An Analysis of Occupational Health in Pork Production

Terrance M. Hurley,[a] James B. Kliebenstein,[b] and Peter F. Orazem[b]

Staff Paper No. 284
December 1996

Visiting Scientist[a] and Professor[b], Department of Economics.

We are grateful to Kelly Donham and Susanna Von Essen for useful comments at the early stages of this research and to the National Pork Producers Council for partial research support. Donna Otto and Cynthia Pease prepared the manuscript.

An Analysis of Occupational Health in Pork Production

Abstract

The rapid expansion of large-scale pork production has been accompanied by increasing concerns regarding potential detrimental consequences of environmental hazards on the health of producers. This study makes use of health indicators obtained from attendees at the World Pork Expo between 1991 and 1995 to evaluate the impact of pork production generally and of confinement production, specifically, on producer health. The analysis expands existing studies because the larger number of participants allows for detailed analysis, both nonfarmers and non-pork farmers are used as controls, both objective as well as self-reported health measures are considered, and personal characteristics such as height, weight, age, gender, smoking habits, and years of exposure to confinement operations and swine operations are controlled. The analysis shows that pork producers are more likely to report nagging respiratory symptoms (cough, sinus problems, sore throat) than are other farmers. Confinement operators have increased incidence of some symptoms relative to other pork producers. However, there was no evidence of permanent loss of pulmonary function associated with pork production or confinement operation. Farmers suffered from a greater incidence of hearing loss and loss of dominant hand strength relative to nonfarmers. Pork producers had even greater incidence of lost hand strength than other farmers but had no added incidence of hearing loss. On the plus side, farmers had lower blood pressure than did nonfarmers.

Introduction

Confinement operations represent an increasing share of pork production over the past 20 years. Operations have become larger, more specialized, more capital intensive, and less labor intensive. The movement toward confinement in swine production has increased concerns over environmental quality and employee health. Livestock production facilities can expose employees, producers and animals to dust, gas, and other elements at levels that can have detrimental health consequences. Donham et al. (1977) and Donham and Gustafson (1982) indicate the potential health hazards for employees and producers working in confinement swine production facilities. However, documented evidence on the relationship between livestock production systems and employee health remains limited.

The health effects on employees in pork-production can include acute or chronic bronchitis, increased levels of asthma, systemic flu-like symptoms, sinus (nasal) problems, and chronic hoarseness (Donham, 1995; Von Essen, 1996). Donham et al. (1989) and Iverson et al. (1988) found that acute cough symptoms were reported by 67% of swine production employees, phlegm by 56%, scratchy throat by 54%, runny nose by 45%, burning or watering eyes by 39%, headaches by 37%, tightness of chest by 36%, and shortness of breath by 30% of the employees. The prevalence of the acute symptoms was about 1.5-2 times that seen for chronic symptoms.

Donham et al. (1995) and Reynolds et al. (1996) have shown that employees working in a confinement facility for more than six years are at greatest risk for chronic health effects. A 6-year follow-up study of Canadian swine producers found that after six years 15% reported exiting the industry due to respiratory problems (Holness et al., 1987). Additionally, Donham et al. (1977) showed that 60% of the veterinarians who provided services for confinement facilities reported adverse respiratory symptoms. In a review article, Donham (1995) concluded that the prevalence of chronic symptoms in swine employees was two to four times that of comparison employees. Additionally, health symptoms for employees in swine confinement operations were almost 50% greater than for swine employees not using confinement production facilities.

Although the earlier studies are suggestive, they suffer from several shortcomings that cloud their conclusions. The studies, in general, focus narrowly on swine producers, so it is unclear how much the reported health outcomes differ from those of other farmers or the population at large. Additionally, for many, the small number of participants make it difficult to establish the reliability of the health outcomes. For others, reliance on self-reported rather than objective health measures further cloud the interpretation of the results.[1] A narrow focus on respiratory illness leaves open the possibility of other positive or negative health outcomes associated with pork production. Finally, and most importantly, a lack of control over confounding factors (age, weight, height, gender, and smoking habits) common among pork producers but unrelated to pork production may bias the estimated health impacts.

This study extends earlier work by including nonfarmers and farmers without swine operations; by using objective and subjective measures of a variety of health outcomes; and by controlling for confounding factors. A large sample of World Pork Expo attendees from 1991-1995 form the base for the analysis. The estimated health outcomes include hearing, hand strength, blood pressure, and respiratory. Results indicate that farmers have significantly greater incidence of hearing loss and weakened hand strength, but have lower blood pressure than nonfarmers with the same physical attributes. Pig farmers are more likely to report respiratory symptoms, but objective measures of lung capacity do not reveal any permanent loss of respiratory function for pork producers. Results also indicate a large divergence between self-reported and objective measures of health outcomes, indicating that studies based on subjective self-reported information may be misleading, or that producers and employees have not been exposed to confinement facilities for a sufficient length of time for long-run health effects to become evident.

