Hot Spots in Animal Agriculture, Emerging Federal Environmental Policies and the Potential for Efficiency and Innovation Offsets

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Abstract: In North America and Northern Europe high livestock densities in concentrated areas (hot spots) have led to manure surpluses, which have resulted in water pollution problems. Using the emerging policy objectives for animal waste in the European Union and the United States as a backdrop, this paper discusses the impact of environmental regulation on farm profits. A theoretical model of the farm is presented where pollution is a joint output of production and where inefficiency in production prevails. Given this assumption, environmental regulations affect both the level of inefficiency and the extent of technological change and can induce cost offsets. Data from the Netherlands, where strict environmental regulation has been in place for animal agriculture since 1987, are used to test the hypothesis about efficiency and innovation offsets. Furthermore, differences in these offsets between farm types are assessed.

Keywords: environmental policy, animal agriculture, Porter hypothesis, efficiency offsets, innovation offsets.
1. Introduction

Water pollution problems caused by nutrient pollution are among the most important issues of environmental concerns in areas with a high density of livestock population. Although there are differences in market, demographic and geographical conditions between North America and Northern Europe, environmental problems and policies are comparable. Intensive livestock farming in concentrated areas has led to manure surpluses at the farm and regional level, which has resulted in the release of nutrients into the environment. This paper discusses the impact of environmental regulation on costs and profits using the emerging federal policy objectives for animal waste in the European Union (EU) and the United States (US) as a backdrop. Particularly the paper explores the existence of efficiency and innovation offsets.

The objective of this paper is twofold. Firstly, we develop a theoretical model of the farm where pollution is a joint output of production. In this model, inefficiency in production prevails. Given this setting, environmental regulations affect both the level of inefficiency and the extent of technological change. Therefore, the conditions are established whereby regulations induce cost offsets (cf. Altman [1]). If efficiency improvements and green innovation indeed combine environmental advantages with economic advantages, these offsets would offer a free lunch adjustment to environmental regulations. The second objective of this paper is to present an empirical analysis of the existence of efficiency and innovation offsets that uses the Netherlands as a case study of animal agriculture hot spots.

The plan of the paper is as follows. The next two sections give an overview of the institutional setting and of the specific characteristics of the animal waste nitrate problem, respectively. Section 4 provides a theoretical discussion of efficiency and innovation offsets, followed by the empirical
analysis in section 5. We conclude with a discussion of the policy implications and a summary of the main findings.

1. Emerging federal policies in the EU and the US

The severity of the animal waste problem in the European countries varies widely. Spatial analysis of the nitrate (N) surplus per hectare (Schleef and Kleinhans [2]) and the identification of zones vulnerable to nitrate leaching identify hot spots (see Figure 1). Perception of the severity of the problem is reflected in the content of the national policies that were developed in the 1980s. A harmonized EU policy plan for animal agriculture was first issued in 1991 when the Nitrate Directive was enacted. The centerpiece of the Nitrate Directive is a maximum standard for nitrate of 50 mg per liter of drinking water. The final EU objective is that by 2003 manure application should not exceed 170 kg N per hectare in the vulnerable zones. Member states may set less restrictive amounts [3] as long as this does not violate the 50 mg nitrate per liter objective (Frederiksen [4]). According to the EU’s subsidiary principle implementation of EU Directives is not the task of the EU but of the national, regional or local level. The most important EU hot spots, the Netherlands and Belgium implemented standards on manure application and farm-level manure bookkeeping in the late 1980s. These standards have been reduced gradually but are still far above the EU standard of 170 kg per hectare. Financial impacts of the EU standard are expected to be dramatic particularly for the numerous land-limited producers in the European hotspots.

