An Economic Evaluation of Livestock Odor Regulation Distances

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ABSTRACT

Setback regulations—legislated distances that livestock production facilities must be removed from surrounding properties—are meant to mitigate odor impacts. If the setback length is too short, then there is evidence that surrounding properties and people suffer uncompensated damages. If, on the other hand, setback lengths are too long, then livestock producers may be paying more than that required to compensate for odor-related environmental damages. The purpose of this study is to assess the impact of Kentucky's livestock production facility setbacks on the value of surrounding properties and farm financial management decisions. This paper develops a model of the benefits of livestock odor reduction and the livestock odor abatement cost associated with setback lengths paid by producers. The results of this investigation indicate that the mandated setback lengths for Kentucky are too short. Livestock production firms are worse off under longer setback lengths, but the losses to surrounding home owners far exceed the firm gains at the mandated setbacks. A finding of this study is that the firm has no incentive to completely protect the legislated setback length. Livestock producers in compliance with the relevant setback length may feel protected from odor lawsuits despite damage being done to surrounding property. This suggests that the perceived threat of lawsuit is currently low in the state of Kentucky. Both industry and public goals could be met from further research including location and economic impact of livestock production.

Odor complaints related to animal production, particularly confined animal feeding operations (CAFOs), have increased dramatically during the past decade. Livestock production facilities, regardless of the waste disposal, feed management, or ventilation system employed produce more than 160 odorous compounds (Funk, 2003). This odor can impact the health, economic status, and personal security of persons who live or work near production sites as well as environmental quality (Hoag and Roka, 1995; Roka and Hoag, 1996; Letson and Gollehon, 1996; Hurley et al., 1996).

Recent studies have attempted to measure the economic impact of livestock odors (specifically swine) on the environment by measuring the change in value of surrounding properties. For example, Abeles-Allison and Connor (1990) found that the addition of 1000 head of hogs (*Sus scrofa*) reduced surrounding property values by as much as $430 depending on the size of the production facility and the distance the property is located from the production facility. Similarly, Palmquist et al. (1997) showed that the value of a house 804.7 m (0.5 miles) from a 2400 head finishing facility was reduced by as much as 5% while that same house located 3218.7 m (2 miles) away could experience a reduction of nearly 0.6%. Ready and Abdalla (2003) showed that odor reduced surrounding home values nearly 7% at 500 m, but that odor had no impact at 1600 m. If property values reflect the amenity value of the surrounding environment, then odors arising from livestock production facilities have a deleterious impact on the environment. Although livestock are a valuable commodity (the per-capita consumption of meat products has remained strong since 1960; Purcell, 2002), finding a solution that satisfies all parties concerned is not as simple as some land owners have suggested—a blanket prohibition of livestock production.

If prohibition of livestock production is not feasible, then the next step is to find ways to minimize the impact of odor-related damages. Setback regulations—legislated distances (measured in feet in the USA) that new production facilities must be removed from surrounding private or public properties—are meant to mitigate odor impacts. Such legislation is based on the "polluter pays" principal where the cost of environmental damage is the responsibility of those who pollute (Randall, 1999). For example, when the setback laws for Kentucky were first proposed, producers were required to own or long-term lease land within the prescribed setback length for production facilities. The impact of this requirement would have increased the cost of production and potentially reduced output. In a perfect world, the level of output attained by setback regulations would be the social optimal (i.e., odor externalities would be internalized by the livestock production).

The science of odor evaluation is subjective because many facets (e.g., character, acceptability, intensity, hedonic tone, and so forth) can only be quantified by a subjective instrument (the human nose). This subjectivity leads to a good deal of complication when it comes to selecting appropriate odor criteria. The traditional atmospheric (odor) dispersion models and modeling guidance were originally developed to assess specific compound concentration effects; assessing the effects of odors, however, requires significant differences in approach. The implications of these differences make odor dispersion models less powerful in policy evaluation. In the absence of an odor dispersion model, this study uses a livestock odor damage function estimated by Ready and Abdalla (2003).

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Published in J. Environ. Qual. 33:1997–2006 (2004).

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Abbreviations: AEU, animal equivalent units; BMP, best management practice; CAFO, confined animal feeding operation; FOC, first order conditions; GAMS, General Algebraic Modeling System; KFBM, Kentucky Farm Business Management; NREPC, Natural Resources and Environmental Protection Cabinet; SOC, second order conditions. (See the Appendix for a list of other symbols or abbreviations with their definitions and units.)

The purpose of this study is to measure "more efficient" setback lengths using economic modeling of setback acquisition cost and property damage reduction to assess the economic impact of Kentucky's livestock production facility setbacks on the value of surrounding properties and farm financial management decisions. If the setback length is too short, then there is evidence that surrounding properties and people suffer uncompensated damages. If, on the other hand, setback lengths are too large, then livestock producers may be paying more than that required to compensate for odor-related environmental damages.

BACKGROUND AND EMPIRICAL SETTING

In August 1997, Kentucky Governor Paul Patton imposed a 90-d moratorium on the issuance of permits for the construction of new livestock production facilities. The governor imposed this moratorium largely in response to public concerns surrounding proposed investment in western Kentucky by two large, integrated swine production companies. A major concern was that current regulation was not sufficient to protect people and property from the harmful effects of livestock odors.

To address odor-related concerns, Kentucky's Natural Resources and Environmental Protection Cabinet (NREPC) mandated a number of setback requirements for livestock operations. Specifically targeted were production facilities with one-time site capacity >190 512 kg (420 000 pounds) live weight (e.g., approximately 1000 animal equivalent units; AEUs). The current legislation (Kentucky Administrative Regulation 5:009E, 1998) stipulates setback lengths for both livestock production facilities and livestock manure application areas. Table 1 reports setback lengths for livestock production facilities (i.e., barns and manure storage).

