

Effects of Hog Production on Ambient Air Pollution in the Top Ten Hog-Producing States

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Abstract:

Hog production has been increasingly implicated in negative air quality. What has been missing in the research is studies of effects of hog production on ambient air pollution, the type of pollution to which community residents are exposed. In order to estimate health-based externality costs of hog operations, it is necessary to estimate the effects of this industry on ambient air quality. In this paper, I use annual county-level data for 1980 to 2005 from the top ten hog-producing states in order to examine effects in the most intensive areas. The results show a 0.10 elasticity between hog production and air pollution, after controlling for a number of covariates and fixed effects. Further, this effect is increasing over time. The Environmental Protection Agency's current endeavor to regulate large-scale hog operations under the Clean Air Act appears justified and well-timed.

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The Environmental Protection Agency (EPA) is currently gathering air emissions data from livestock producers across the United States in order to regulate these facilities under the Clean Air Act (CAA). In order to get this data, the EPA has asked the livestock producers to collect the data themselves, in exchange for clemency for past air pollution violations. While this data collection may enable estimates of emissions from a wider range of hog production facilities than current numbers reflect, it will not necessarily provide an indication of hog production on ambient air pollution. Community residents in the vicinities of hog operations experience ambient air pollution, and therefore estimates of effects are necessarily for estimating health-based externalities.

In this paper I use annual county-level data on geographic changes in the top ten hog-producing states between 1980 and 2005 in order to estimate effects of hog production on air pollution. Unlike prior studies which use aggregated animal units (Sneeringer, 2005) or individual air quality observations (Sneeringer, 2007), this study uses county-level measures and data on just hogs to estimate effects. I limit the sample to just the top 10 hog-producing states in order to focus on effects from states with the highest densities of hogs. These states will yield estimates more reflective of industrial-style production. Additionally, if there is a non-linear relationship between hog production and air pollution, then this will provide the effects in the top end of the distribution.

The results show that after controlling for a number of time- and county-varying as well as fixed confounders, a doubling of hog production yields a strongly significant 10.0% increase in ambient sulfur dioxide (SO₂), a regulated air pollutant indicated in

numerous health problems. In terms of the magnitude of this effect, air pollution declines would be 13% larger in North Carolina had this states not experienced the increases in hog production that it did. Further, the effects of hogs on air pollution in the top ten states is increasing over time, suggesting that the EPA's attempt to regulate these operations under the CAA is well-founded and should happen sooner than later.

Shifts in the Hog Industry

The numerous changes in hog production over the past several decades have received a great deal of attention. As noted by Rhodes (1995) and Abdalla, Lanyon, and Hallberg (1995), hog production has become increasingly industrialized, with several thousand swine grown at a typical operation (USDA, 1996). Over the past several decades, the number of hog operations has declined even as the number of hogs has increased. This increasing industrialization has been enabled by new technologies involved in raising hogs. Improved disease control measures and housing facilities have meant that hogs can be raised in confinement (Martin and Zering, 1997).

Accompanying this concentration of livestock farming is intensification of manure production, which can become an extensive problem if not handled appropriately (Letson and Gollehon, 1996; Gollehon and Caswell, 2000). A single feeder pig annually produces about 3.5 times the amount of solid waste as a human (Fleming and Ford, 2001); with several thousand hogs at an operation, this leads to a significant amount of waste. Public sewer systems are not able to handle the immense amount of waste from these facilities; therefore hog operations must manage manure in an alternate fashion.

Hog facility manure management includes mixing manure with water in order to

create a liquid form. This liquid manure is then flushed into vast open-air pits called “lagoons” which can extend to several acres in size. An oft-used method of disposing of manure in these holding pits is land application. Livestock workers periodically pump out a portion of the manure in the lagoons and spray it, frequently onto cover crops such as bermudagrass (Mallin, 2000). The high nitrogen content of manure makes it usable as fertilizer; however, over-application can lead to run-off that seeps into groundwater (Hooda et.al., 2000; Hunt et al., 1995).

Another feature of the changing hog industry has been vertical integration of different portions of the pork manufacturing process (Kliebenstein and Lawrence 1995; Martin and Zering, 1997). Hog producers contract with growers to grow hogs. The producer provides the hog and the feed, and the grower raises the hogs. The producer agrees to pay a fixed price at the time of the contract; if the market price is higher than this price, the producer profits. The grower does not gain from market prices. This has led to a situation in which numerous growers locate around a central producer.

Based in part on the vertical integration and increasing industrialization, the industry has also experienced geographic concentration (Hubbell and Welsh 1998; Goetz 1997; Kellogg et al., 2000). Hog production has become increasingly divorced from crop production, and therefore is less reliant on land or nearness to feed.

Because hog production has become so concentrated, it has come under increasing environmental scrutiny (Sullivan, Vasavada, and Smith 2000; Meyer and Mullinax, 1999). Livestock production has been legally recognized as a source of water pollution at least since the 1972 Clean Water Act. In that piece of federal legislation, large-scale livestock farms were designated as “point sources” of pollution and were

required to file permits. The enforcement and granting of these permits was left to individual states, which could also employ different regulatory schemes. As such, there is significant variation by state in environmental regulation of hog production (Metcalf 2000).

This variation by state has led to the possibility of hog pollution havens where production moves to places where the costs of regulatory compliance are lower. Research on the importance of these costs in location decisions yields mixed evidence. These costs appear to be significantly important, as witnessed by the changes in hog location correlated with regulatory stringency (Herath, Weersink, Carpentier 2005). Evidence from Canada (Weersink and Eveland, 2006) suggests that in that country, siting of livestock facilities is based more strongly on agglomeration economies than on environmental regulations.

Other factors beyond environmental and zoning regulations affect where hog operations locate or grow. These include proximity to water sources, availability and price of land, population density, and climate (Pfof and Fulhage, 2000). Additionally, urban encroachment and standard economic variables including proximity to inputs have shaped the location of livestock operations (Roe, Irwin, and Sharp, 2002).