Data

The data for the analysis came from attendees of the World Pork Expo spanning the 5-year period, 1991-1995. A health pavilion was set up in which various subjective and objective health assessments were conducted by medical professionals. The collection effort by the National Pork Producers Council was in response to concerns regarding occupational health and safety in the pork industry. As such, these data represent a unique opportunity to examine the incidence of occupational injury and disease in the pork industry. The World Pork Expo is an exposition featuring the pork production industry, drawing a wide range of industry stakeholders and others interested in the industry.

There are several advantages to this type of data. First, it offers a large number of observations on pork producers generally and on confinement operators specifically. If more intensive pork production is associated with progressive deterioration in pulmonary function, for example, evidence may be evident only in large samples. On the other hand, poor health outcomes commonly associated with pork producers may be true of farmers more generally. The large number of farmers in the sample who are not engaged in pork production serve as a useful reference group for comparison with pork producers generally, or confinement operators specifically.

Attendees at the Pork Expo are broadly representative of pork producers in the Midwest; thus, the health measures should be broadly representative of health outcomes for farmers currently engaged in pork production. However, there are some clear disadvantages with this sample, which may color the interpretation of the results. First, the sample is predicated upon sufficient interest in the pork industry to attend the Pork Expo. Although this is fine for the sample of pork producers, the non-pork producers will not be representative of the population at large. More seriously, the sample includes only those who felt well enough to travel to the Expo, so those with serious illnesses or debilitating injuries will be excluded. Therefore, the study will concentrate on analysis of illnesses or injuries that may limit, but not require abandonment of occupational pursuits. Furthermore, the sample is best suited for a general comparison of confinement against nonconfinement pork producers and pork producers against farmers more generally.

There is a more serious shortcoming in this data, which is common in epidemiological analyses. Exposure to occupational hazards is predicated on self-selection into the occupation. Therefore, if an occupation involves exposure to known environmental contaminants, those remaining in the occupation will be disproportionately resistant to the occupational hazards. For example, asthma sufferers will be underrepresented in jobs involving exposure to dust such as pork production. As such, there will be lower incidence of occupational illnesses in a sample of self-selected farm operators than would be true if individuals were randomly assigned to farming.

As shown later, the availability of repeated observations for individuals who attended the Pork Expo two different years with continuous exposure to occupational hazards helps to correct for the potential self-selection bias.

Empirical Strategies

Health outcomes are viewed as a combination of H_{it}: human capital variables such as age, gender, and height, and predetermined individual choices with potential health consequences such as smoking or weight; and O_{it}: occupational variables that measure the presence of and intensity of exposure to job attributes that can enhance or diminish health outcomes. The production process can be described as

$$\textbf{(1)} \qquad h_{it} = f(H_{it}, O_{it} \mu_{it})$$

where h_{it} is a measure of health for individual i at time t and μ_{it} is an individual-specific health endowment.

Several measures of h_{it} were collected, some subjective and others measured scientifically. Such data enable the assessment of whether damage has occurred and whether individuals perceive the damage. These comparisons can be made between perceived hearing loss and measured hearing loss and between perceived respiratory health and measured respiratory health. Objective measures of blood pressure and hand strength were also obtained.

The empirical health measures come in three different specifications, continuous variables, dichotomous variables, and ordered limited dependent variables. On the basis of the nature of the data, ordinary least squares, probit, or ordered probit regression are used. For individual i at time t, the specifications take the form

$$\textbf{(2)} \qquad h_{it} = H_{it}\gamma_H + D_{it}\gamma_D + F_{it}\gamma_F + F_{it}P_{it}\gamma_P + F_{it}P_{it}C_{it}X_{it}\gamma_C + \mu_{it}$$

where the vector of occupational attributes includes exposure to dust, D_{it}; a dummy variable indicating farming occupation, F_{it}; a dummy variable indicating pork producer, P_{it}; a dummy variable indicating confinement operation, C_{it}; and a vector of confinement intensity measures, X_{it} including a constant, years of confinement operation, and usual hours spent per week in the confinement operation. Because all confinement operators in the data set are pork producers and all pork producers are farmers, this specification leads directly to tests of health outcomes between confinement operators relative to other pork producers, pork producers relative to other farmers, and farmers relative to nonfarmers. For farmers, the health outcome for the average farmer (F) relative to a nonfarmer (N) with identical human capital attributes is[2]

$$\textbf{(3)} \qquad \bar{h}_F - \bar{h}_N = (\bar{D}_t^F - \bar{D}_t^N)\gamma_D + \gamma_F + \bar{P}_t^F\gamma_P + \bar{P}_t^F\bar{C}_t^P\bar{X}_t^C\gamma_C$$

where $\bar{D}_t^F$ is average hours of dust exposure in farm operations, $\bar{D}_t^N$ is average dust exposure among nonfarmers, $\bar{P}_t^F$ is the proportion of farmers with pork operations, $\bar{C}_t^P$ is the proportion of pork operators with confinement operations, and $\bar{X}_t^C$ is the average intensity of exposure to confinement operation activities conditional on having a confinement operation.