Because this article is concerned only with odor-related damages arising from livestock production facilities, our focus is the 457.2- and 914.4-m (1500- and 3000-ft) setback lengths for barns and manure storage (e.g., lagoons). Specifically, dwellings not owned by the applicant plus churches, schools, businesses, and other structures to which the general public has access including parks must be 457.2 m (1500 ft) from production facilities. This setback length applies to features not in an incorporated city. If the nearest feature is within an incorporated city limit, then production facilities must be setback 914.4 m (3000 ft). Kentucky livestock producers, as is the case in most states, simply have to show that production facilities are the required distance from the setback feature.

THEORETICAL MODEL OF ODOR SETBACK LENGTH

One purpose regulators cite for drafting and implementing setback legislation from livestock production facilities is to protect homeowners from odor-related impacts. Complying with setback lengths imposes additional cost to producers; thus, a profit maximizing producer will attempt to minimize this cost. But when minimizing cost, producers must also decide if they should protect themselves from construction of future homes within the setback area. Most setback regulations require that newly constructed livestock production facilities locate themselves the specified distance from existing structures. But these laws do not prevent the public from building new homes within the setback area. In some states, right to farm (or first in time, first in right) laws are in place. But in Kentucky, for example, these new home owners can sue (and have successfully sued) for odor damages. The possibility of future lawsuits and associated fines represent a real cost that must be included in the producer's (the firm's) cost function.

Producers have many decisions to make when siting a new facility. One of the major decisions centers on land ownership. In our analysis of the setback regulations, producers are left with four distinct choices: (i) own all of the land required by the setback provision, (ii) rent/lease the necessary land to meet the provision, (iii) take on the risk of encroachment and the subsequent lawsuits/fines/fees, or (iv) adopt odor-controlling technologies to reduce the likelihood of fines and reduce the size of the protected setback zone. The protected area (r_P) is represented by a fee simple ownership of land area and/or a long-term lease/rental agreement. The nonprotected area (r_{NP}) is the length where the owner chooses not to prevent encroachment into his/her setback area by future property owners. The total setback length (r_T) is defined as the protected setback length (r_P) + the nonprotected setback length (r_{NP}) as denoted in Eq. [1].

$$r_T = r_P + r_{NP} \quad [1]$$

To maximize social surplus, regulators should set the setback length (r_T) where the marginal benefits of odor reduction (MB_O) equal the marginal cost of odor reduction (MC_O). This solution is achieved by maximizing the net benefits of odor reduction (NB_O), defined as the

Table 1. Kentucky setback lengths from swine-production sites.†

Existing setback feature	Barns and lagoons
	m
Dwelling not owned by applicant, church, school and school yard, business, other structure to which the general public has access	**457.2**
Incorporated city limits	**914.4**
Lake, river, blue-line stream, karst feature	**45.7**
Water well not owned by applicant	**91.4**
Property line	**228.6**
Downstream water listed as other than use protected, outstanding resource water	**1609.3**
Downstream public water supply surface water intake	**8046.5**

† Kentucky Administrative Regulation 401 KAR 5:009E page 10 (water.nr.state.ky.us/dow/5-009.htm).

difference between the total benefits of odor reduction (TB_O) and the total costs of odor (TC_O). The total benefits of odor reduction (TB_O) and TC_O, thus NB_O, are assumed to be continuous and twice differentiable. Furthermore, to guarantee a maximum, TB_O must increase at a decreasing rate and TC_O must increase at an increasing rate. In Eq. [2], Z_B and Z_C represent the exogenous factors of benefit and cost, respectively.

$$\text{Max } NB_{O_{[rT]}} (r_T; Z_B, Z_C) = TB_O (r_T; Z_B) - TC_O (r_T; Z_C)$$

$$\text{where} \quad \frac{\partial TB_O}{\partial r_T} > 0; \frac{\partial^2 TB_O}{\partial r_T^2} = \frac{\partial MB_O}{\partial r_T} < 0$$

$$\frac{\partial TC_O}{\partial r_T} > 0; \frac{\partial^2 TC_O}{\partial r_T^2} = \frac{\partial MC_O}{\partial r_T} < 0 \quad [2]$$

Differentiation of NB_O by r_T yields the first-order conditions (FOCs) in Eq. [3]. The marginal benefits of odor reduction, MB_O, is a continuous, twice-differentiable function that decreases as r_T increases. The marginal costs of odor reduction, MC_O, is also continuous and twice-differentiable, but MC_O is an increasing function of r_T. The total setback length, r_T, is optimal assuming that second-order conditions (SOCs) for a maximum hold.

$$\frac{\partial NB_O (r_T; Z_B Z_C)}{\partial r_T} = \frac{\partial TB_O (r_T; Z_B)}{\partial r_T} - \frac{\partial TC_O (r_T; Z_C)}{\partial r_T}$$

$$= MB_O (r_T; Z_B) - MC_O (r_T; Z_C) \overset{\text{SET}}{=} 0 \quad [3]$$

The total costs of odor, TC_O, is composed of two parts. The first part (PC_O) represents the cost of odor reduction associated with protecting the firm from future encroachment by homeowners. The second part (NPC_O) represents the cost of odor reduction if the firm does not protect itself from encroachment, but instead assumes the risk of future lawsuits and/or fines. An increase in either PC_O or NPC_O increases TC_O. The variable PC_O is a continuous, twice differentiable function that increases with the distance that the firm chooses to protect (r_P). It is assumed that the firm will acquire protection over an area adjacent to the production facility. In Eq. [4], Z_P represents the exogenous components associated with protection.