Air-Based Emissions from Hog Operations

There is a substantial body of research linking concentrated animal production to ground- and surface-water contamination (see, for example, Becker, Peter and Masoner, 2003; Copeland and Zinn, 1998; CDC, 1998; Gould, 1995; Hooda et al., 2000; Hunt et al., 1995; Mallin, 2000). Most of the pollution associated with livestock is nutrient-

based, including nitrogen and phosphorus. More recently, concern regarding possible air pollution associated with concentrated livestock farms has been growing. The concentration of animals in smaller locales may lead to higher concentrations of air pollutants in those areas, increasing pollutant level above thresholds for harm.

What is known about air pollution from hog production has been summarized in two major studies, one by members of the Iowa State University and The University of Iowa (2002) and the other by the National Research Council Ad Hoc Committee on Air Emissions from Animal Feeding Operations (2003). These combine all of the research on air emissions from hog facilities, and describe the gaps in the literature.

A number of studies have examined the level and types of gases emitted by livestock facilities (see Hoff et al., 2002, for a review). These studies mostly arise from case studies or test facilities. Air pollutants arise from livestock farms via lagoons, spray application of manure, drying fecal matter, and from the animals themselves. Bacteria act upon the manure in lagoons in the form of anaerobic digestion, emitting nitrogen-based gases. Agitation of liquid manure in lagoons, which occurs during pumping and transportation, also leads to the release of gases. Spraying liquid manure can lead to gases emitted into the air as well as the binding of particulates to air. The manure also breaks into gases once it has encountered the ground. The animals themselves and drying manure in barns can also lead to a host of air quality concerns in the forms of particulates, gases, vapors, and odoriferous compounds.

Experiments with lab animals and studies on livestock have shown the effects of different gases emitted from livestock operations, particularly hydrogen sulfide and ammonia (see Carson, et al., 2002, and Holland, et. al., 2002, for reviews). Depending on

level, frequency, and duration of exposure, these gases create different degrees of damage, particularly to the respiratory system.

Human health effects associated with hydrogen sulfide and ammonia have followed the symptoms seen in laboratory animals and livestock (see Merchant et al., 2002, for a review). These studies are mostly on workers in specific industries who are exposed to hydrogen sulfide and ammonia in the course of employment. Hydrogen sulfide exposure is associated with respiratory symptoms, headaches, and an elevated spontaneous abortion rate. The studies examining the effects of these gases of non-workers in the vicinities of the emissions find similar effects. Infants exposed to hydrogen sulfide have increased occurrence of respiratory infection. Finally, studies examining health problems in livestock facilities without measuring air quality find elevated occurrences of respiratory problems. A review piece by Donham (2002) covers the effects of indoor air pollution inside swine operations, finding that workers suffer from hydrogen sulfide poisoning and respiratory problems.

Ambient Air Pollution from Hog Operations

Several questions are unanswered with regards to air pollution from hog operations. The EPA is correct in committing resources to gathering data on emissions from these facilities; consistent monitoring is an emphasized need in the above two reports. While facility-based monitoring may provide emissions data, it may not be the most accurate indicator of *ambient* pollution levels in the area around the facility. Ambient levels provide indications of harm to humans, and are therefore necessary to ascertain any health-based externality costs associated with hog production pollution. As

noted in the above two reports, effects of pollutants on community residents, not just those who work inside facilities, is a missing aspect of knowledge. Evidence that air pollution in the vicinity of livestock operations may hurt health via an air pollution mechanism can be found in Sneeringer (2008). In this article, the author finds elevated infant mortality rates associated with livestock production, with respiratory-related causes of death most implicated.

Another reason for ascertaining the ambient air pollution levels associated with the swine industry is for regulatory consistency. The EPA intends to regulate livestock facilities under the Clean Air Act (CAA); while this legislation has many facets, one that has played an important role is Title I, which requires counties to reduce ambient air pollution below certain levels or face regulation. Counties that do not exhibit pollution levels below the thresholds are described as “not in attainment” and are subject to regulatory action. If livestock operations are to be regulated under the CAA Title I, then it is necessary to understand their contribution to ambient air quality.

Two studies have examined ambient air pollution from livestock facilities. Sneeringer (2005) uses aggregated animal units from four Censuses of Agriculture (1982-1997) and county-level data and finds a significant correlation with sulfur-based air pollution under certain functional form specifications. Sneeringer (2007) uses annual data for 1980-2005 for the entire nation to estimate the effects of hog production on air pollution. In this study the unit of observation is the ambient air pollution observation; results show a significant relationship between hog production and air pollution.

This article employs a similar strategy to these pieces, but adds to the understanding of effects through several features. First, this study examines effects in

just the top ten hog-producing states, which not only provides more similarities across states, but also means that results can be interpreted as representative of specific types of production. States that are large hog producers may have similar historical settings that enable unobserved characteristics to be better controlled for. These states may also be similar in terms of their proximities to their historical access to inputs. Because these states are more likely to engage in industrial-style hog production, it also enables results to be representative of this style of hog production, rather than a myriad of types.

Second, if the relationship between hog production and air pollution is non-linear, then it is important to look at different portions of the production distribution. Using just the top ten hog-producing states enables focus on the top end of the distribution.

Examining the entire U.S. will provide averaged effects; the context of increasing concentration of livestock, this means that more places have fewer livestock and a few places have a great deal of livestock. This suggests that averages weighing all regions equally will, over time, be more likely to represent less agricultural-intense areas. This may be different from effects in the areas that are growing in terms of hog production.

Finally, since the literature on ambient pollution effects from livestock operations is so sparse, studies using different data sets allow for comparison of results. If the result can be reproduced with different data sets, this provides more credibility to findings.

Empirical Strategy

In order to learn about the effects of hog production on ambient air pollution levels, we can use so-called “natural experiments.” In a natural experiment, the researcher relies on “nature” (or more generally something out of the researcher’s

control, like a policy) to randomly “treat” certain groups but not others. In a laboratory experiment, random assignment yields treatment and control groups that are alike in everything that could potentially affect the outcome. The only difference is the treatment, and therefore any change in the outcome can be causally attributed to it. Since the researcher does not have the ability to randomly assign treatment in a natural experiment, the goal is to be as confident as possible that the treatment and control groups are alike prior to the treatment. When observable characteristics are found to be different between groups, or when it can be reasonably believed that unobservable characteristics are different in ways that could affect the outcome, it becomes necessary to turn to econometric techniques. With these, the researcher is able to non-parametrically control for potentially heterogeneous unobservable characteristics that might affect the outcomes.

