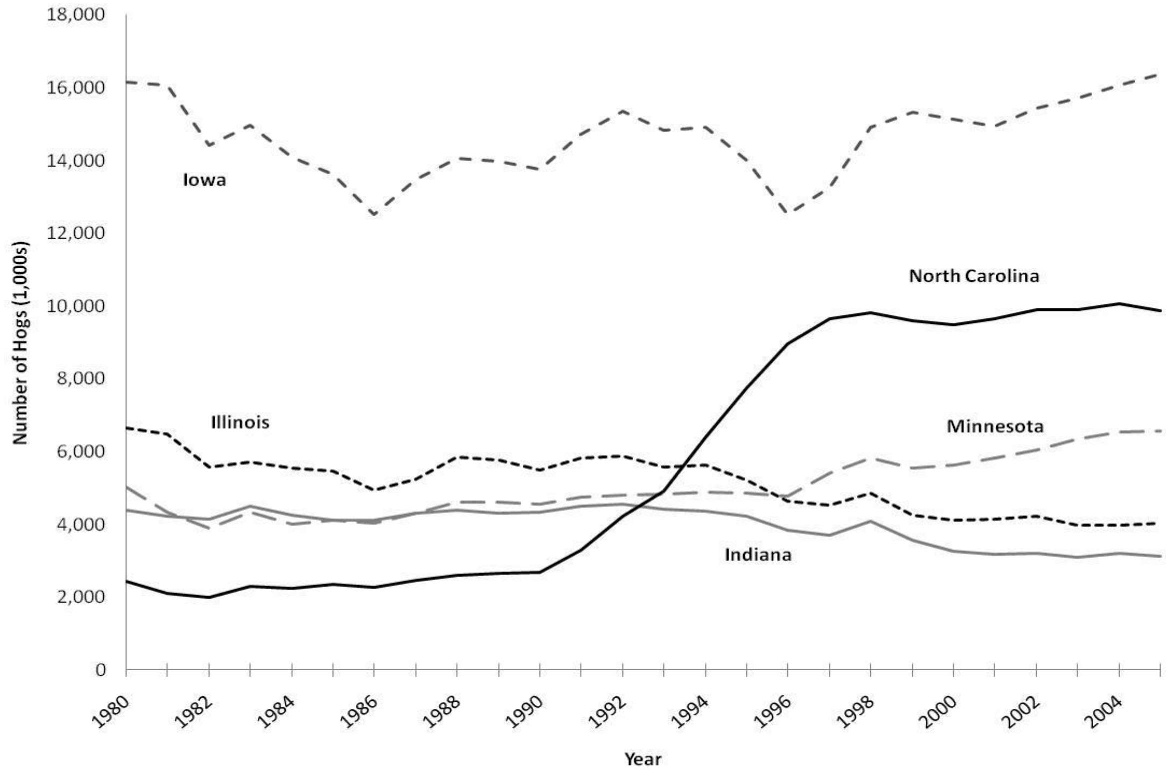

Fig. 2: Normalized Difference between SO2 in North Carolina Versus the Rest of the U.S., 1980-2005

(with 95% confidence interval)