$$TC_O (r_P, r_{NP}; P, Z_P, Z_B) = PC_O (r_P; Z_P) + P\, MB_O (r_P; Z_B)\, r_{NP}$$

$$\text{where } \frac{\partial PC_O}{\partial r_P} > 0 \text{ and } \frac{\partial^2 PC_O}{\partial r_P^2} \lesseqgtr 0$$

$$\frac{\partial MB_O}{\partial r_P} < 0 \text{ by Eq. [2]} \quad [4]$$

The cost of odor reduction due to nonprotection, NPC_O, is also a continuous, twice differentiable function that increases with the distance that the firm chooses not to protect (r_{NP}). Following Harford (1978), NPC_O is composed of two parts, the probability of being fined (P) and the size of the fine (F). Increasing P or F will increase NPC_O. Unlike Harford, to make the problem tractable, P is an exogenous constant. The size of the fine depends on the per-unit cost of damages × the distance over which damages occur. New homes cannot be built any closer than r_P to the firm. Thus, unit damages are defined by the marginal benefit function in Eq. [2]

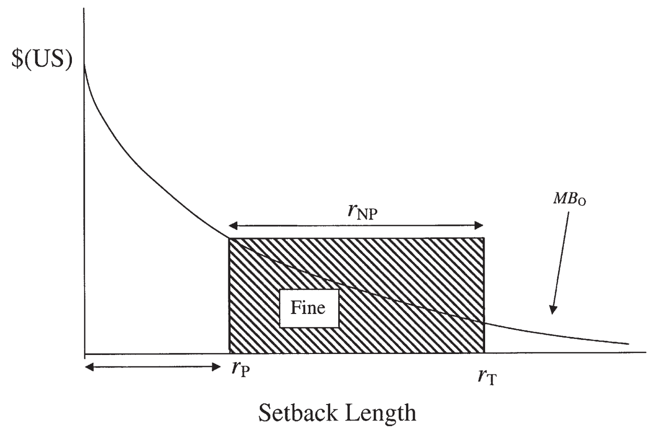

Fig. 1. The fine (F) received for odor damages is equal to the marginal benefit of odor reduction (MB_O) measured at the protected setback length (r_P) times the unprotected setback length (r_{NP}) where r_{NP} is defined as the difference of total setback length (r_T) and r_P.

measured at r_P. The distance over which damages are calculated is defined by r_{NP}. Figure 1 illustrates the derivation of F.

In Eq. [4], because F is defined by MB_O, Z_B represents the exogenous variables associated with total benefits. Equation [1] shows that r_P is a function of r_{NP} and r_T; thus, NPC_O increases at an increasing rate with respect to r_{NP}. Also, as a consequence, TC_O increases at an increasing rate as required by Eq. [2]. The total cost of odor reduction, TC_O, does so with respect to r_{NP}, not r_T, but again r_T depends on r_{NP} (and r_P).

According to theory, the regulator sets r_T^* where MB_O equals MC_O and then the firm sets r_P^* and r_{NP}^* where the marginal cost of protection and the expected marginal cost of nonprotection equal the shadow price of r_T^*. Mathematically, this result is achieved by substituting Eq. [1] and [4] into Eq. [2] and maximizing NB_O with respect to r_T, r_P, r_{NP}, and λ, where λ is the shadow price of r_T.

$$\underset{\{r_T, r_P, r_{NP}, \lambda\}}{\text{Max}} NB_O = TB_O (r_T; Z_B) - [PC_O (r_P; Z_P) + P\, MB_O (r_P; Z_B)\, r_{NP}] + \lambda (r_P + r_{NP} - r_T) \quad [5]$$

The FOCs for Eq. [5] with respect to r_T, r_P, r_{NP}, and λ (in order) are provided below (Eq. [6]–[9]). The second derivatives of Eq. [5] with respect to r_T, r_P, r_{NP}, and λ can be formed into a bordered Hessian matrix H. The elements of the second and third principal minors of H can be defined such that H is negative definite. This result guaranties that NB_O is maximized. The necessary conditions that guarantee that H is negative definite can be obtained from the authors.

$$\frac{\partial NB_O}{\partial r_T} = \frac{\partial TB_O}{\partial r_T} - \lambda = MB_O (r_T) - \lambda \overset{\text{SET}}{=} 0 \quad [6]$$

$$\frac{\partial NB_O}{\partial r_P} = -\left[\frac{\partial PC_O}{\partial r_P} + P \frac{\partial MB_O (r_P)}{\partial r_P} r_{NP}\right] + \lambda \overset{\text{SET}}{=} 0 \quad [7]$$

$$\frac{\partial NB_O}{\partial r_{NP}} = -[P\, MB_O (r_P)] + \lambda \overset{\text{SET}}{=} 0 \quad [8]$$

$$\frac{\partial NB_O}{\partial \lambda} = r_P + r_{NP} - r_T \overset{\text{SET}}{=} 0 \quad [9]$$

Given that Eq. [5] is maximized, then the FOCs of Eq. [5] can be solved to provide two insights concerning the optimal values of r_T, r_P, and r_{NP}. The first insight concerns λ and r_{NP}. Equation [6] indicates that λ is the per-unit price (the shadow price) of odor reduction associated with r_T^*. From Eq. [7], the derivative of λ with respect to r_{NP} indicates that λ is a decreasing function of r_{NP}. Thus, livestock firms will reduce their per-unit costs of odor reduction by making the nonprotected setback lengths as long as economically feasible.