Such a natural experiment is used by Chay and Greenstone in a study of the effects of air pollution on infant mortality (2003). In this *Quarterly Journal of Economics* paper, the authors use the 1980-1982 recession to investigate the effects on air quality on infant mortality. The recession rapidly altered manufacturing location, causing spatial and temporal variation in air pollution. Because they find few other contemporaneous changes in factors affecting infant mortality, any witnessed changes may be attributed to air pollution, particularly after controlling for a host of both fixed and time- and area-variant confounders.

In this study I use the geographic changes in the hog industry between 1980 and 2005 to study their effects on air pollution. As described in the literature above, hog location decisions are made according to factors other than air pollution policy or levels.

The three primary reasons for hog location decisions as expressed in the literature are historical setting, agglomeration economies, and environmental regulations. While none of these is directly associated with air pollution, they may be correlated either positively or negatively with it. If they are, then any associations between hog production and air pollution could be due to this third factor. Thus consideration of how to control for these variables and what effects they may have on results is important in attempting a causal link between hog production and air pollution.

To assess the impact of hog production on air pollution, the most basic econometric approach is to regress the pollution level on the production level. To illustrate the issues that arise with this approach, consider a straightforward ordinary least squares regression model. Consider a set of counties denoted by i in a single time period. Let A_i refer to the air pollution level and H_i refer to the number of hogs. In order to estimate the elasticity between hogs and air pollution, the regression specification is

$$(1) \quad \ln(A_i) = \mathbf{a} + \mathbf{I} \ln(H_i) + X_i' \mathbf{b} + u_i$$

where X_i refers to a set of county-varying variables that possibly affect air pollution (for example, population density, per capita income, precipitation, and temperature). The log-log functional form not only allows for relative ease of interpretation, but also implicitly controls for county size and therefore production density. The elasticity between number of hogs and air pollution will be the same as that between hogs per square mile and air pollution.

The first potential issue with this approach is endogeneity. Livestock operations may locate in low air pollution areas, because the animals are affected by air pollution in a similar way to humans. This would yield $\mathbf{I} < 0$. Because of this endogeneity, the

coefficient I may be biased downward. If hog producers locate in areas with high air pollution, such a scenario would yield $I > 0$ and bias this coefficient upward.

Another potential issue is classic omitted variable bias, where hog producers may choose locations based on some omitted confounding variable that affects air pollution. An example is water supply, which would be generally fixed in the time period of interest. Hog producers may choose locations with high availability of water, the presence of which may also partially determine pollution levels. The literature suggests that hog producers locate on the basis of historical setting, environmental regulation, and proximity to markets and finishers. The first solution to potential omitted variable bias is to actually include the omitted variable. I therefore include confounders on number of building permits (as a proxy for land prices), population density, per capita income, unemployment rate, percent of the population over 65 (as a partial proxy for economic activity), precipitation, temperature, and number of establishments in six other industries.

Barring data on specific variables, or in cases where variables cannot be observed, a solution is to use panel data for multiple states and to non-parametrically control for fixed characteristics of counties and time periods, in addition to adding time- and county-varying confounders. With panel data for multiple states, one can also non-parametrically control for events that occur in a specific time period to all counties within a state. This yields a regression of the form

$$(2) \quad \ln(A_{ist}) = \mathbf{a} + I \ln(H_{ist}) + X_{ist}' \mathbf{b} + \mathbf{g}_{is} + \mathbf{g}_t + \mathbf{g}_{st} + u_{ist}$$

Here, t denotes time period while s denotes state. \mathbf{g}_{is} represents fixed effects for county i in state s , and \mathbf{g}_t denotes fixed effects of time period t . Fixed characteristics of counties

that are correlated with hog production and also effect air pollution will be captured in \mathbf{g}_{is} . These include historical market setting, environmental amenities such as slope, and non-time-varying preferences for hog production and air pollution.

A set of dummies for time period (\mathbf{g}_t) will capture characteristics of individual years that occur for all counties in all states. For example, a national recession could lower pork consumption (lowering H) as well as air pollution.

This empirical strategy controls for the primary confounders that may bias affects of hogs on air pollution. Environmental regulations at the level of the state have been shown to affect hog operation decisions. County-level data for multiple states introduces within-state variation in hog location that can be used to identify effects on air pollution. This type of data allows non-parametric control of state-level legislation in specific years without actually knowing the details of the regulation. This is done with a set of state-time dummies (\mathbf{g}_{st}) that capture effects of an individual time period that are constant for all counties in a state, including state legislation by year. These dummy variables will also capture input prices that are similar by state for specific time periods. Although it is unclear how corn prices could be correlated with air pollution, and thereby influence the estimate of the coefficient of interest, the state-time dummies will capture these effects.

A second primary concern that may bias results is that livestock will locate in an area based on historical setting, and this setting will have high or low air pollution. Historical setting refers to an area's attitudes towards agriculture, its workforce's experience with swine, and its landscape. Because these characteristics are fixed over time or before the start of the time period in question, they will be captured in the fixed effect for the county. Historical setting also can mean areas that are more urban or rural.

If hog producers locate in areas with historically lower air pollution, then without the county-fixed effects the results will be biased downward.

The third and final primary worry is agglomeration economies. The problem here is that hog producers may locate in areas with other hogs, which, assuming the result in question, suggests that they would be locating in areas with high air pollution. To believe that this is driving the results means that one needs to first believe the results, which in effect suggests that any change in pollution associated with a change in hogs is an effect of the hogs.

Agglomeration economies could also air pollution associated with more dense populaces. In order to control for this possibility and isolate the effect of hogs on air pollution, I include county- and time-varying confounders for per capita income, population density, unemployment rate, and the number of building permits. These variables will capture many effects of agglomeration. Related to agglomeration, we may be concerned that hog production systematically varies with another high-polluting industry. I therefore include time- and county-varying confounders for six other industries.