In the US, particularly the swine [5] and poultry industries experienced changing market structures and rapid growth in the 1980s and 1990s. The large-scale units favored by the new supply chains produce vast amounts of animal waste that are highly concentrated geographically. As in Europe, hot
spots are identified by spatial examination of N application to cropland and soil hydrological vulnerability (Letson et al., [7]), see Figure 2. There are several states that have some kind of (usually rather recent) statute in response to the increased concerns over environmental quality and human health (Drabenstott [8]). At the federal level, the Clean Water Action Plan (CWAP) of February 1998 was the first response to the concerns over animal waste pollution. Grounded on the US standard for nitrate in groundwater of 10 ppm (10 mg per liter), the Plan announced new effluent limitation guidelines (ELGs) for confined animal feeding operations (CAFOs) and a Unified National AFO Strategy. Present ELGs prohibit direct discharge of animal waste as a point source pollutant into surface water [9]. The new ELGs will include limits on non-point source discharges from cropland application of animal waste (Selinsky Johnson et al., [10]). Main element of the unified strategy is that all AFOs develop and implement a site-specific Comprehensive Nutrient Management Plan (CNMP) to help realize the limits on non-point pollution. Similar to the European manure bookkeeping systems the CNMP contains: feed management, manure handling and storage, land application of manure, land management, record keeping of manure utilization and other manure utilization options (Featherstone and Atwood [6]). The ELGs and CNMP are currently being investigated on their costs and feasibility particularly for land-limited livestock producers who are typically located in the hot spots.

3. Specific characteristics of the animal waste nitrate problem

Non-point source nitrate pollution [11] of water associated with animal waste represents a fairly new field for federal policy design. The issue is the more challenging because of three specific features. First, the clustering of confined animals as such does not necessarily mean that manure nutrients will
contribute to water quality problems. It is the balance of manure production and crop nutrient use that
determined movement of nutrients to water bodies. However, there is no direct link between current
land application levels and drinking water quality. Groundwater is slowly renewable and a nitrate load
appears to persist for decades. Besides, since emissions are non-point, costly to measure and stochastic
[12], controls must be targeted at estimated emissions rather than actual emissions. Second, there are
few abatement options once nitrate is released into the environment. Third, many producers are
involved whose production conditions and practices differ. These special features determining the
process of nitrogen emission from agricultural production systems may be depicted as in Figure 3. Due
to the first two features, environmental control of animal waste has to focus on prevention as with the
European standard of 170 kg N per hectare and the new ELGs in the US. The environmental
compliance costs these standards impose on farmers depend largely on options for improvement in
animal production practices (e.g., feed management, housing) and in manure and crop management.
We will discuss these options in more detail theoretically and empirically.

4. Theoretical Model: Efficiency and Innovation Offsets

Production externalities most often result from specific inputs that have the characteristics of joint
inputs (animal feed), as any quantity simultaneously produces the intended agricultural output
(meat) and the unintended externality (water quality problems). The combination in which these
marketable outputs and bad side effects are generated is not fixed but rather depends on the
production method chosen. Generally, several production methods are available that vary both in
their costs and in their environmental impacts. These possibilities to produce are usually shown in a
simplified diagram assuming a given resource base, fixed technology and given production inputs. The production possibility frontier (PPF) in Figure 4 depicts the feasible set of economic performance (profit or farm income associated with animal production) and water quality levels produced by a farm in a given natural production environment as defined by climate/weather and soil type. The shape of the PPF expresses the extent to which economic and environmental performances are compatible. Profits and water quality are complements over the increasing range of the frontier and substitutes over the decreasing range. Where markets for environmental services are missing, the larger part of the production possibility frontier is steeply downward sloping as with the PPF in Figure 4 (cf. Aldy et al., [13]). The presentation in Figure 4 assumes optimal, profit maximizing behavior of agricultural producers and a given technological state of the art. In practice there will be inefficiency in production and progress in production technology through innovations.