The second insight is derived by solving Eq. [8] for λ, substituting this result into Eq. [6] and solving for P. The ratio of the marginal benefits of odor (MB_O) functions with respect to the total and protected setback lengths (r_T and r_P) will equal P, the exogenous probability of receiving a fine for odor damages. Given that $0 \leq P \leq 1$, the MB_O associated with r_P will exceed the MB_O associated with r_T except when $P = 1$, the point where they are equal. Furthermore, given that the underlying functions for $MB_O(r_P)$ and $MB_O(r_T)$ are the same and have a negative slope, r_T will exceed r_P; thus, r_{NP} will exceed 0. This is true except when $P = 1$. At this point r_T and r_P are equal and r_{NP} is 0. When $P = 0$, $MB_O(r_T)$ equals 0 and r_T is set at its maximum length, r_{NP} is at its maximum length, and r_P is at its shortest length.

AN EMPIRICAL APPLICATION

In this section Eq. [5] is defined for conditions to better understand the firm's choice to protect itself against odor lawsuits. The marginal benefit of odor reduction, MB_O, is based on Ready and Abdalla (2003), who measured the impact of disamenities (including odor) on residential property values in Berks County, Pennsylvania. The Ready and Abdalla (2003) hedonic property price model closely follows that of Palmquist et al. (1997), both of which stem from the seminal work of Rosen (1974).

$$MB_O\,(r_T;Z_B) = -\,112.968\left(\frac{1}{r_T} - \frac{1}{1600}\right) + 25391.44\left(\frac{1}{r_T^2} - \frac{1}{(1600)^2}\right) \quad [10]$$

For an isolated farm, Ready and Abdalla (2003) defined MB_O as Eq. [10]. Here, r_T is the distance from the animal production facility to a house (in meters). Odor impact is calculated for individual homes. There is no aggregation across homes until after the property value impact is calculated for each home. It is important to note that this model is defined only for 500 m $\leq r_T \leq$ 1600 m. Also, as is true in the Palmquist et al. model, there is no relationship between the capacity of the production site (measured in head or animal equivalent units) and odor impact. While, perhaps, unintuitive, this is a consistent result with important policy implications if true.

Because this paper concerns the 457.2- and 914.4-m (1500- and 3000-ft) setback lengths for newly constructed livestock facilities (i.e., barns and manure storage) in Kentucky, the use of Eq. [10] is problematic given that it is defined for 500 m $\leq r_T \leq$ 1600 m. To circumvent this problem, MB_O was estimated for incremental values of r_T from 500 to 1600 m. Regression analysis was then employed to project the MB_O function back to $r_T = 0$. The resulting equation for MB_O is Eq. [11], which is continuous and twice-differentiable with respect to r_T as required by Eq. [2].

$$\begin{aligned} MB_O\,(r_T;Z_B) &= HV_0\,(b_0 - b_1\,r_T + b_3\,r_T^2) \\ &= HV_0\,(0.11806 - 0.00012\,r_T + 0.0000000288\,r_T^2) \end{aligned} \quad [11]$$

Integration of MB_O yields a TB_O function (Eq. [12]) that is continuous, twice differentiable, and increases at a decreasing rate with respect to r_T as required by Eq. [5].

$$TB_O\,(r_T;Z_B) = HV_0\left[b_0\,r_T - \left(\frac{b_1}{2}\right)r_T^2 + \left(\frac{b_3}{3}\right)r_T^3\right] \quad [12]$$

Note that Eq. [11] is defined for 0 m $\leq r_T \leq$ 1600 m. At $r_T = 0$, the value of an individual home is reduced b_0% (here 11.8%), the greatest possible reduction. At r_T = 1600 m, the value of a home is no longer impacted by odor.

In Eq. [11] and [12], the parameter HV_0 represents the average value (in $US) of homes in the area where a producer plans to locate. The parameter HV_0 is exogenous and can assume any positive value. The average value of homes in the area will vary by location and depends on macroeconomic forces (e.g., home values in rural Kansas may be different than home values in rural Kentucky). Using HV_0 this study is able to differentiate between "low" and "high" protection areas. Low protection areas represent rural areas where there are few homes, little demand for housing, and little development pressure; thus, the average value of a home is low. High protection areas represent nonrural areas or rural areas near an incorporated city where development pressures and the demand for housing (thus average home value) are high. In Kentucky, low and high protection areas are protected from animal odors via, respectively, the 457.2- and 914.4-m setback lengths.

Following Fleming (1999) and Fleming et al. (1998), PC_O in Eq. [13] is defined as the \$ ha^{-1} annual land acquisition cost (LAC) times the number of hectares acquired to protect the firm against lawsuits.

$$PC_O\,(r_P;Z_P) = LAC\left(\frac{\pi \cdot r_P^2}{10\,000}\right)(1 + g) \quad [13]$$

Given that land is an asset, LAC is compounded by a rate of asset appreciation ($0 \leq g \leq 1$; here $g = 0.03$; Barry, 1996). The parameter LAC can be any value, but the cash rental rate or annual land payment less returns (on a per-hectare basis) best represent LAC. Following Eq. [6], Eq. [13] is a continuous, twice differentiable function that increases with r_P. Note that r_P is converted to hectares using the standard formula to calculate area and dividing by 10 000 m^2 ha^{-1}.

Again, NPC_O is defined using work by Harford (1978), Viscusi and Zeckhauser (1979), and Keeler (1991). The parameter NPC_O is simply the product of the probability of being fined (P) and MB_O measured in terms of r_P, and r_{NP} (see Eq. [8]). Substituting Eq. [11] into Eq. [8] and substituting r_P from r_T yields Eq. [14].

$$NPC_O = P\,[HV_1\,(b_0 - b_1\,r_P + b_3\,r_P^2)]\,r_{NP} \quad [14]$$

The parameter P represents the firm's rational expectation of being sued for odor damages. The probability of being sued, P, is exogenously determined and can assume any value between 0 and 1. This expectation is reasonably based on the area (high or low protection area) and the average value of the home. However, other factors like neighbor's familiarity with agricultural production practices and social involvement of the firm in the community play a role. The parameter NPC_O is a continuous, twice differentiable function that increases with P and r_{NP} as required by Eq. [7] and [8].