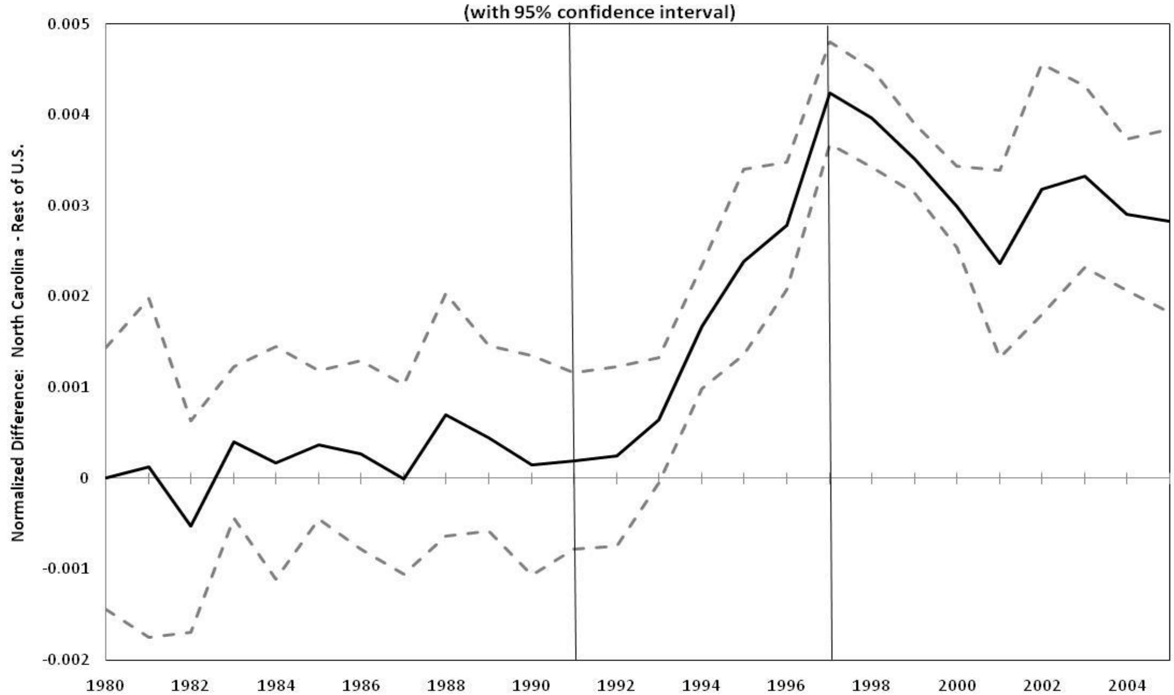

Fig. 3: Normalized Difference between PM10 in North Carolina Versus the Rest of U.S., 1990-2005

(with 95% confidence interval)