The formation of the concentration could also suggest increased vehicle traffic. To test for this possibility, I perform a falsification test of whether carbon monoxide is related to hog production. If this result is the case, then other air pollutant effects could reasonably be attributed to increased vehicular traffic associated with vertical integration, rather than the hogs themselves. While a positive result is also suggestive that hog operations contribute to air pollution, sulfur-based air pollution could be attributed to the vehicular traffic rather than manure disposal. However, if there is no effect on carbon

monoxide but effects on sulfur-based air pollutants, this points to air pollution related to the hogs themselves.

Data

County-level measures of hog production come from the National Agricultural Statistics Service (NASS). NASS provides public-use data on the number of hogs by county and year. The number of hog operations is not available in this data, therefore the size of operations cannot be controlled for.

Air quality observations come from the EPA's Air Quality System (AQS). These are annual summaries of different pollutants from fixed monitors. The observations include the state and county of the monitor, the number of observations, and the mean observed value. These monitors observe the ambient levels of six specific "criteria" air pollutants. The ideal pollutants related to hog production are hydrogen sulfide and particulate matter. While particulate matter is a criteria pollutant, hydrogen sulfide is not, and there is therefore no consistent monitoring of this gas. While particulate matter would appear to be the method of ascertaining changes in air pollution related to hog production, the EPA complicated the ability to do so. In 1987 the EPA switched its air quality standard regarding particulate matter from total suspended particulates (TSPs) to PM10 (particulate matter of up to 10 microns in diameter), a non-constant subset of TSPs. The number of monitors recording data for TSPs dropped precipitously while those for PM10 grew. Because this change occurs in the middle of the period in which I have hog data, I do not evaluate effects on particulate matter.

Because hydrogen sulfide is not a criteria air pollutant and is therefore not monitored on a consistent basis, I instead use a proxy. Hydrogen sulfide (H₂S) oxidizes to sulfur dioxide (SO₂), which is a criteria air pollutant.² Additionally, hog production has been implicated in sulfur dioxide emissions directly (Okoli et al., 2006; Thorne, 2002). Therefore, I examine ambient sulfur dioxide levels.

I garner data on a number of time- and county-varying controls from a number of sources. The controls are variables that are conceivably correlated with livestock and air pollution. These include per capita income (in 2005\$), population density, temperature, precipitation, number of building permits, unemployment rate, percent of the population over aged 65, and variables for the number of establishments in six other industries. Temperature and precipitation influence air pollution levels and may influence where livestock producers operate. These variables come from the U.S. Historical Climate Networks' annual data. Per capita income, unemployment rate, and percent of the population over age 65 are used to control for economic setting, which influences both air pollution and hog production. Per capita income will also partially control for land prices. These variables come from U.S. Census data and Area Resource File data. Population density and the 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 hogs. These come from U.S. Census data. Finally, the variables for six other industries, which include construction, manufacturing, utilities, wholesale trade, transportation, and mining, come from annual County Business Pattern data.

Table 1 shows state-level statistics as well as county-year averages by state. The

² See Seinfeld and Pandis (1998), Finlay-Pitts and Pitts (2000), and Friedl, Brune, and Anderson (1985).

state-level ranks are generally reflected in hogs per square mile density as well the totals. In all states, the majority of hogs are at operations with greater than 1,000 head. State-level sulfur dioxide levels do not clearly correlate with hog levels; this is to be expected, since SO₂ is associated with a number of other industries.

Sulfur dioxide levels during this period are generally decreasing across the U.S. Therefore, any change in air pollution associated with hogs will look like declines that are smaller than they could have been, rather than unconditionally increases.

Variation in Hog Production in the Top 10 Hog-Producing States

Figure 1 shows trends between 1980 and 2005 in the number of hogs for the nation's top five hog-producing states. For visual ease, the five states in the constituting ranks six through ten are not shown; they show relatively little change. Figure 1 shows a great deal of variation in where hogs are located. North Carolina only became the second largest hog-producing state in 1994. Before that time, the state held the rank of fifth, behind Illinois, Minnesota, and Indiana. As is evidenced, North Carolina saw a precipitous increase in the number of hogs between 1991 and 1998, after which it leveled off. Comparisons with the other four top hog-producing states show that the 1991-98 increase was not experienced in the other states, suggesting that this rise was not due to a macroeconomic feature such as input prices declining or demand increasing. Instead, this sudden increase in hog production in North Carolina was motivated by changes in legislation related to hogs. A series of bills supported by Senator Wendell Murphy as well as the creation by Murphy Family Farms of the world's largest slaughterhouse promoted the current hog landscape in North Carolina.

While North Carolina experiences trend breaks in hog production, Iowa appears to significantly fluctuate. This may be correlated at least some of North Carolina's experiences. Noticeably, the number of hogs does not fluctuate in the same way in each state, suggesting that macroeconomic forces (such as weather conditions affecting the price of grain) do not affect all states in the same manner. If they did, we might see increases in all states at the same time, or similar fluctuations.

Other state witnessing increases include Minnesota and Oklahoma. Minnesota sees a trend break in 1996, while Oklahoma changes its trend in 1993, to level off again in 1999. In comparison to these, the other six top-producing states show relatively little variation in hog numbers.

Econometric Analysis Results

Table 2 provides regression results. Several models are shown in order to provide an understanding of the effect of inclusion of different covariates. In Column I, the covariates included are all of the county- and time-varying confounders. This column shows estimates of running the regression described in equation (1). This shows no statistically significant relationship between hogs and air pollution. The other covariates except for temperature are statistically significant. The economic variables are all of the expected sign.

The third column shows the results of include just the county and year fixed effects, without any time- or county-varying confounders. The result is markedly different from that in Column I. This shows a statistically significant positive elasticity between hogs and air pollution; a doubling of hogs yields a 13.8% increase in SO₂.