The parameter HV_1 in Eq. [14] is similar to the parameter HV_0 in Eq. [11] in that it represents the average value of homes (in $US). However, in this case HV_1 is the expected value of homes that are expected to move into the unprotected setback area defined by r_{NP}. The parameter HV_1 is exogenous and will vary by location (i.e., according to the type of protection areas). Yet, it is assumed that HV_1 will be equal to or exceed HV_0 because HV_1 represents growth in the local housing market.

Given Eq. [12] to [14], the objective function is redefined as Eq. [15].

$$\begin{aligned}\underset{\{r_T, r_P, r_{NP}, \lambda\}}{\text{Max}}\ NB_O = {} & HV_0\left[b_0\,r_T - \left(\frac{b_1}{2}\right) r_T^2 + \left(\frac{b_3}{3}\right) r_T^3\right] - \\ & \left\{LAC\left(\frac{\pi\,r_P^2}{10\,000}\right)(1 + g) + \right. \quad [15] \\ & \left. P\,[HV_1\,(b_0 - b_1\,r_P + b_3\,r_P^2)]\,r_{NP}\right\} + \\ & \lambda\,(r_P + r_{NP} - r_T)\end{aligned}$$

MODEL DATA

Because Eq. [15] includes a third-degree polynomial and interaction terms of the choice variables, changes in the optimal values of r_T, r_P, and r_{NP} with respect to the exogenous variables HV_0, LAC, P, and HV_1 had to be derived analytically. Using the General Algebraic Modeling System (GAMS) computer program, values of r_T, r_P, and r_{NP} were calculated for sequential values of the exogenous variables.

The parameter HV_0 was assigned four values, two representing the median and high value for housing in rural, low protection areas and two representing the median and high values for housing in more urban, high protection areas. Data from U.S. Census Bureau (2003) was used to determine the values for HV_0 (and HV_1). The top 10 Kentucky counties based on median housing value were used to determine the range for HV_0 in high protection areas. Here housing value ranged from a minimum lower quartile value of $77 600 to a maximum upper quartile value of $219 200. Median housing value ranged from $103 000 to $158 600 and averaged $117 690. Based on this range, HV_0 was assigned values of $100 000 and $150 000 in high protection areas.

Data from 15 counties were used to determine the values of HV_0 in low protection areas. Each county is from the rural, western end of Kentucky and is among the bottom 45 countries (out of 120) in terms of median housing value. Here housing value ranged from a minimum lower quartile value of $29 500 to a maximum upper quartile value of $85 200. Median housing value ranged from $40 500 to $58 800 and averaged $53 573. Based on this range, HV_0 was assigned values of $40 000 and $60 000 in low protection areas.

The parameter HV_1 represents expectations concerning the value of homes that might encroach into setback areas and trigger future lawsuits. Values of HV_1 are based on ranges presented above for median housing value in the high and low protection areas. In high protection areas HV_1 is expected to be $0 to $50 000 higher than HV_0. Thus, in high protection areas, HV_1 takes on the values of $100 000 and $150 000 when HV_0 is $100 000 and the values of $150 000 and $200 000 when HV_0 is $150 000. The parameter HV_1 in low protection areas is calculated similarly, but the added values are $0 and $20 000.

The parameter P was incremented from 0 to 1 by steps of 0.1 (i.e., P was assigned 11 values). The land acquisition cost, LAC, was assigned two values representing high and low ha^{-1} LAC. Using Kentucky Farm Business Management (KFBM) association data from 1998 to 2002, the cash rental rate for crop acres ranged from $39.54 to $471.97 ha^{-1} ($16–$191 $acre^{-1}$) and averaged $218.76 ha^{-1} ($88.53 $acre^{-1}$) across all farm types (e.g., crops only, mixed crops and livestock, and livestock only). Over the same period crop land averaged nearly $3707 ha^{-1} ($1500 $acre^{-1}$) or 17 times of the rental rate. Assuming a 20-yr loan at 8%, the annual cost of purchasing land calculates to $377.53 ha^{-1} ($152.78 $acre^{-1}$). The KFBM association data suggest that the difference between the average amortized value of land and the average cash rental rate is approximately equal to the return to land. Thus, the cash rental rate is a fair approximation for the cost of land. In this investigation, LAC is assumed to range from $81.54 to $247.10 ha^{-1} ($33–$100 $acre^{-1}$).

RESULTS AND DISCUSSION

The first objective of this research is to estimate "more efficient" setback lengths for a range of economic conditions. Using GAMS to optimize Eq. [15], where the exogenous variables of HV_0, LAC, P, and HV_1 in Eq. [15] are assigned the values reported above, resulted in 176 observations. Values for r_T, r_P, and r_{NP} are summarized in Tables 2 and 3 for low and high protection areas, respectively. To limit table size, setback lengths are reported only for P values of 0, 0.10, 0.50, 0.90, and 1. Note that in Table 4, the net social benefits (or costs of odor reduction) are measured as changes in per firm NB_O arising from changes in r_T (thus, changes in r_P and r_{NP}). The firm cost of odor reduction is measured as the per-meter setback cost paid by the firm—a weighted average of the costs associated with r_P and the costs associated with r_{NP}. Table 4 also reports the cost (in terms of lost social welfare) of the 457.2-m (1500-ft)

Table 2. Optimal total, protected, and non-protected setback lengths (m) for values of land cost, neighboring housing value, and probabilities of being sued for livestock odor damages in low protection areas.