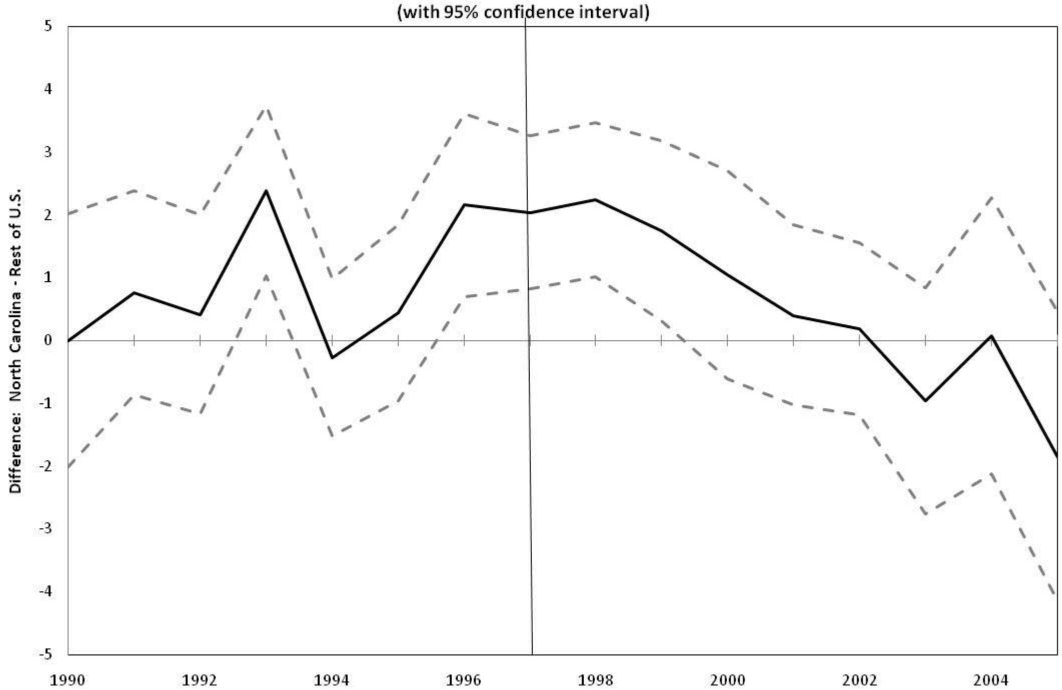

Table 1: Comparison of Hog Production and Air Pollution in North Carolina and Other States, Pre-, During, and Post-Murphy

	1980-1990	1991-1996	1997-2005	Difference, 1980-1990 to 1997-2005
North Carolina				
Hogs	25,491	67,226	103,192	77,700
	(50,228)	(207,039)	(312,500)	
Change per year	1,140	10,544	266	
	(12,570)	(37,856)	(12,767)	
SO2 (ppm)	0.0047	0.0040	0.0043	-0.0005
	(0.0023)	(0.0011)	(0.0012)	
Change per year	-0.0001	0.0001	-0.0021	
	(0.0019)	(0.0009)	(0.0006)	
PM10 (μg/m^3)		23.7	21.6	
		(3.66)	(3.25)	
Change per year		-0.38	-0.63	
		(2.5)	(1.6)	
All other states				
Hogs	20,588	15,613	13,625	-6,963
	(40,261)	(32,880)	(37,286)	
Change per year	-289	-175	-19	
	(4,157)	(6,359)	(5,208)	
SO2 (ppm)	0.0079	0.0062	0.0046	-0.0033
	(0.005)	(0.0037)	(0.0027)	
Change per year	-0.0002	-0.0004	-0.0129	
	(0.0023)	(0.0015)	(0.1998)	
PM10 (μg/m^3)		24.8	22.2	
		(7.24)	(5.94)	
Change per year		-0.89	-0.19	
		(3.8)	(3.4)	
Relative Difference, North Carolina versus Rest of U.S., 1980-1990 to 1997-2005				
Hogs				84,663
SO2 (ppm)				0.0028

Notes: Standard deviations shown in parentheses.

Table 2a: Comparison of Levels of Hog Production and Air Pollution Determinants in North Carolina and Other States, Before, During, and After Murphy

	Averages in years before Murphy (1980-1990)		Averages in years during Murphy (1991-1996)		Averages in years after Murphy (1997-2005)	
	North Carolina	**All other states**	**North Carolina**	**All other states**	**North Carolina**	**All other states**
Population density	134.6	105.3	146.4	107.9	165.7	123.8
	(146.1)	(278.9)	(166.)	(251.2)	(198.3)	(325.9)
Per capita income (2005$)	$20,156	$20,947	$23,599	$22,857	$26,253	$25,498
	($3,982)	($4,552)	($3,757)	($4,547)	($4,294)	($5,150)
Percent over age 65	12.8%	14.4%	14.4%	15.2%	14.3%	15.0%
	(3.0%)	(4.0%)	(3.3%)	(4.1%)	(3.5%)	(3.9%)
Unemployment rate	5.9	7.8	6.0	6.6	5.5	5.3
	(2.1)	(3.5)	(2.3)	(3.1)	(2.)	(2.1)
Number of building permits	535	428	564	345	841	465
	(1,158)	(2,100)	(1,177)	(1,068)	(1,802)	(1,538)
Population	65,201	67,480	72,641	64,366	83,529	69,340
	(75,111)	(255,734)	(90,218)	(181,934)	(111,836)	(194,216)
Poverty rate	16.4	16.3	15.8	16.4	14.0	14.5
	(5.4)	(7.3)	(5.1)	(7.1)	(5.4)	(3.9)
Annual precipitation (inches)	48.0	38.1	50.7	40.3	48.8	39.4
	(9.5)	(14.2)	(8.6)	(14.5)	(10.1)	(13.7)
Temperature (F)	58.7	54.5	58.9	54.3	59.1	55.2
	(2.7)	(7.3)	(2.8)	(7.5)	(2.9)	(7.4)
Mining employment	15.0	198.0	17.0	144.0	12.9	101.4
	(55.8)	(1,447.8)	(53.1)	(1,349.6)	(41.8)	(763.2)
Construction employment	1402.4	1233.6	1641.7	1229.0	2188.9	1535.1
	(2,949.2)	(5,733.6)	(3,263.)	(4,710.4)	(4,417.9)	(5,553.5)
Manufacturing employment	7611.5	4999.6	8552.1	4994.1	5575.4	3682.0
	(10,548.8)	(24,800.9)	(10,829.7)	(16,768.3)	(8,673.)	(13,048.6)
Utilities employment	271.0	266.3	329.4	292.9	135.2	119.7
	(918.3)	(1,414.2)	(1,049.7)	(1,375.4)	(659.1)	(714.5)
Wholesale trade employment	1314.8	1445.4	1585.3	1488.4	1733.3	1503.1
	(3,613.2)	(8,070.2)	(4,527.2)	(6,956.8)	(5,197.)	(6,705.8)
Transportation and warehousing employment	550.0	542.1	671.4	597.9	760.7	743.1
	(1,856.3)	(2,878.7)	(2,128.8)	(2,802.3)	(2,429.6)	(4,349.9)