Health effects for pork producers (P) differ from other farmers with identical human capital attributes according to

$$\textbf{(4)} \qquad \bar{h}_P - \bar{h}_F = (\bar{D}_t^P - \bar{D}_t^F)\,\gamma_D + \gamma_P + \bar{C}_t^P\,\bar{X}_t^C\,\gamma_C$$

where $\bar{D}_t^P$ is average dust level in pork production and the other variables are defined as before.

Confinement operator (C) health effects differ from those of other pork producers with identical human capital attributes according to

$$\textbf{(5)} \qquad \bar{h}_C - \bar{h}_P = (\bar{D}_t^C - \bar{D}_t^P)\,\gamma_D + \bar{X}_t^C\,\gamma_C$$

The estimated marginal occupational health effects defined by equations (3)-(5) are linear in the parameters and subject to standard linear significance tests or likelihood ratio tests.

However, differences in health outcomes between the k^{th} and j^{th} occupations are most easily interpreted in percentages rather than levels because the units are not comparable across health outcomes.[3] The percentage measures make it easier to interpret relative magnitudes of occupational health effects across indicators. For ordinary least squares estimates, percentage differences in health outcomes between the k^{th} and j^{th} occupations are reported as

$$\textbf{(6)} \qquad \frac{h_k(\bar{H},\ \bar{O}_k) - h_j(\bar{H},\ \bar{O}_j)}{h_j(\bar{H},\ \bar{O}_j)} \times 100$$

where the $\bar{h}_k$ and $\bar{h}_j$ are predicted health outcomes for individuals in occupations k and j with identical human capital attributes, $\bar{H}$, but different occupational attributes.

For the probit and ordered probit specifications, the percentage differences in health outcomes are reported as

$$\textbf{(7)} \qquad \frac{F(\bar{H},\ \bar{O}_k) - F(\bar{H},\ \bar{O}_j)}{F(\bar{H},\ \bar{O}_j)} \times 100$$

where F(·) is the cumulative normal distribution function evaluate at the sample means for H and the occupation-specific means of O.

In the tables that follow, the occupational health effects are reported in percentage form using (6)-(7), but the reported significance tests are from the linear estimates using equations (3)-(5).

As already indicated, these results are subject to self-selection bias. Individuals with large health endowments may be more willing to enter occupations with health risks. As a consequence, cross-sectional analysis will understate the true health consequences of risky occupations. A standard correction is to first difference the data to eliminate the health endowment effect, provided longitudinal data on health outcomes are available.

Suppose that the individual-specific health component, μ_t, can be decomposed into a time-invariant effect, and a random error term so that $\mu_{it} = \bar{\mu}_i + \xi_{it}$. The first term, $\bar{\mu}_i$, is an individual's health endowment from birth, and the second term, ξ_{it} is a random error uncorrelated with the regressors in (2). First differencing health outcomes between years t and t+1 the result is,

(8) $$h_{it+1} - h_{it} = (V_{it+1} - V_{it})\ \gamma + (\xi_{it-1} - \xi_{it})$$

where V_{it} is the vector of human capital and occupational variables for individual i at time t and γ is the vector of parameters, $(\gamma_N, \gamma_D, \gamma_F, \gamma_P, \gamma_C)'$. First differencing eliminates the individual fixed effect from the regression. In addition, most of these variables (smoking, sex, height, weight and occupation) do not change over time, so the only components in V_{it+1} - V_{it} are changes in age and length of time in confinement. Therefore, the empirical formulation for (8) is

(9) $$(h_{it+1} - h_{it}) = (\Delta \text{ Age})\ \gamma_A + (\Delta \text{ Confinement Yrs.})\ \gamma_C + (\xi_{it+1} - \xi_{it}).$$

In the specification reported, separate constants are allowed for farm and pork production to check for differential health growth rates across occupations.