	Land acquisition cost (LAC), $/ha							
	$81.54				$247.10			
	Value of neighboring homes Current value (HV_0)/expected value (HV_1) ($1000)							
Probability of sued/fined	**40/40**	**40/60**	**60/60**	**60/80**	**40/40**	**40/60**	**60/60**	**60/80**
P	m							
	Protected setback length (r_P)							
0	0	0	0	0	0	0	0	0
0.10	1348	1405	1410	1443	1105	1197	1206	1264
0.50	1507	1522	1533	1541	1383	1413	1439	1458
0.90	1525	1526	1546	1547	1420	1421	1468	1469
1	1526	1526	1547	1547	1421	1421	1469	1469
	Nonprotected setback length (r_{NP})							
0	1592	1592	1592	1592	1592	1592	1592	1592
0.10	215	155	162	127	419	318	335	273
0.50	41	17	29	16	96	40	72	41
0.90	6	0	4	0	15	0	11	0
1	0	0	0	0	0	0	0	0
	Total setback length (r_T)							
0	1592	1592	1592	1592	1592	1592	1592	1592
0.10	1563	1560	1571	1570	1524	1515	1541	1537
0.50	1548	1539	1562	1558	1479	1453	1511	1499
0.90	1532	1526	1551	1547	1435	1421	1480	1469
1	1526	1526	1547	1547	1421	1421	1469	1469

Table 3. Optimal total, protected, and non-protected setback lengths (m) for values of land cost, neighboring housing value, and probabilities of being sued for livestock odor damages in high protection areas.

	Land acquisition cost (LAC) ($/ha)							
	$81.54				$247.10			
	Value of neighboring homes Current value (HV_0)/expected value (HV_1) ($1000)							
Probability of sued/fined	**100/100**	**100/150**	**150/150**	**150/200**	**100/100**	**100/150**	**150/150**	**150/200**
P	m							
	Protected setback length (r_P), m							
0	0	0	0	0	0	0	0	0
0.10	1470	1503	1505	1523	1313	1377	1382	1420
0.50	1555	1562	1567	1571	1492	1509	1522	1532
0.90	1564	1564	1573	1573	1513	1513	1537	1538
1	1564	1564	1573	1573	1513	1513	1538	1538
	Nonprotected setback length (r_{NP}), m							
0	1592	1592	1592	1592	1592	1592	1592	1592
0.10	109	75	78	60	245	178	186	146
0.50	18	7	13	7	48	20	34	20
0.90	3	0	2	0	8	0	5	0
1	0	0	0	0	0	0	0	0
	Total setback length (r_T), m							
0	1592	1592	1592	1592	1592	1592	1592	1592
0.10	1579	1578	1583	1583	1558	1554	1568	1566
0.50	1574	1570	1580	1578	1540	1529	1556	1551
0.90	1567	1564	1575	1573	1520	1513	1542	1538
1	1564	1564	1573	1573	1513	1513	1538	1538

and 914.4-m (3000-ft) setback lengths currently enforced in Kentucky.

Model results indicate that r_T decreases as P increases from 0 to 1, other things being equal. As predicted r_T is maximized (at approximately 1600 m) when $P = 0$. Also, as predicted, the protected length (r_P) is 0 when $P = 0$, increases with P, and is equal to r_T when $P = 1$. Specifically, as the probability of being sued increases, the protected setback length increases indicating that the firm would choose to increase the distance of their setback area. This result is consistent with intuition. However, the economic incentives are such that some portion of r_T will be left unprotected until $P = 1$.

An increase in LAC reduces r_T and r_P, other things being equal. However, the rate of reduction in r_P exceeds the rate of reduction in r_T; thus, r_{NP} increases. Consistent with intuition, higher land costs provide an incentive to reduce the size of the protected setback area. But as P increases, the increase in r_{NP} associated with an increase in LAC declines and approaches 0 when $P = 1$.

When the current value of neighboring homes (HV_0) increases, r_T and r_P increase, other things being equal.

Table 4. Net benefits and firm setback cost measured at the optimal and mandated setback lengths for livestock odor damages.

	Land acquisition cost (LAC), $/ha							
	$81.54				$247.10			
	Value of neighboring homes Current value (HV_0)/expected value (HV_1) ($1000)							
Probability sued/fined	**40/40**	**40/60**	**60/60**	**60/80**	**40/40**	**40/60**	**60/60**	**60/80**
P	$							
	Low protection areas							
	Net benefit (NB_0) ($1 000 000) at the optimum setback lengths							
0	$2.99	$2.99	$4.48	$4.48	$2.99	$2.99	$4.48	$4.48
1	$2.92	$2.92	$4.41	$4.41	$2.81	$2.81	$4.29	$4.29
	at the state mandated setback length of 457.2 m							
0	$1.69	$1.69	$2.54	$2.54	$1.69	$1.69	$2.54	$2.54
≥0.10	$1.69	$1.69	$2.54	$2.54	$1.68	$1.68	$2.52	$2.52
	Firm cost ($/m) at the optimum setback lengths							
0	$0	$0	$0	$0	$0	$0	$0	$0
1	$40.26	$40.26	$40.81	$40.81	$113.70	$113.70	$117.50	$117.50
	at the state mandated setback length of 457.2 m							
0	$0	$0	$0	$0	$0	$0	$0	$0
≥0.10	$40.26	$40.26	$40.81	$40.81	$36.56	$36.56	$36.56	$36.56
	High protection areas							
	Value of neighboring homes Current value (HV_0)/expected value (HV_1) ($1000)							
	100/100	**100/150**	**150/150**	**150/200**	**100/100**	**100/150**	**150/150**	**150/200**
	Net benefit (NB_0) ($1 000 000) at the optimum setback lengths							
0	$7.46	$7.46	$11.19	$11.19	$7.46	$7.46	$11.19	$11.19
1	$7.40	$7.40	$11.13	$11.13	$7.27	$7.27	$10.99	$10.99
	at the state mandated setback length of 914.4 m							
0	$6.51	$6.51	$9.77	$9.77	$6.51	$6.51	$9.77	$9.77
≥0.10	$6.49	$6.49	$9.75	$9.75	$6.45	$6.45	$9.70	$9.70
	Firm cost ($/m) at the optimum setback lengths							
0	$0	$0	$0	$0	$0	$0	$0	$0
1	$41.27	$41.27	$41.51	$41.51	$121.00	$121.00	$122.90	$122.90
	at the state mandated setback length of 914.4 m							
0	$0	$0	$0	$0	$0	$0	$0	$0
≥0.10	$24.13	$24.13	$24.13	$24.13	$73.11	$73.11	$73.11	$73.11