Note: Standard deviations shown in parentheses.

Table 2b: Comparison of Trends in Hog Production and Air Pollution Determinants in North Carolina and Surrounding States, Before, During, and After Murphy

	Averages changes per year in years before Murphy (1980-1990)		Average changes per year in years during Murphy (1991-1996)		Average changes per year in years after Murphy (1997-2005)	
	North Carolina	All other states	North Carolina	All other states	North Carolina	All other states
Population density	1.6	0.8	2.2	1.1	3.0	1.4
	(3.3)	(12.8)	(4.1)	(4.5)	(7.4)	(8.9)
Per capita income (2005$)	473.5	291.5	477.5	347.5	216.8	314.6
	(729.0)	(1377.6)	(524.9)	(1186.9)	(868.4)	(1131.3)
Percent over age 65	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%
	(0.1%)	(0.3%)	(0.2%)	(0.5%)	(0.3%)	(0.6%)
Unemployment rate	-0.1	0.0	-0.3	-0.3	0.1	0.0
	(1.0)	(1.2)	(1.1)	(1.2)	(1.2)	(1.0)
Number of building permits	4.6	-3.3	55.3	24.2	33.7	16.1
	(392.8)	(725.7)	(273.6)	(222.8)	(302.2)	(274.1)
Population	804.3	696.2	1,158.1	679.2	1,597.4	734.7
	(1,913.3)	(7,842.9)	(2,507.0)	(3,037.4)	(4,298.3)	(3,667.7)
Poverty rate	-0.1	0.0	-0.1	-0.3	0.1	-0.2
	(1.1)	(1.4)	(1.1)	(1.0)	(0.9)	(1.1)
Annual precipitation (inches)	0.3	0.5	-0.5	-0.1	0.4	-0.2
	(12.2)	(9.5)	(8.8)	(9.7)	(12.3)	(9.0)
Temperature (F)	0.2	0.1	-0.4	-0.3	0.1	0.2
	(1.3)	(1.7)	(0.9)	(1.5)	(1.3)	(1.6)
Mining employment	0.0	-7.3	-0.4	-2.7	-0.3	-5.4
	(31.0)	(304.2)	(25.3)	(514.3)	(32.3)	(284.1)
Construction employment	24.1	8.8	90.7	45.7	27.9	19.9
	(356.2)	(666.6)	(296.0)	(360.7)	(358.1)	(406.0)
Manufacturing employment	-5.3	-53.9	31.9	65.2	-530.5	-280.9
	(5,913.4)	(11,110.0)	(804.0)	(857.1)	(1,578.9)	(1,822.3)
Utilities employment	7.6	6.0	4.1	7.1	-28.2	-33.6
	(62.7)	(94.2)	(81.4)	(92.2)	(576.9)	(469.3)
Wholesale trade employment	29.2	26.4	46.7	27.8	-9.5	-18.5
	(203.5)	(396.5)	(251.7)	(339.8)	(379.7)	(469.4)
Transportation and warehousing employment	15.7	12.5	8.9	14.6	23.0	25.6
	(126.6)	(190.2)	(163.3)	(185.8)	(342.7)	(741.4)