Column III shows the effect of adding the time- and county-varying confounders except for the other industries. These have very little effect on the relationship between hogs and sulfur dioxide, suggesting that they are uncorrelated with hog production or sulfur dioxide. Indeed, only population density and number of building permits are statistically significant. In Column IV the other industry variables are added; their inclusion has little effect on the size of the effect, suggesting that hog production does not systematically move with another polluting industry. Comparison of Columns I and IV shows that the fixed effects play an important role in the relationship between hog production and air pollution. Without them, the estimated coefficient is biased downward, suggesting that hog producers locate in areas with generally lower air pollution. This makes sense, considering that most highly polluted areas are densely populated, and hog producers have historically located in less-populated areas.

Finally, state legislation may affect both hog location and air pollution. Column V shows a model that includes state-year dummy variables to control for state-level legislation in the year. This has an effect on the size of the coefficient of interest, although it still remains statistically significant. Inclusion of the state-year fixed effects lowers the coefficient of interest to 0.10, meaning that a doubling of hogs in a county will yield a 10% increase in SO₂.

In order to provide a test of whether the increased vehicular traffic associated with agglomeration economies is driving results, I examine effects of hogs on carbon monoxide (CO), a pollutant most associated with cars and trucks. Column VI shows that carbon monoxide is not correlated with hog production, suggesting that the SO₂ pollution is due to a feature of hog production unrelated to vehicles.

To test whether the effects of hog production on air pollution are changing over time, I interact the hog production variable with a set of time period dummy variables. The time periods are broken into three-year intervals, and the covariates include all of those in Column V. The omitted category is the first time period, 1980-1984. Figure 2 shows the coefficients of these interacted terms. As is evidenced, the size of the effect of hogs on production is increasing over time. In 2003-2005, a doubling of hogs in a county led to a 10.3% greater increase in sulfur dioxide, relative to the effect in 1980-1984, after controlling for fixed effects and covariates.

Discussion and Conclusions

The results show a strongly significant relationship between hog production and air pollution, with an elasticity of 0.10. This result is remarkably robust to the addition of covariates, suggesting that adding further time- and county-varying variables will not affect results greatly. Simple cross-sectional results will strongly underestimate effects of hog production on air pollution.

To put the magnitude of the main finding effect in perspective, consider North Carolina's 6.4% increase in hogs between 1980 and 2005. The results show that this increase would yield a 0.64% SO₂ increase. Considering that North Carolina actually did see a 4.95% decrease in SO₂ over the time period, without the change in hogs, this decline could have been 13% higher. This suggests that hogs can play a significant role in air pollution.

In comparison to prior work on ambient air pollution from hog production in the entire U.S., focusing on just the top ten hog producing states shows different results.

First, the article using the entire U.S. (Sneeringer, 2007) shows a 0.043 elasticity between hog production and air pollution for the years 1980 to 2005. The results here yield an effect that is over twice as large, suggesting that effects are more severe in more hog-intensive states. Further, compared to the results for the entire U.S. which show declining effects over time, the results here show *increasing* effects over time. These two results are compatible; as hog production has become geographically concentrated, the hog producing areas account for a decreasing portion of the country. If effects are lower for less-hog-intensive areas, then aggregating will show declining effects. In order to understand how hog production will affect the places most likely to see increases in the future, it is therefore necessary to examine these high-intensity states.

The results in this article demonstrate that hog production causes ambient sulfur-based air pollution. In states where hog production is growing, the effects are growing stronger over time. If the EPA wishes to abide by the Clean Air Act's goal of protection of human health, then it should regulate this industry in a similar fashion to other polluting industries.

References

- Abdallah CW, Lanyon LE, Hallberg MC. 1995. "What we know about historical trends in firm location decisions and regional shifts: Policy issues for an industrializing animal sector," *American Journal of Agricultural Economics* 77(5), 1229-1236.
- Barrington, S.F. and Broughton, R.S. 1988. "Designing earthen storage facilities for manure," *Canadian Agricultural Engineering* 30, 289-292.
- Becker, M.F., Peter, K.D., and Masoner, J. 2003. Possible sources of nitrate in ground water at swine licensed-managed feeding operations in Oklahoma, 2001. Oklahoma City: United States GPO.
- Bonner, J., Moore, R., Thomas, J., Crenshaw, M., McKinley, B., and Burcham, T. 2003. "Managing animal waste nutrients." Publication 1937 of the Mississippi State University Extension Service. Accessed online.
- Carson, T.L., Osweiler, G.D., and Thorne, P.S. 2002. "Adverse health effects: Toxicology," in *Iowa Concentrated Animal Feeding Operations Air Quality Study*. Iowa State University and The University of Iowa Study Group. Online publication. <http://www.public-health.uiowa.edu/ehsrc/CAFOstudy.htm>. Accessed Sept. 27, 2004.
- Centers for Disease Control and Prevention. 1998. *A survey of the quality of water drawn from domestic wells in nine Midwest states. Sept. 1998*. Online publication. <http://www.cdc.gov/nceh/programs/emergenc/WellWater/MidwestWell.htm>.
- Chay K, Greenstone M. 2003. "The impact of air pollution on infant mortality: Evidence from geographic variation in pollution shocks induced by a recession," *The Quarterly Journal of Economics* Aug., 1121-1167.

- Copeland C, Zinn J. 1998. "Animal waste management and the environment: Background for current issues," Congressional Research Service Report 98-451.
- DeTar, W.R. 1979. "Infiltration of liquid dairy manure into soil," *Transactions of the American Society of Agricultural Engineers* 79, 520-531.
- Donham, Kelley J. 2000. "The concentration of swine production: Effects on swine health, productivity, human health, and the environment," *Toxicology* 16(3), 559-597.
- Finlayson-Pitts, B.J. and Pitts, J.N. 2000. *Chemistry of the Upper and Lower Atmosphere: Theory, Experiments, and Applications*. San Diego: Academic Press.
- Fleming, Ron and Ford, Marcy. 2001. "Humans versus animals – comparison of waste properties." Accessed Jan. 6, 2004.
- Friedl, R.R., Brune, W.H., and Anderson, J.G. 1985. "Kinetics of SH with NO₂, O₃, O₂, and H₂O₂," *Journal of Physical Chemistry* 89, 5505-5510.
- Gollehon N, Caswell M. 2000. "Confined animal production poses manure management problems," *Agricultural Outlook* Sept., 12-18.
- Gould, M. Charles. 1995. "Nitrate-nitrogen levels in well water in the Little River/Rooty Creek agricultural non-point source hydrological unit area," in *Animal Waste and the Land-Water Interface*. K. Steele (ed.). Boca Raton: Lewis Publishers.
- Herath D, Weersink A, Carpentier CL. 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.
- Hoff, S.J., Hornbuckle, K.C., Thorne, P.S., Bundy, D.S., O'Shaughnessy, P.T. 2002. "Emissions and community exposures from CAFOs" in *Iowa Concentrated Animal Feeding Operations Air Quality Study*. Iowa State University and The University of

Iowa Study Group. Online publication. <http://www.public-health.uiowa.edu/ehsrc/CAFOstudy.htm>.