The essence of the theoretical model adopted here is that farms are typically x-inefficient. Firms are considered x-inefficient if output (environmental performance, profit) is less than the ideal maximum. X-efficiency is therefore defined by the outermost production possibility frontier. There are several reasons why there would be inefficiencies. For a given production technology, lack of information about the production frontier may lead producers to use inputs inefficiently. Producers may also have limited knowledge of the set of alternative production technologies that are available and their economic and environmental characteristics, as well as a lack of information about how their actions affect environmental quality (Ribaudo and Horan [14]).

The importance of inefficiencies is illustrated by farm A_1 in Figure 4. Farm A_1 earns profit P_1 and generates an environmental quality level of W_1. Now assume an environmental performance standard W_s is implemented that specifies the maximum amount of pollution. Efficiency offsets available to
Farm A₁, given a standard of Ws, are along the portion BC of the PPF. Points along the lower part of the PPF do not provide offsets because profit would decrease.

Prior to the implementation of an environmental performance standard, farms do not bear any direct costs from water degradation. Farms like A₂, which utilize available production technologies, will be close or on the Y-axis. Efficiency offsets are not available for (the already efficient) farm A₂ and it will encounter compliance cost of P₂-Pₚ. In the above presentation, it has been assumed for simplicity that there is only one production technology. However, under the environmental regulation price structure, a profit-maximizing farm will seek out technologies that lower the costs of environmental compliance. Under the initial pre-regulation situation there was no such incentive for a farmer to economize on discharges. Hick’s induced innovation hypothesis and the Porter hypothesis assert that environmental regulations in the form of economic incentives can trigger innovations (Porter and van der Linde [15]).

Introducing clean technologies that help achieve environmental goals with fewer inputs shifts the PPF outward to PPF₁ [16]. As Xepapadeas and De Zeeuw [18] show, such innovations can partially offset the private environmental compliance costs for the maximizing, i.e. x-efficient agent, because of accelerated modernization. Assume new technologies become available after some time [19]. Farm A₂ will shift out to this new frontier PPF₁ and depending on the shape of this new frontier, the innovations will partially offset the environmental compliance costs. If farm A₂ positions itself at H on PPF₁ it will reduce the cost of complying with the new standard from P₂-Pₚ to P₂-Pₙ. For farm A₁ innovation offsets expand the already existing efficiency offsets from BC to DG.

To complete the illustration, consider farm A₃ that earns little income from animal agriculture but would not have to change practices to meet the standard. Point Gₐ indicates the
weighted average of the population $A_1$-$A_3$ of farms before the standard is implemented (Figure 5). With the implementation of the standard, the new gravity point will be located north east of $G_A$. The continuous establishment of new and larger production units (such as farm $C_{NEW}$) and winding up of less profitable ones (farm $A_3$ in our case) will shift the new gravity point further north. A possible expansion path $G_A$-$G_B$-$G_C$ is depicted in Figure 5.

Whether environmental quality and costs competitiveness are mutually consistent hinges upon whether or not producers are typically efficient in production and whether environmental regulation immediately induces technical change. Of course there can be situations where no efficiency or innovation offsets are possible and the gravity point of the farm population will move southeast with more stringent environmental standards. Finally notice that a classification of the farm population in farm types will show variations in offsets because different PPFs (and PPF$^1$s) characterize farm types. Variation in environmental standards according to farm type could further influence these differences in offsets.

In summary, the opportunity of the two types of “free lunch” adjustments is dependent on: (1) the positioning of farms with respect to PPF, (2) where the environmental standard is set, (3) whether new technologies (PPF$^1$) become available in time, and (4) the shape of PPF and PPF$^1$ that expresses the extent to which economic performance and environmental performance are compatible.

5. Empirical evidence

The theoretical model suggests that efficiency improvements and innovations can offset the compliance cost incurred by environmental standards and that these offsets will vary between farm types. To test
these two hypotheses, the Netherlands was used as a case study. In this country, application standards on N were imposed during 1987-1997 [21]. These standards varied by type of land and were gradually reduced from 700 to 220 kg N per hectare for silage corn, from 500 to 270 kg for grassland and from 250 to 220 kg for cropland.