Note: Standard deviations shown in parentheses.

Table 3: Results of Conditional Differences-in-Differences Estimation

	(i)	(ii)	(iii)	(iv)	(v)
	Entire U.S.		Entire U.S. with SO2 data		
	ln(Hogs)	Hogs	ln(Hogs)	ln(SO2)	SO2 (ppb)
(Post-1996)*(NC=1)	0.579***	80,022***	0.564*	0.525***	3.492***
	(0.16)	(29761)	(0.33)	(0.10)	(0.66)
Other county covariates?[a]	Y	Y	Y	Y	Y
Other industry variables?[b]	Y	Y	Y	Y	Y
County fixed effects?	Y	Y	Y	Y	Y
Year fixed effects?	Y	Y	Y	Y	Y
Observations	32,326	32,326	3,966	3,966	3,966

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. All samples include only 1980-1990 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 number of establishments in 6 other industries.

Table 4: Effects of Murphy on Number of Hogs and Hog Density

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
	Full sample				**Sample with SO2 data**	**Excluding other top hog states**
	ln(Hogs)	ln(Hogs)	ln(Hogs)	Hogs	ln(Hogs)	ln(Hogs)
Year	-0.0240***	-0.00744**	-0.00813**	-100.2	-0.000977	-0.00776**
	(0.0017)	(0.0033)	(0.0033)	(97.9)	(0.012)	(0.0037)
(Year-1991)*(Post-1990)	-0.0502***	-0.0461***	-0.0424***	157.7	-0.0677***	-0.0426***
	(0.0047)	(0.0062)	(0.0064)	(163)	(0.014)	(0.0068)
(Year-1997)*(Post-1996)	0.0414***	0.0493***	0.0535***	159.6	0.0640***	0.0575***
	(0.0062)	(0.0081)	(0.0081)	(133)	(0.020)	(0.0085)
Year*(NC = 1)	-0.00364	0.0142	0.0131	1685*	0.0165	0.0142
	(0.0086)	(0.0090)	(0.0090)	(863)	(0.022)	(0.0091)
(Year-1991)*(Post-1990)*(NC=1)	**0.109*** **	**0.0993*** **	**0.102*** **	**10,401*** **	**0.111*** **	**0.102*** **
	(0.020)	**(0.021)**	**(0.021)**	**(3,349)**	**(0.038)**	**(0.021)**
(Year-1997)*(Post-1996)*(NC=1)	**-0.143*** **	**-0.163*** **	**-0.165*** **	**-12,651*** **	**-0.171** **	**-0.169*** **
	(0.024)	**(0.026)**	**(0.026)**	**(3,916)**	**(0.071)**	**(0.026)**
Other county covariates?[a]	N	Y	Y	Y	Y	Y
Other industry variables?[b]	N	N	Y	Y	Y	Y
County fixed effects?	Y	Y	Y	Y	Y	Y
Observations	56,819	43,595	43,595	43,595	5,269	38,248

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.

[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 number of establishments in 6 other industries.