III. Results

Tables 1-4 report the results of the health production functions. As already discussed, bivariate or ordered probit analysis was used to explain discretely measured health outcomes, whereas continuous measures of health outcomes were analyzed by using ordinary least squares. The human capital effects including smoking, age, gender, height, and weight are included to establish a population norm against which farmer health can be assessed. The estimated marginal impacts of farming, pork production, and confinement pork production on health indicators from equations (3)-(7) are reported at the bottom of each table. Although the human capital and occupational parameters are reported for completeness, the discussion will concentrate on these estimated marginal health effects.

a) Hearing

Analysis of subjective and objective measures of hearing are reported in Table 1. Farmers do not perceive that they have hearing problems. Indeed, they are significantly less likely than nonfarmers to report problems with tinnitus (ringing in the ear), temporary hearing loss, or headache symptoms that might indicate hearing problems. However, the objective measures of hearing do reveal significant occupational damage to hearing for farmers. Farmers were 186% or almost three times more likely to have hearing in the left ear diagnosed as abnormal at high frequencies. The marginal probability of high-frequency hearing loss in the right ear was even greater. Similar marginal probabilities were estimated at low frequencies (not reported). Farmers were nearly four times more likely to be diagnosed as sufficiently hearing impaired to be referred to a hearing specialist as compared with nonfarmers with the same human capital attributes. The hearing loss seems to be related to farming generally, not to pork production specifically. This suggests that the hearing loss is associated with factors that are common among farmers, such as grain production or the use of noisy machinery, and not factors specifically associated with livestock production. None of the objective marginal hearing health effects for pig farmers or confinement operators (equations (4)-(5)) were significant. The contrast between subjective and objective outcomes is interesting, suggesting that farmers are unaware of the effects of farming on their own hearing or, at least, believe that the hearing loss is not large enough to merit mentioning as a problem.

b) Hand Strength

The first three columns of Table 2 present the results of hand strength tests. The hand strength measures were coded in quartiles with the highest quartile representing the top 25% in the population. Farmer hand strength lagged behind nonfarmers by 10.5%, and pig farmers had even greater incidence of weakened dominant hand strength. The loss of strength in the dominant hand suggests only that the loss of strength is associated with use on the job and not to illness or exposure to hazards. As a consequence, farmers were 11 times more likely than nonfarmers with the same human capital attributes to be diagnosed as needing additional tests. Pig farmers were 4.5% more likely to be referred for additional tests than were other farmers, with some evidence of an even higher probability of referrals for confinement operators. Loss of hand strength associated with farming occurs even though farming might have been viewed as more physically demanding and populated by relatively strong individuals. The root cause for the lessened hand strength would require additional research, but carpal tunnel syndrome or other injuries associated with repeated movements would be likely candidates for this occupational injury. Farmers may also be more exposed to debilitating hand injuries than nonfarmers.

c) Blood Pressure

The last two columns of Table 2 present the analysis of blood pressure tests. Here, the story for farming is better. Farmers have lower blood pressure, other things equal, although the effect is relatively small. Systolic blood pressure is 2% lower, and diastolic blood pressure is 3.8% lower for farmers than for nonfarmers with the same age, gender, stature, and smoking habits. These differences in blood pressure are not large enough to draw any major conclusion, although it does seem that farmers benefit from their active occupation relative to more sedentary work. The pig farm effect or confinement effect was not significantly different from the farm effect. Farmers in general had better blood pressure readings.

d) Respiratory Health

Tables 3 and 4 report results of the subjective and objective assessments of respiratory health. The subjective measures include questions regarding recurrent congestion, sore throat, or flu-like symptoms. In addition, farmers were asked if exposure to the hog operation after a period of absence resulted in heightened symptoms or if family members were adversely affected by exposure to the operation. Farmers were more than twice as likely as nonfarmers to report recurrent coughs and flu symptoms. Pig farmers were more likely than other farmers to report all six symptoms, significantly more likely for coughs, sinus and throat irritation, and family symptoms. Confinement operators had symptoms similar to those of other pork producers except for the last two columns. Confinement operators after a two day absence from work, and their families reported significantly more symptoms than other pig farmers.

The subjective assessments can be viewed as nagging problems, which may make life less pleasant. It is not clear if recurrent sinus, throat, or flu symptoms will result in permanent disability. The issue of chronic pulmonary problems is addressed in Table 4 Two objective measures of lung capacity were taken at the Pork Expo, forced vital capacity (FVC) and forced expiratory volume (FEV). Despite the higher incidence of reported symptoms associated with farming and pork production, there is no evidence of reduced lung capacity that might signal permanent disabling occupational disease. Indeed, pork production and confinement operations were associated with marginally greater lung capacity. When compared with population norms for individuals of the same gender, age, and stature, pork producers had lung capacity within the normal ranges.