Data on farm income and nutrient surpluses are available from the annual survey of 1,500 farms by the Agricultural Economics Research Institute (LEI-DLO). The published data are averages by farm type for the total country by year (LEI-DLO [23]; LEI-DLO [24]; Daatselaar [25]). The analysis was conducted for five farm types (dairy farms, confined animal farming operations (CAFOs), pig farms, arable farms, and mixed farms, [26]) and 10 years (1987-1996). We used these pooled cross section time series data to estimate the following equation:

\[ Inc_{it} = \alpha_0 + \alpha_1 NS_{it-1} + \alpha_2 LA_{it} + \alpha_3 Lb_{it} + \alpha_4 PI_{it} + \alpha_5 FS_{it} + \varepsilon_{it} \]  

(1)

where the dependent variable \( Inc_{it} \) denotes average annual income of farm type \( i \) in year \( t \); \( NS_{it-1} \) is the average nitrogen surplus in kg per hectare of farm type \( i \) in year \( t-1 \); \( LA_{it} \) and \( Lb_{it} \) are the land application standards in kg N per hectare for the land use associated with farm type \( i \) times a dummy for CAFOs and pig farms [27] and other operations, respectively; \( PI_{it} \) is the profitability index for farm type \( i \) and year \( t \), and \( FS_{it} \) denotes size for farm type \( i \) in year \( t \) [28]. Given the fact that the relationship between farm income and nitrogen surplus is unlikely to be contemporaneous, the nitrogen surplus variable was lagged one period. Farm income was converted into constant 1990 Guilders using the purchasing power index. The profitability indices and the purchasing power were taken from CBS & LEI-DLO [24]. The estimation was performed using the SAS-TSCS/PARKS procedure to account for potential cross sectional heteroscedasticity and temporal first-order auto regression (Parks [29]). Results are presented in Table 1.
The parameters $\alpha_2$ and $\alpha_3$ are the critical coefficients for testing the hypothesis about efficiency and innovation offsets of the compliance cost incurred by the land application standards as reflected in $La_{it}$ and $Lb_{it}$. Specifically, if $\alpha_2 = 0$ then the application standards do not affect income of CAFOs/pig farms, and if $\alpha_3 = 0$ the income of crop farms, dairy farms and mixed farms is not affected. Table 1 shows that for CAFOs/pig farms the hypothesis about efficiency and innovation offsets can not be rejected by the parameter estimates. The income effects of stringent nitrogen standards (which is equivalent to lower allowable application rates) $La_{it}$ were non-significant for these two farm categories, even though the standards were considerably tightened during 1987-1996. For the other farm types, for which the nitrogen standards were reduced less, the estimated farm level marginal income effect was NLG 37.8 per kg N (US$ 17) and the value of the $t$-statistics was 1.86, significant at the 0.10 level. For example, for the average dairy farm this implies a total income loss of NLG 3,450 (US$ 1,554) due to reduction in the standard from 500 to 270 kg N per ha.

Next, to evaluate differences in income effects between the two groups of farm types, the following model was estimated:

$$Inc_{it} = \beta_0 + \beta_1 NS_{it-t-1} + \beta_2 La_{it} + \beta_3 Pa_{it} + \beta_4 PI_{it} + \beta_5 FS_{it} + \epsilon_{it}$$ (2)

where $La_{it}$ denotes the land application standards for each farm type $i$, year $t$ and the other variables are defined as before. A test of whether $\beta_3 = 0$ checks for significant differences in income effect between the two groups (Greene, [30, p. 239-230]). Table shows a significant negative estimate for $\beta_3$ and this indicates that CAFOs and pig farms were less affected by the nitrogen standards than were the other farm types (crop farms, dairy farms and mixed farms).