Table 5: Effects of Murphy on Air Pollution

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
	Entire U.S.						NC and surrounding states[c]	Entire U.S., excluding other top hog states[d]
	ln(SO2)	ln(SO2)	ln(SO2)	SO2 (ppb)	ln(CO)	ln(ozone)	ln(SO2)	ln(SO2)
Year	-0.0239***	-0.0178***	-0.0182***	-0.167***	-0.0194***	-0.00149	-0.0209**	-0.0114
	(0.0029)	(0.0059)	(0.0060)	(0.039)	(0.0061)	(0.0013)	(0.0083)	(0.0075)
(Year-1991)*(Post-1990)	-0.0332***	-0.0365***	-0.0353***	-0.207***	-0.0347***	0.00875***	-0.0262**	-0.0425***
	(0.0061)	(0.0075)	(0.0075)	(0.058)	(0.0079)	(0.0017)	(0.011)	(0.0086)
(Year-1997)*(Post-1996)	0.0250***	0.0226**	0.0228***	0.188***	-0.00736	-0.0164***	0.00405	0.0293***
	(0.0067)	(0.0088)	(0.0087)	(0.056)	(0.0086)	(0.0019)	(0.014)	(0.0088)
Year*(NC = 1)	-0.00687	0.00236	0.00207	0.0691	-0.0306*	0.00684	-0.000680	0.00310
	(0.020)	(0.021)	(0.021)	(0.12)	(0.017)	(0.0054)	(0.022)	(0.021)
(Year-1991)*(Post-1990)*(NC=1)	**0.109*** **	**0.102** **	**0.102** **	**0.517** **	**0.0297**	**-0.0054**	**0.0956** **	**0.106*** **
	(0.040)	**(0.041)**	**(0.041)**	**(0.21)**	**(0.020)**	**(0.0067)**	**(0.045)**	**(0.040)**
(Year-1997)*(Post-1996)*(NC=1)	**-0.145*** **	**-0.143*** **	**-0.145*** **	**-0.712*** **	**0.0051**	**-0.0093*** **	**-0.123*** **	**-0.143*** **
	(0.033)	**(0.034)**	**(0.036)**	**(0.16)**	**(0.021)**	**(0.0034)**	**(0.034)**	**(0.037)**
Other county covariates?[a]	N	Y	Y	Y	Y	Y	Y	Y
Other industry variables?[b]	N	N	Y	Y	Y	Y	Y	Y
County fixed effects?	Y	Y	Y	Y	Y	Y	Y	Y
Observations	6,647	5,269	5,269	5,269	3,037	6,789	1,530	4,458

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.

[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 number of establishments in 6 other industries.

[c]Included states: NC, SC, GA, VA, TN , AL, KY, WV.

[d]Top hog producing states excluded: IA, IN, IL, MO.

Table 6: Effects of Murphy on Hogs and PM10, 1991-2005

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
	Entire U.S.	Entire U.S. with PM10 data	Entire U.S.				NC and Surrounding States[c]	Entire U.S., excluding other top hog states[d]
	Dependent Variable							
	ln(Hogs)	ln(Hogs)	ln(PM10)	ln(PM10)	ln(PM10)	PM10	ln(PM10)	ln(PM10)
Year	-0.0608***	-0.0783***	-0.0268***	-0.0276***	-0.0278***	-0.706***	-0.0302***	-0.0284***
	(0.0080)	(0.019)	-0.0019	-0.0026	-0.003	-0.076	(0.0040)	(0.0031)
(Year-1997)*(Post-1996)	0.0617***	0.0735***	0.00990***	0.0117***	0.00476	0.170*	-0.000683	0.00507
	(0.0087)	(0.024)	-0.0029	-0.0041	-0.0043	-0.096	(0.0050)	(0.0043)
Year*(NC = 1)	0.102***	0.0525	0.0155***	0.0160***	0.0155***	0.332***	0.0139***	0.0160***
	(0.020)	(0.039)	-0.0042	-0.0046	-0.0043	-0.1	(0.0047)	(0.0043)
(Year-1997)*(Post-1996)*(NC=1)	**-0.149*** **	**-0.100** **	**-0.0324*** **	**-0.0268*** **	**-0.0289*** **	**-0.574*** **	**-0.0235*** **	**-0.0295*** **
	(0.024)	**(0.049)**	**-0.0072**	**-0.0086**	**-0.0079**	**-0.18**	**(0.0089)**	**(0.0079)**
Other county covariates?[a]	Y	Y	N	Y	Y	Y	Y	Y
Other industry variables?[b]	Y	Y	N	N	Y	Y	Y	Y
County fixed effects?	Y	Y	Y	Y	Y	Y	Y	Y
Observations	23,385	3,778	4,635	3,979	3,778	3,778	1,321	3,564