It is possible that the lack of an adverse effect of pork production on lung capacity is due to self-selection into the pork industry. Those with asthma or other predisposition to respiratory problems do not go into pork production, so pork producers have disproportionately large lung capacity when they enter the industry. Therefore, even if pork production is associated with diminishing respiratory function over time, the adverse effect may be masked in cross sections. The effect is similar to that of smoking in Table 4. Smoking is associated with significantly greater lung capacity in the sample, even though it is known that smoking reduces lung capacity over time. As other studies have shown[4], smokers tend to have atypically large lung capacity in the early years of smoking because asthmatics, allergy sufferers, and others with poor respiratory health endowments never smoke. The true adverse effect of smoking on respiratory health is evident only in longitudinal data for which the respiratory health endowment can be first differenced away.

There were lung capacity observations from two different years for 132 individuals. Using equation (9), the individual health fixed effect was differenced away, and observations were made on how confinement operations affect the change in lung capacity over time. As the results in the last two columns of Table 4 show, pig farmers and confinement operators have reduced lung capacity from continuous exposure, but the coefficients are very small and not significant. These results support the conclusions based on the cross-sectional data that pork production does not seem to reduce pulmonary function for Pork Expo attendees.

The contrast between the adverse subjective health outcomes associated with pork production reported in Table 3 and the neutral objective effects reported in Table 4 merits several additional comments. First, the subjective health results suggest that pork production is associated with significant disamenities to the producer and the family. Even if the health outcomes are not permanently disabling, they may be sufficiently irritating to dissuade some farmers from entering pork production. Therefore, pork production may be associated with a permanent positive profit differential to compensate operators and their families for the increased temporary health symptoms suffered as a consequence of pork production. Between 1986 and 1995, the 10-year return on investment was 10.8% for hog production as compared with 7.1% for beef feeding, 9.5% for dairy, and 7.4% for grain production (Iowa Farm Costs and Returns). Although there may be multiple factors involved in these differences, these results suggest that positive return differentials exist between pork production and other farm enterprises.

Additionally, pig production systems can have differing levels of gases and dust, resulting in different levels of worker health impacts. This would suggest the potential for employee trade-offs between salary and environment, gas, and/or dust levels in pig production facilities.

The second point is that the objective measures may be taken over too short a period to capture permanent reductions in pulmonary function. These temporary symptoms in Table 3 may signal more permanent disability if damage to lung capacity becomes known only after years of exposure to environmental contaminants associated with pork production. Most of the longitudinal observations are one or two years apart, which may be too short a period to observe significant adverse pulmonary effects. Additionally, those severely impacted may no longer be attending the Pork Expo. If exposure over several years or even decades is necessary for permanent health effects to occur, then a much longer-term investigation of pulmonary function is required.

Conclusions

Analysis of health outcomes for attendees at the World Pork Expo corroborate the findings of Donham et al. (1995) and Iverson et al. (1988) regarding increased incidence of self-reported respiratory illnesses for pork producers. We also found partial support for Donham's (1995) finding that producers with confinement operations were more likely than other pork producers to report health symptoms, although there was no significantly increased incidence reported for flu, sore throat, sinus problems, or cough for confinement operators in our sample. Objective measures of respiratory function did not reveal permanent loss of pulmonary function associated with pork production. Additional analysis shows that farmers suffer three to four times greater incidence of hearing loss, although they seem unaware of their auditory problems. Farmers also had 11 times greater incidence of weakened hand strength. On the plus side, farmers had small but significant health advantages in blood pressure.

Farming has been singled out as an atypically dangerous occupation in terms of the job related risk of injury or death. This study points out several areas in which farmers may also face increased incidence of occupational disability. To the extent that farmers are not perfectly insured against these risks, compensating differentials (in the form of higher profits for operators or higher wages for employees) will be required for the riskier production types. A study by Hurley, Kliebenstein and Orazem (1996) showed that workers in the pork industry do receive added compensation in return for exposure to more dangerous work environments. Whether acceptance of these occupational hazards is rewarded by higher profits and/or wages in other settings is an important area for future work.

Footnotes

[1]Studies have examined how type of operation affects objective measures of animal health. Donham (1991) related air quality (dust, ammonia, bacteria, and fungi) and measures of feed efficiency and weight gain. Boessen et al. (1988) related facility type to lung lesions and turbinate damage. To our knowledge, similar analyses of objective health outcomes on a large population of humans have not been published.

[2]For these and all subsequent simulated health outcomes, the vector H is set at sample means, and occupational variables are measured at sample means for that occupation.

[3]For example, health outcomes are measured in blood pressure for one indicator, fluid volume in another, and probability of abnormal hearing in a third.

[4]See, for example, Miller 1986.

References

Boessen, C., J. Kliebenstein, R. Cowart, K. Moore, and C. Burbee. "Determination of Swine Pneumonia and Impacts on Production Costs Through Slaughter Checks," Staff Paper No. 190, Economics Department, Iowa State University, June 1988.