Holland, R.E., Carson, T.L., and Donham, K.L. 2002. "Animal health effects," in *Iowa Concentrated Animal Feeding Operations Air Quality Study*. Iowa State University and The University of Iowa Study Group. Online publication. <http://www.public-health.uiowa.edu/ehsrc/CAFOstudy.htm>.

Hooda, P.S., Edwards, A.C., Anderson, H.A., and Miller, A. 2000. "A review of water quality concerns in livestock farming areas," *The Science of the Total Environment* 250, 143-167.

Hubbell BJ, Welsh R. 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.

Huffman, R.L. and Westerman, P.W. 1995. "Estimated seepage losses from established swine waste lagoons in the lower coastal plain of North Carolina," *American Society of Agricultural Engineers* 38(2), pp. 449-453.

Hunt, P.G., Stone, K.C., Humenik, F.J., and Rice, J.M. 1995. "Impact of animal waste on water quality in an eastern coastal plain watershed," in *Animal Waste and the Land-Water Interface*. K. Steele (ed.). Boca Raton: Lewis Publishers.

Innes, R. 2000. "The economics of livestock waste and its regulation," *American Journal of Agricultural Economics* 82, 97-117.

Kellogg, R.L., Lander, C.H., Moffitt, D.C., and Gollehon, N. 2000. *Manure nutrients relative to the capacity of cropland and pastureland to assimilate nutrients: Spatial and temporal trends for the United States*. Online publication of the USDA National

Resources Conservation Service.

<http://www.nhq.nrcs.usda.gov/land/index/publication.html>.

- 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.
- Mallin, Michael. 2000. "Impacts of industrial animal production on rivers and estuaries," *American Scientist* 88, 26-34.
- Letson, D. and Gollehon, N. 1996. "Confined animal production and the manure problem," *Choices* Third Quarter, 18-24.
- Martin L, Zering K. 1997. "Relationship between industrialized agriculture and environmental consequences: The case of vertical coordination in broilers and hogs," *Journal of Agricultural and Applied Economics* 29(1), 45-56.
- Meyer D., Mullinax DD. 1999. "Livestock nutrient management concerns: Regulatory and legislative overview," *Journal of Animal Science* 77 (Suppl. 2), 51-62.
- 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.
- Okoli IC, Alaehie DA, Okoli CG, Akano EC, Ogundu UE, Akujobi CT, Onyicha ID, Chinweze CE. 2006. "Aerial pollutant gases concentrations in tropical pig pen environment in Nigeria," *Nature and Science* 4(4), 1-5.
- Pfost D, Fulhage D. 2000. "Selecting a site for livestock and poultry operations," Missouri University Extension Publication EQ378.

- Rhodes VJ. 1995. "The industrialization of hog production," *Review of Agricultural Economics* 17(2), 107-118.
- Roe B, Irwin EG, Sharp JS. 2002. "Pigs in space: Modeling the spatial structure of hog production in traditional and nontraditional production regions," *American Journal of Agricultural Economics* 84(2), 259-278.
- Seinfeld, J.H., and Pandis, S.N. 1998. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*. New York: Wiley and Sons.
- Sneeringer, S. 2005. *Essays in Empirical Environmental Economics and Health*. Ph.D. Dissertation, University of California, Berkeley.
- Sneeringer S. 2007. "Does concentrated hog production cause air pollution?" Working paper, Wellesley College.
- Sneeringer, S. Forthcoming. "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*.
- Sullivan J, Vasavada U, Smith M. 2000. "Environmental regulation and location of hog production," *Agricultural Outlook* Sept., 19-23.
- Thompson MD. 2000. "This little piggy went to market: The commercialization of hog production in Eastern North Carolina from William Shay to Wendell Murphy," *Agricultural History* 74(2), 569-584.
- Thorne PS. 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. <http://www.public-health.uiowa.edu/ehsrc/CAFOstudy.htm>.

Weersink A, Eveland C. 2006. "The siting of livestock facilities and environmental regulations," *Canadian Journal of Agricultural Economics* 54, 159-173.

United States Department of Agriculture. 1996. "Environmental practices/management by U.S. pork producers" Pamphlet of the USDA's Animal and Plant Health Inspection Service.