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.

[a]County covariates refers to ln(per capita income), mean temperature, precipitation, population density, 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 number of establishments in 6 other industries.

[c]Surrounding states: NC, SC, GA, VA, TN , AL, KY, WV.

[d]Top hog producing states excluded: IA, IN, IL, MO.

Appendix

Appendix Table A.1: Sources of Confounders

Variable	Source and Description
Per capita income (2005$)	Bureau of Economic Analysis Regional Economic Accounts Local Personal Income Table CA1-3. http://www.bea.gov/regional/reis/
Population	Population size comes from the U.S. Census Bureau's Age-Sex-Race files for 1980 to 2005. http://www.census.gov/popest/estimates.php.
Population density (people per square mile)	Constructed from variables from the U.S. Census Bureau and the 2006 Area Resource File. Land area in square miles comes from the Area Resource File.
Unemployment rate	Bureau of Labor Statistics Local Area Unemployment Rates. http://www.bls.gov/LAU/
Poverty rate	From the Area Resource File, a data set compiled by the U.S. Dept. of Health and Human Services. The original source is the U.S. Census Small Area Income and Poverty Estimates.
% Population over 65	Constructed from U.S. Census Bureau Age-Sex-Race files. See above.
Number of building permits	U.S. Bureau of the Census. http://censtats.census.gov/bldg/bldgprmt.shtml. Data for 1990-2005 downloaded; data for 1980-1989 obtained via U.S. Census Bureau.
Annual precipitation (inches) Mean annual temperature (^{0}F)	U.S. Historical Climate Network. http://cdiac.ornl.gov/epubs/ndp019/ndp019.html. Individual month and monitor data were averaged by county and year. When data were not available for specific county, the county was assigned the values for the state climate division.
Construction employment Manufacturing employment Utilities employment Wholesale trade employment Transportation and warehousing employment Mining employment	1980 to 2005 Annual County Business Patterns. Data for years 1986 to 2000 downloaded from http://www.census.gov/epcd/cbp/index.html. Data prior to 1986 were obtained through the National Archives. County Business Pattern data switches from a Standard Industrial Classification (SIC) system to the North American Industrial Classification System (NAICS) in 1998. To convert data for 1998 to 2005 to SIC codes, I use the "crosswalk" at http://www.census.gov/epcd/ec97brdg/index.html was used.