Donham, K.J. "The Effects of Environmental Conditions Inside Swine Housing on Worker and Pig Health," Australian Pig Science Association, Canberra, Nov. 26-29, 1995.

Donham, K.J., and K.E. Gustafson. "Human Occupational Hazards from Swine Confinement." *Ann. Am. Conf. Gov. Ind. Hyg.* 2(1982):137-142.

Donham, K.J., P. Haglind, Y. Peterson, R. Rylander, and L. Belin. "Environmental and Health Studies of Farm Workers in Swedish Swine Confinement Buildings." *Br. J. Ind. Med.* 46(1989):31-37.

Donham, K.J., S.J. Reynolds, P. Whitten, J.A. Merchant, L.F. Burmeister, and W.J. Popendorf. "Respiratory dysfunction in swine production workers: dose-response relationship of environmental exposures and pulmonary function." *Am. J. Ind. Med.* 27(1995):405-418.

Donham, K.J., M.J. Rubino, T.D. Thedell, and J. Kammermeyer. "Potential Health Hazards of Workers in Swine Confinement Buildings." *J. Occup. Med.* 27(1977):383-387.

Holness, D.L., E.L. O'Glenis, A. Sass-Kortsak, C. Pilger, and J. Nethercott. "Respiratory Effects and Dust Exposures in Hog Confinement Farming." *Am. J. Ind. Med.* 11(1987):571-580.

Hurley, T.M., J.B. Kliebenstein, and P.F. Orazem. "The Structure of Wages and Benefits in the U.S. Pork Industry," Iowa State University, mimeo, October 1996.

Iowa Farm Costs and Returns - 1995, Iowa Coop. Ext. Serv. (Publ.) FM-1789, 1996.

Iverson, M., R. Dahl, J. Korsgaard, T. Hallas, and E. Jensen. "Respiratory Symptoms in Danish Farmers: An Epidemiological Study of Risk Factors," *Thorax* 48(1988):872-877.

Miller, A. "Spirometry and Maximum Expiratory Flow-Volume Curves," in A. Miller, ed., *Pulmonary Function Tests in Clinical and Occupational Lung Disease*. Orlando, FL: Grune and Stratton, Inc., 1986, pp. .

Reynolds, S.J., K.J. Donham, P. Whitten, and J.A. Merchant. "A Longitudinal Evaluation of Dose-Response Relationships for Environmental Exposures and Pulmonary Function in Swine Production Workers." *Am. J. Ind. Med.* 29(1996):33-40.

Von Essen, Susanna. "Human Health and the Swine Confinement Environment," University of Nebraska Medical Center, Omaha, Nebraska, 1996.

Table 1: Probit Analysis of Subjective and Objective Measures of Hearing

	Subjective			Objective		
	Tinnitus	Hearing loss	Headaches	Left ear abnormal	Right ear abnormal	Hearing impaired
Smoker	0.06999 (1.75*)	0.07756 (3.68***)	-0.00883 (0.22)	-0.27315 (7.52***)	-0.21378 (6.11***)	-0.10286 (2.02**)
Age	-0.00590 (3.31**)	0.00133 (1.32)	-0.00359 (2.04**)	0.01349 (9.53***)	0.01398 (9.95***)	0.02039 (9.93***)
Male	0.09438 (1.63)	0.02208 (0.63)	-0.17897 (3.39***)	0.26148 (5.27***)	0.19004 (3.95***)	0.29043 (4.56***)
Height	0.00158 (0.20)	0.00002 (0.01)	0.00786 (1.08)	-0.00262 (0.42)	-0.00079 (0.13)	-0.00056 (0.07)
Weight	-0.00002 (0.03)	-0.00016 (0.46)	-0.00074 (1.26)	0.00038 (0.75)	0.00087 (1.77*)	0.00024 (0.35)
Farmer	-0.65459 (3.07**)	-0.19629 (1.57)	-0.83066 (4.60***)	0.29881 (3.96***)	0.28617 (3.75***)	0.43888 (4.68***)
Pig farmer	-0.07518 (1.04)	-0.01994 (0.52)	0.09396 (1.34)	-0.05402 (0.96)	-0.04221 (0.74)	0.03277 (0.44)
Dust exposure (hrs.)	0.00427 (2.24**)	0.00084 (0.88)	0.00382 (2.28**)	0.00023 (0.16)	0.00056 (0.39)	-0.00023 (0.12)
Confinement	0.00487 (0.07)	-0.05275 (1.35)	-0.15535 (2.44**)	-0.06162 (1.06)	-0.03144 (0.55)	0.05394 (0.67)
Years of confinement	0.00661 (2.10**)	0.00240 (1.33)	0.00284 (0.91)	0.00390 (1.46)	0.00101 (0.39)	-0.00175 (0.47)
Hours/week confinement	-0.00097 (0.75)	0.00040 (0.53)	0.00165 (1.36)	0.00025 (0.23)	0.00160 (1.50)	-0.00031 (0.21)
Constant	0.76377 (1.43)	-0.04743 (0.16)	0.43013 (0.87)	-0.99329 (2.42**)	-1.21340 (3.03***)	-1.45520 (2.64***)
N	775	647	768	1075	1049	784
R^2						
X^2/F	51.45**	27.3**	98.18**	267.16**	244.57**	242.4**
Farm effect	-41.5 (17.1**)	-87.0 (3.21*)	-73.2 (47.5*)	185.95 (18.8**)	223.9 (19.6**)	279.6 (48.9**)
Pig farm effect	-.33 (.17)	-3.75 (.49)	1.59 (.39)	-1.97 (1.18)	-1.08 (.39)	.85 (.52)
Confinement effect	3.94 (2.66)	-5.26 (.21)	-8.52 (4.57**)	-.68 (.00)	1.71 (.18)	1.26 (.22)