Table 1: Summary Statistics

	Iowa	North Carolina	Minnesota	Illinois	Indiana	Missouri	Nebraska	Kansas	Oklahoma	Ohio
State-level statistics										
Rank in 2005	1	2	3	4	5	6	7	8	9	10
Total number of hogs, 2005 (1,000s)	16,375	9,875	6,575	4,038	3,113	2,813	2,800	1,720	2,388	1,550
Hogs per square mile of land, 2005	2.9	2.0	0.8	0.7	0.9	0.4	0.4	0.2	0.3	0.4
Percent of hogs at operations with over 1,000 head, 2002	86%	99%	86%	82%	81%	86%	79%	90%	97%	72%
Average SO ₂ , 2005 (ppm)	0.0033	0.0032	0.0015	0.0040	0.0052	0.0034	0.0023	0.0017	0.0035	0.0057
County averages, 1980-2005										
Hogs	149,803 (72,211)	75,421 (236,009)	24,593 (36,638)	48,536 (42,366)	33,227 (32,016)	13,638 (20,328)	21,500 (19,740)	7,640 (8,017)	11,220 (10,428)	2,182 (1,333)
Average SO ₂ (ppm) by county	0.0052 (0.0037)	0.0045 (0.0019)	0.0040 (0.0033)	0.0065 (0.0033)	0.0088 (0.0037)	0.0060 (0.0042)	0.0024 (0.0013)	0.0033 (0.0025)	0.0090 (0.0045)	0.0055 (0.0045)
Per capita income	27,163 (3,614)	26,566 (6,127)	32,618 (6,926)	28,428 (5,299)	25,743 (3,746)	28,069 (6,190)	34,751 (4,364)	24,170 (2,619)	26,101 (4,963)	25,831 (5,398)
Population density	0.16 (0.12)	0.30 (0.33)	0.83 (1.04)	0.65 (1.32)	0.30 (0.44)	0.97 (1.78)	1.01 (0.52)	0.40 (0.48)	0.66 (0.75)	0.36 (0.4)
Unemployment rate	0.051 (0.019)	0.058 (0.023)	0.047 (0.02)	0.073 (0.028)	0.064 (0.025)	0.056 (0.026)	0.041 (0.012)	0.061 (0.02)	0.076 (0.026)	0.058 (0.016)
Number of building permits	350 (416)	1,578 (2,782)	2,051 (1,943)	1,687 (3,187)	586 (1,079)	1,464 (1,681)	1,905 (1,117)	312 (642)	1,084 (1,658)	1,500 (2,541)
Annual precipitation (inches)	34.7 (6.8)	47.5 (7.6)	30.0 (5.2)	39.5 (7.)	43.9 (7.2)	41.5 (8.5)	27.8 (7.1)	34.0 (9.)	39.7 (6.3)	41.2 (8.3)
Mean annual temperature (°F)	48.6 (2.1)	59.4 (2.1)	43.2 (2.8)	52.3 (2.7)	53.0 (2.7)	54.1 (1.8)	50.6 (1.4)	55.6 (2.1)	51.1 (2.1)	59.6 (1.6)

Note: For county averages, standard deviations shown in parentheses.

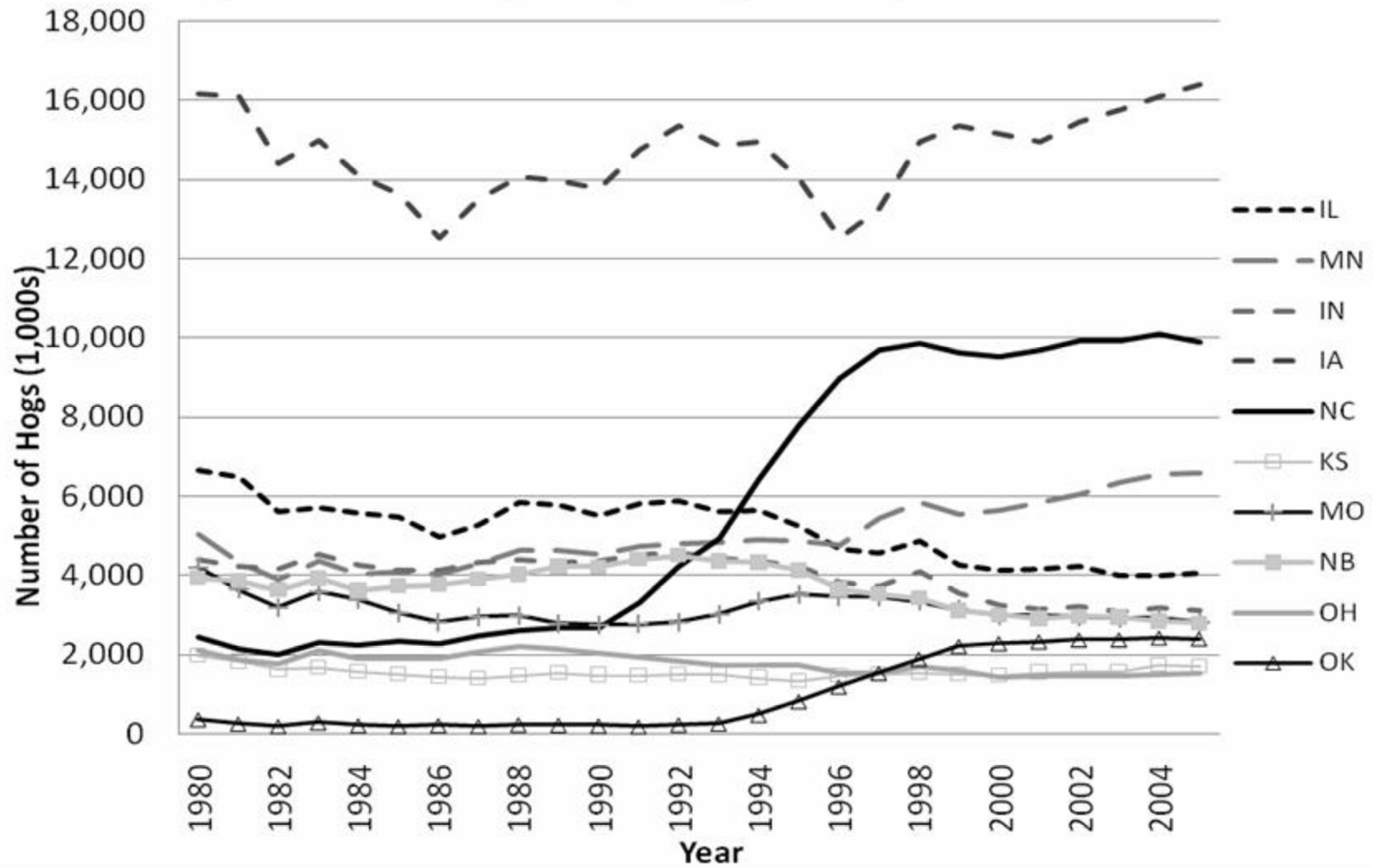
Table 2: Results of Air Pollution Measures on Hog Density