Appendix Table A.2: Effects of Changes in North Carolina on Other Industries

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Independent Variable	**ln(Mining)**	**ln(Construction)**	**ln(Manufacturing)**	**ln(Utilities)**	**ln(Wholesale trade)**	**ln(Transportation and Warehousing)**
Year	-0.0285***	-0.0154***	0.0309***	0.0596***	-0.0147***	-0.000345
	(0.0043)	(0.0029)	(0.0045)	(0.0038)	(0.0028)	(0.0034)
(Year-1991)*Post-1990	0.0258***	0.0444***	-0.0343***	-0.187***	0.00592	-0.0141**
	(0.0079)	(0.0051)	(0.0072)	(0.0072)	(0.0053)	(0.0060)
(Year-1997)*Post-1996	-0.0295***	-0.0135**	-0.198***	-0.169***	-0.0155**	-0.00482
	(0.0097)	(0.0066)	(0.010)	(0.0094)	(0.0070)	(0.0098)
Year*(NC = 1)	0.0246	0.0155***	0.00659	0.0352***	0.00610	-0.00276
	(0.016)	(0.0057)	(0.0079)	(0.0069)	(0.0085)	(0.0077)
(Year-1991)*Post-1990*(NC=1)	**-0.0275**	**-0.0441*** **	**0.0118**	**-0.0769*** **	**-0.0384***	**0.0124**
	(0.032)	**(0.010)**	**(0.025)**	**(0.023)**	**(0.020)**	**(0.022)**
(Year-1997)*Post-1996*(NC=1)	**0.0281**	**0.0246***	**0.0105**	**0.0374**	**0.0474****	**-0.0845****
	(0.040)	**(0.014)**	**(0.031)**	**(0.038)**	**(0.022)**	**(0.037)**
Other county covariates?[a]	Y	Y	Y	Y	Y	Y
Other industry variables?[b]	Y	Y	Y	Y	Y	Y
County fixed effects?	Y	Y	Y	Y	Y	Y
Observations	43595	43595	43595	43595	43595	43595

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.

[a]County covariates refers to ln(hogs), ln(Per capita income), population density, mean temperature, annual inches of 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(hogs) and for each of the other 6 industries.

Appendix Table A.3 Effects of Murphy on Hogs and SO2 including SO2 emissions, 1991-2002

	I	II	III	IV	V	VI	VII	VIII
	Entire U.S.						NC and surrounding states[c]	Entire U.S., excluding other top hog states[d]
	ln(SO2)	ln(SO2)	ln(SO2)	SO2 (ppb)	SO2 (ppb)	SO2 (ppb)	ln(SO2)	ln(SO2)
Year	-0.0463***	-0.0443***	-0.0428***	-0.385***	-0.367***	-0.355***	-0.0436***	-0.0479***
	(0.0075)	(0.0082)	(0.0082)	(0.056)	(0.062)	(0.061)	(0.011)	(0.0084)
(Year-1997)*(Post-1996)	0.00969	0.00675	0.00762	0.169**	0.101	0.109	-0.0222	0.0183
	(0.012)	(0.014)	(0.014)	(0.069)	(0.078)	(0.079)	(0.024)	(0.014)
Year*(NC = 1)	0.111***	0.114***	0.111***	0.577***	0.588***	0.566***	0.102***	0.115***
	(0.016)	(0.016)	(0.016)	(0.083)	(0.078)	(0.080)	(0.020)	(0.016)
(Year-1997)*(Post-1996)*(NC=1)	-0.163***	-0.159***	-0.159***	-0.806***	-0.757***	-0.761***	-0.135***	-0.167***
	(0.028)	(0.028)	(0.028)	(0.11)	(0.11)	(0.11)	(0.034)	(0.028)
SO2 emissions (short tons)	0.00249***		0.00225***	0.0221***		0.0196***	0.00168	0.00233***
	(0.00070)		(0.00074)	(0.0072)		(0.0068)	(0.0012)	(0.00083)
Carbon monoxide emissions (short tons)		0.000582***	0.000442**		0.00607***	0.00486***	-0.000489	0.000376*
		(0.00021)	(0.00021)		(0.0015)	(0.0016)	(0.0016)	(0.00020)
Other county covariates?[a]	Y	Y	Y	Y	Y	Y	Y	Y
Other industry variables?[b]	Y	Y	Y	Y	Y	Y	Y	Y
County fixed effects?	Y	Y	Y	Y	Y	Y	Y	Y
Observations	1,973	1,826	1,826	1,973	1,826	1,826	595	1,636

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.

[a]County covariates refers to ln(per capita income), mean temperature, precipitation, population density, 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 employment in 6 other industries.

[c]Surrounding states: NC, SC, GA, VA, TN , AL, KY, WV.

[d]Top hog producing states excluded: IA, IN, IL, MO.