t-statistics in parentheses. * indicates significance at the 10% level. ** indicates significance at the 5% level.

Table 2: Analysis of the Determinants of Hand Strength and Blood Pressure

	Dynameter			Blood pressure	
	Dominant[a] hand	Nondominant[a] hand	Hand[b] recheck	Systolic[c]	Diastolic[c]
Smoker	-0.15819 (0.88)	-0.30542 (1.60)	0.04187 (0.77)	-0.703 (0.76)	-2.174 (3.28**)
Age	0.00665 (1.44)	0.00603 (1.25)	0.00371 (2.98**)	0.183 (4.93**)	0.080 (2.99**)
Male	-1.17840 (8.35**)	-0.95935 (6.76**)	-0.00549 (0.13)	8.698 (6.74**)	2.570 (2.78**)
Height	0.15085 (7.57**)	0.12705 (6.32**)	-0.01985 (3.24**)	-0.694 (4.04**)	-0.330 (2.67**)
Weight	0.00295 (1.69*)	0.00350 (2.00**)	0.00080 (1.66*)	0.144 (10.44**)	0.096 (9.67**)
Farmer	-0.25248 (0.83)	ne[b]	0.22327 (2.71**)	-2.628 (1.39)	-2.761 (2.04**)
Pig farmer	-0.37741 (2.13**)	-0.19772 (1.08)	0.02764 (0.55)	0.462 (0.30)	0.102 (0.09)
Dust exposure (hrs.)	0.00810 (1.41)	0.00567 (0.98)	0.00109 (0.74)	0.037 (0.88)	0.028 (0.93)
Confinement	-0.11338 (0.55)	-0.19091 (0.96)	0.09279 (1.77*)	-0.452 (0.29)	-2.287 (2.02**)
Years of confinement	0.01041 (1.06)	0.01473 (1.56)	-0.00359 (1.49)	-0.103 (1.40)	0.076 (1.41)
Hours/week confinement	-0.00142 (0.40)	-0.00082 (0.22)	0.00073 (0.76)	0.057 (1.84*)	0.042 (1.89*)
Constant	-8.72020 (6.60**)	-7.62980 (5.92**)	0.56288 (1.43)	133.77 (12.01**)	77.73 (9.71**)
N	520	483	678	1136	1132
R^2				.20	.14
X^2/F	100.7**	70.12**	49.27	247.0**	168.6**
Farm effect	-10.5 (7.37**)	0[d]	1011.64 (19.23**)	-2.01 (3.27*)	-3.76 (8.09**)
Pig farm effect	-1.04 (4.44**)	-.53 (1.30)	4.59 (1.86)	0.01 (.00)	-0.02 (.03)
Confinement effect	0.00 (.00)	-.11 (.01)	12.05 (3.15*)	-0.12 (.42)	-.16 (.38)

t-statistics in parentheses. * indicates significance at the 10% level. ** indicates significance at the 5% level.
[a]Ordered Probit. [b]Probit. [c]Ordinary least squares. [d]Coefficient constrained to zero.