Also note that as the rate of change in r_P exceeds the rate of change in r_T, r_{NP} shrinks rapidly as HV_0 increases. Intuitively, this result suggests that higher initial benefits are indicative of longer optimal setback lengths. Furthermore, the higher the initial benefit, the greater the incentive for the firm to assume protection cost. At higher LAC, r_T and r_P are shorter, but the rate of increase in r_T and r_P with respect to HV_0 is higher. At higher values of P, the rate of increase in r_T and r_P with respect to HV_0 slows and the rate of change in r_P approaches the rate of change in r_T.

Unlike HV_0, r_P increases as HV_1 increases, but r_T decreases, other things being equal. The expected future value of homes built within the setback area if left unprotected, HV_1, is associated with the fine a firm will pay if successfully sued. This result indicates that a higher potential fine shortens r_{NP} by simultaneously increasing r_P and decreasing r_T. The intuition behind this finding is illustrated by Fig. 1. As P increases, the rate of change in r_P with respect to HV_1 decreases to 0. The rate of change in r_T with respect to HV_1 increases with P, reaches a maximum, and then decreases. As HV_0 increases the rate of change in r_P and r_T with respect to HV_1 decreases in absolute value. On the other hand, with increases in LAC the rate of change in r_P and r_T with respect to HV_1 increases in absolute value.

The second objective of this research is to assess the economic impact of Kentucky's livestock production facility setbacks relative to the calculated, "more efficient" lengths. Across the values considered, r_T ranged from 1421.3 to 1592.4 m (approximately 1600 m) and averaged 1523 m in low protection areas. In contrast, the state mandated setback length for low protection areas in Kentucky is 457.2 m. In high protection areas, where the state mandated setback length is 914.4 m, r_T ranged from 1513.3 to 1600 m and averaged 1561.3 m. Although only 38.2 m different, the mean setback values for low and high protection areas are statistically different with 99% confidence.

Under no condition did the model generate a value of r_T equal to the state mandated setback length. Further investigation reveals that r_T will equal 457.2 m in low protection areas when P is between 0.17 and 1.06%, depending on LAC, HV_0, and HV_1. In high protection areas, r_T will equal 914.4 m for values of P between 0.31and 1.96%. These results indicate that Kentucky's legislated odor setback lengths assume a low probability of the firm being sued and fined.

The results of Table 4 indicate that Kentucky's legislated odor setback lengths compared with the optimum results are unfavorable to society. At $r_T^{\ddagger}$ for the 176 estimates, per firm NB_O ranged from $2.81 to $4.48 million (mean $3.62 million) in low protection areas and ranged from $7.27 to $11.19 million (mean $9.21 million) in high protection areas. Setting r_T to 457.2 m in low protection areas and 914.4 m in high protection areas reduced NB_O. At 457.2 m, NB_O ranges from $1.68 to $2.45 million (mean $2.11 million), a statistically significant reduction of $1.52 million at the mean (99% confident). At 914.4 m, NB_O ranges from $6.45 to $9.77 million (mean $8.10 million), a statistically significant reduction of $1.11 million at the mean (99% confident). Interestingly, at the mean, lost social welfare is higher in low protection areas than it is in high protection areas.

Although unfavorable to society, Table 3 indicates that Kentucky's legislated odor setback lengths compared with the optimum results are favorable to the firm. At $r_T^{\ddagger}$, firm cost ranged from $0 to $337.60 m^{-1} (mean $140.85) in low protection areas and ranged from $0 to $353.36 m^{-1} (mean $150.34) in high protection areas. At 457.2 m, firm cost ranges from $0 to $36.56 m^{-1} (mean $22.10) representing a statistically significant reduction of $118.75 m^{-1} at the mean (99% confident). At 914.4 m, firm cost ranges from $0 to $73.11 m^{-1} (mean $44.20) representing a statistically significant reduction of $106.14 m^{-1} at the mean (99% confident). In the case of firm cost reduction, firms are better off under state regulation in low protection areas. This result is consistent with intuition because the firm will pay more to comply with a 914.4-m vs. 457.2-m setback length.

CONCLUSIONS

Air quality and odor nuisance regulation have become key issues in many states in the USA. Traditionally, odor nuisance was considered a legal matter and solutions to odor problems were dealt with by the common law concept of nuisance (Watts and Sweeten, 1995). Unlike water quality issues that can be measured and monitored, it is more difficult to objectively measure livestock odor. Because of heightened public concern, extensive research to measure, eliminate, or, at least, reduce odors has received political attention. Currently, regulations regarding livestock odors focus on separation distances (setback policy) between facilities or manure storage, and the nearest nonowner residence or public area.