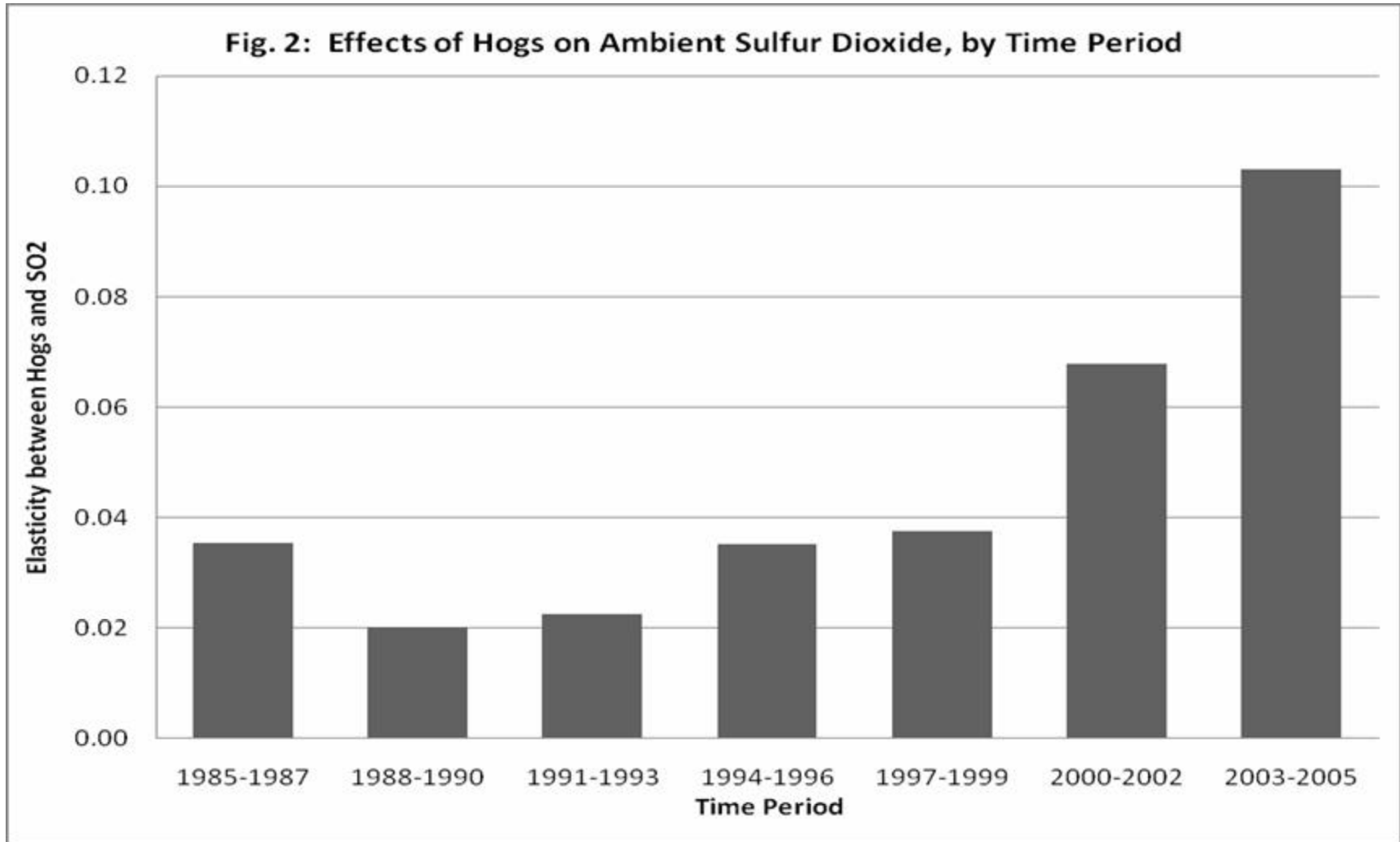
	I	II	III	IV	V	VI
	Dependent variable					
	Ln(SO2)	Ln(SO2)	Ln(SO2)	Ln(SO2)	Ln(SO2)	Ln(CO)
Ln(Hogs)	0.0151 (0.012)	0.138*** (0.030)	0.122*** (0.029)	0.123*** (0.031)	0.100*** (0.033)	0.0672 (0.043)
Ln(Per Capita Income)	-0.638*** (0.17)		-0.105 (0.27)	0.236 (0.29)	0.157 (0.27)	0.910** (0.45)
Unemployment rate	0.0623*** (0.0088)		-0.00883 (0.0077)	-0.00730 (0.0081)	-0.0193** (0.0077)	-0.0371* (0.019)
Population Density (1000s/sq. mile)	0.0816* (0.047)		-0.237*** (0.076)	-0.121 (0.074)	-0.179* (0.099)	-0.167** (0.081)
Percentage of county over 65	1.558** (0.79)		-11.03*** (3.39)	-9.766*** (3.42)	-8.829*** (3.25)	-4.845 (4.66)
Annual Precipitation (100s of Inches)	0.582*** (0.22)		0.0127 (0.14)	0.0988 (0.14)	-0.0490 (0.18)	-0.233 (0.28)
Annual Mean Temperature (°F)	-0.000977 (0.0052)		0.00474 (0.013)	0.0145 (0.012)	0.0205 (0.020)	0.0147 (0.023)
Number of building permits (1,000s)	0.0380*** (0.014)		0.0351*** (0.013)	0.0385** (0.017)	0.0251 (0.017)	-0.0279** (0.012)
Other industry levels^a	Y	N	N	Y	Y	Y
County fixed effects?	N	Y	Y	Y	Y	Y
Year fixed effects?	N	Y	Y	Y	Y	Y
State*year controls?	N	N	N	N	Y	Y
Adjusted R-squared	0.201	0.779	0.839	0.842	0.882	0.842
Observations	1,197	2,041	1,280	1,197	1,197	579

Notes: Robust standard errors shown in parentheses. *** refers to significance at the 1% level, ** refers to significance at the 5% level, and * refers to significance at the 10% level.

^aRefers to the number of establishments for 6 different industries, including construction, manufacturing, utilities, wholesale trade, transportation, and mining.

Fig. 1: Number of Hogs in Top 10 Hog-Producing states, 1980-2005





Notes: Omitted time period is 1980-1984. Example of interpretation: In 2003-2005, a doubling of hogs in a county led to a 10.3% greater increase in sulfur dioxide, relative to the effect in 1980-1984, after controlling for fixed effects and covariates