Table 3: Probit Analysis of the Determinants of Subjective Respiratory Health

	Cough/ phlegm	Sinus problems	Sore throat	Flu symptoms	Absence effect	Family affected
Smoker	0.05974 (1.71*)	0.18631 (5.09***)	0.16666 (4.97***)	0.06112 (1.92*)	0.06520 (2.52**)	0.04021 (1.16)
Age	-0.00221 (1.43)	-0.00384 (2.31**)	-0.00128 (0.86)	-0.00212 (1.47)	-0.00292 (2.44**)	-0.00426 (2.74***)
Male	0.03484 (0.70)	-0.06352 (1.17)	-0.08418 (1.75*)	0.03063 (0.64)	-0.05659 (1.50)	-0.15508 (3.15***)
Height	0.00066 (0.10)	-0.00661 (0.90)	-0.00738 (1.13)	0.00180 (0.29)	-0.00643 (1.27)	-0.00018 (0.03)
Weight	0.00022 (0.43)	0.00064 (1.14)	0.00026 (0.51)	0.00034 (0.69)	0.00023 (0.59)	-0.00106 (2.00**)
Farmer	0.09868 (0.76)	0[a]	-0.01466 (0.13)	0.11390 (1.10)	-0.00318 (0.04)	0.38888 (2.24**)
Pig farmer	0.11183 (1.69*)	0.24547 (3.19***)	0.12393 (1.99**)	0.05530 (0.93)	-0.04092 (0.84)	0.13560 (2.01**)
Dust exposure (hrs.)	0.00119 (0.77)	0.00299 (1.81*)	0.00317 (2.09**)	0.00409 (2.93***)	0.00202 (1.79*)	0.00316 (2.08**)
Confinement	-0.04126 (0.72)	-0.02727 (0.45)	-0.06587 (1.16)	-0.08758 (1.60)	-0.01064 (0.23)	-0.00866 (0.15)
Years of confinement	0.00457 (1.68*)	-0.00012 (0.04)	0.00338 (1.25)	0.00630 (2.48**)	0.00430 (2.10**)	0.00894 (3.30***)
Hours/week confinement	-0.00006 (0.06)	0.00072 (0.61)	-0.00014 (-.13)	0.00190 (1.84*)	0.00153 (1.86*)	0.00111 (1.03)
Constant	-0.43670 (1.01)	0.07218 (0.15)	0.23198 (0.53)	-0.54151 (1.30)	0.28122 (0.85)	-0.26594 (0.59)
N	901	793	895	1023	976	1047
R^2						
X^2/F	19.99**	55.27**	43.70**	39.07**	33.37**	86.49**
Farm effect	130.9 (3.59*)	[b]	38.6 (.76)	113.8 (4.65**)	[b]	[b]
Pig farm effect	4.20 (4.11**)	8.35 (11.81**)	4.17 (3.59*)	3.03 (2.20)	1.09 (.11)	7.01 (13.65**)
Confinement effect	1.65 (.22)	-.94 .13	-2.34 (.44)	3.86 (1.10)	15.5 (6.86**)	11.46 (12.55**)

t-statistics in parentheses. * indicates significance at the 10% level. ** indicates significance at the 5% level.
[a]Constrained to zero. [b]Not possible to estimate for lack of nonfarm reference group.

Table 4: Analysis of the Determinants of Objective Respiratory Health

	FEV[a]	FVC[a]	Respiration[b] normal	Change[a] in FEV	Change[a] in FVC
Smoker	0.19374 (4.97***)	0.20530 (4.53***)	-0.01309 (0.43)		
Age	-0.02698 (17.15***)	-0.02702 (14.73***)	-0.00225 (1.91*)	.004 (.066)	-.057 (.732)
Male	0.56187 (10.37***)	0.66921 (10.56***)	-0.03114 (0.70)		
Height	0.10741 (14.75***)	0.14176 (16.71***)	-0.00636 (1.11)		
Weight	0.00063 (1.08)	0.00008 (0.11)	-0.00007 (0.16)		
Farmer	-0.07110 (0.90)	-0.14231 (1.54)	0.08646 (1.46)	.218 (.829)	.416 (1.36)
Pig farmer	0.02373 (0.37)	0.05367 (0.71)	-0.07029 (1.35)	-.004 (.016)	-.185 (.591)
Dust exposure (hrs.)	-0.00047 (0.26)	0.00100 (0.48)	-0.00066 (0.49)		
Confinement	-0.01557 (0.24)	0.00132 (0.02)	0.00102 (0.02)		
Years of confinement	0.00583 (1.87*)	0.00570 (1.57)	0.00298 (1.25)	-.011 (.072)	-.004 (.024)
Hours/week confinement	-0.00022 (0.17)	0.00030 (0.19)	-0.00017 (0.16)		
Constant	-3.09370 (6.56***)	-4.66040 (8.48***)	0.77845 (2.12**)		
N	1104	1116	786	130	132
R^2	.60	.61		0.00	0.005
X^2/F	1004.43**	1040.89**	12.39	.79	.68
Farm effect	-.41 (.10)	-.92 (.48)	6.15 (1.16)		
Pig farm effect	.16 (1.13)	.25 (2.53)	-.55 (.88)		
Confinement effect	.42 (1.75)	.53 (2.77*)	1.20 (1.30)		

t-statistics in parentheses. * indicates significance at the 10% level. ** indicates significance at the 5% level.
[a]Ordinary least squares. [b]Probit.