In Kentucky, the Natural Resources and Environmental Protection Cabinet (NREPC) has instituted setback provisions. In this study low protection areas are defined as rural areas where there are few homes, little demand for housing, and little development pressure; thus, the average value of a home is low. These areas are protected by a 457.2-m (1500-ft) setback length from barns and manure storage (e.g., lagoons). Low protection areas are legally defined as "features not in an incorporated city … specifically, dwellings not owned by the applicant plus churches, schools, businesses, and other structures to which the general public has access including parks." High protection areas represent nonrural areas or rural areas near an incorporated city where development pressures and the demand for housing (thus average home value) are high. By regulation, "if the nearest feature is within an incorporated city limit, then production facilities must be setback 3000 feet" (914.4 m).

The results of this study suggest that the 457.2- and 914.4-m setback lengths for low and high protection areas, respectively, are too short for the conditions considered. At the minimum, the setback length should be 1421 m in low protection areas and 1513 m in high protection areas. Livestock production firms are worse off under the longer setback lengths (by as much as $300 m^{-1}), but the losses to surrounding home owners far exceed the firm gains at the legislated setbacks. This result implies that Kentucky's legislated setback lengths are contributing to odor damages to surrounding property. Additionally, Kentucky's policy may be contributing to a false sense of security among livestock producers. Specifically, livestock producers in compliance with the relevant setback length may feel protected from odor lawsuits despite damage being done to surrounding property. In Kentucky, home owners can sue for damages even if the livestock firm is in compliance. The results of this research suggest that the plaintiff is justified in bringing the suit. Furthermore, at the legislated setback length, livestock producing firms are not encouraged to research, develop, or implement odor reduction, best management practices, or technologies.

Although statistically different, results indicate that the setback length for low protection areas be 38 m longer at the mean (a maximum of 100 m longer) than the length for high protection areas. Economic theory has been used to demonstrate that site-specific regulation minimizes social cost relative to uniform regulation because firms are able to take advantage of spatial differences in marginal cost. The results of this study support this finding. However, site-specific regulations are hard to enforce, politically unpopular, and subject to legal challenges. As a consequence, regulators prefer uniform regulation. An implication of this study is that a single setback length of 1550 m is possible. This is the average length across all conditions considered.

Finally, a finding of this study is that the firm has no incentive to completely protect the legislated setback length unless the probability of being sued is high (>70%) and the fine is high. This finding is in agreement with Harford (1978) and others. This outcome is also true, even at the lengths currently mandated by the state of Kentucky. In this study the fine is partly defined by the expected value of housing built within the setback area if that area is not protected. If there is a 70% probability of being sued, the expected value of housing only needs to exceed the current value of housing by $20 000 to trigger full protection. Current value is measured at the point in time when the firm decided to locate in an area. In addition, the higher the current value of surrounding homes, the greater the incentive for the firm to assume protection cost.

A recent article by Babcock et al. (2003) suggests there may be room for beneficial trade between livestock producers and neighboring homeowners. This study concludes that livestock producers who wish to build new facilities might consider paying neighbors for potential declines in property values. While trade between firms and homeowners may exist, our results clearly show that monetary compensation to neighboring homeowners would exceed the firm's ability to negotiate favorable compensation for any potential damages. The property value impacts calculated by Babcock et al. (2003) are similar to those by Palmquist et al. (1997) and Ready and Abdalla (2003). Although Babcock et al. (2003) attempts to estimate downwind impacts, the results of Palmquist et al. (1997) and Ready and Abdalla (2003) indicate that regardless of the capacity of the production site there is no change in the length at which odor damages (in terms of housing value) go to zero. While, perhaps, unintuitive, this is a consistent result with important policy implications if true. This result might suggest that once a certain level of livestock production is attained, adding more production (i.e., animal units) does not change the odor damage function.

Several odor dispersion models have been used to calculate the separation distance due to odor emissions from livestock buildings (Schauberger et al., 2001, 2002; Heber, 1997; Krause and Lung, 1993; Jiang and Sands, 1998). The differences in these odor dispersion models suggest additional research is needed. The next step would be to link these odor dispersion models with the model presented in this paper. In this way it could be possible to better account for pertinent factors such as prevailing wind speed and direction, local topography, climatic factors, capacity of production site, and potential effect of wooded shelter belts to name a few. Such a model might allow for odor generation as a function of capacity, a possible limitation of the Palmquist et al. (1997) and Ready and Abdalla (2003) models.

While few new livestock firms have located in Kentucky in recent years, anecdotal evidence suggests that those firms that did locate in the state chose to protect very little of the mandated setback length. Some of the firms located in relatively "up-scale" areas with higher than average surrounding residential property values. This suggests that the perceived threat of lawsuit is currently low in Kentucky. Unfortunately, as discussed above, lawsuits are likely even with the legislated setback lengths. Not until highly publicized lawsuits occur and large fines are assessed will livestock firms choose to protect their odor setback lengths.

APPENDIX

Symbol or abbreviation	Definition	Units
F	size of the fine	\$US
LAC	land acquisition cost	\$US
MB_O	marginal benefits of odor reduction	\$US
MC_O	marginal costs of odor reduction	\$US
NB_O	net benefits of odor reduction	\$US
NPC_O	costs of odor reduction associated with nonprotection	\$US
P	probability of being fined	%
PC_O	costs of odor reduction associated with protection	\$US
r_{NP}	nonprotected area	m
r_P	protected area	m
r_T	total setback length	m
TB_O	total benefits of odor reduction	\$US
TC_O	total costs of odor reduction	\$US
Z_B	exogenous factors of benefits	
Z_C	exogenous factors of costs	
Z_F	exogenous variables ssociated with F	
Z_{NP}	exogenous components associated with nonprotection	
Z_P	exogenous components associated with protection	

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