The efficiency and innovation offset observed for CAFOs and pig farms were made possible by changes in feed management, in particular. Aside from improvement in nutrition efficiency
using existing diets, significant improvements were achieved by the development of modified feeding regimes for pigs. Feeding two or three rations (phase feeding) offers substantial economic and environmental incentives for producers (cf. Boland et al., [32]). These modified diets reduce the N intake and thereby the N surplus while maintaining or even enhancing daily weight gains.

6. Summary and conclusions

The objective of this paper was to discuss and empirically analyze the implications of efficiency and innovation offsets for the management of non-point source pollution from agriculture.

We presented a theoretical model of the farm where pollution is a joint output of production and where inefficiency in production prevails. Given this assumption, environmental regulations affect both the level of inefficiency and the extent of technological change and can induce cost offsets. Farms for which a new environmental standard is binding will face implementation costs. However, a farm that intends to comply with the environmental standard will invest in technological innovations. This will expand the farm's PPF. Depending on shape and location of this frontier, the strictness of the standard, and the farm's degree of environmental efficiency prior to the new standard, a farm will now realize efficiency offsets and/or innovation offsets (of implementation costs). Efficiency offsets are based on prior environmental inefficiencies due to, for example, lack of information, bounded rationality, or the lack of competitive pressure. Innovation offsets are the result of a farm producing on an expanded PPF.

Empirical evidence for CAFOs and pig farms in the Netherlands (one of Europe's animal agriculture hot spots) showed that farm profits were not significantly affected following the
implementation of increasingly stringent nitrogen standard. In contrast, crop farms, diary farms and mixed farms on average lost income during the observation period of 1987-1996 as a consequence of the environmental standard. For CAFOs and pig farms, efficiency and innovation offsets in response to the changing standard were realized within one year.

From the perspective of the non-point source pollution problem in agriculture the outcomes demonstrate the complexity of factors affecting farmers’ input use decisions. More specifically they demonstrates the interaction of actual, i.e. non-optimal, producer behavior, the potential of agricultural innovation and the design of effective socio-economic regulations. Under the circumstances of x-inefficiency these regulations serve to induce not only a lower level of pollution but also a more efficient production practice. The extent of the resulting efficiency and innovation offsets of compliance cost is an empirical matter that is likely to vary considerably by farm type and farming situation.

References and Notes


3. This must be based on objective criteria such as long growing season, crops with high N-absorption rates, high net precipitation, or soils with exceptionally high denitrification capacities, which would be the case with high groundwater tables.


5. The number of pig farms dropped more than 45% during the 1992-1997 period whereas the number of animals increased by over 28% (Featherstone and Atwood [6]).


9. Except in the event of a rainfall that exceeds the 25-year, 24-hour storm conditions.


11. Some EU-countries and states in the US have policies that include phosphate, the proposed federal policies of the US and the EU however solely address nitrate.

12. Rainfall and temperature affect leaching and denitrification.


16. We disagree with Getzner [17, p. 524] who argues that introducing cleaner technologies shifts the whole PPF upwards instead of outward under the assumption that the new technology is more efficient in terms of factor productivity; i.e., that the rationalized production process can also produce more outputs while the sum of environmental inputs remains constant. In that case the opportunities of innovation may outweigh the cost of compliance. However, environmental regulation would not be needed to trigger these innovations (cf. Xepapadeas and De Zeeuw [18]).


19. A major limiting factor of the potential of innovation offsets is that it takes time to accumulate enough knowledge since R&D is costly (Parry *et al.* [20]).


21. The standards were set in kg P₂O₅ per hectare. The standards for N followed from the phosphate standards due to the fixed ratio of 2:1 for N and P₂O₅ used in the regulations. By 1998 the application standards were replaced by surplus standards per hectare and a tax on surpluses exceeding the standards (see Breembroek *et al.*, [22]).


26. CAFOs are farms with at least 2/3 of their production capacity in poultry and pig production. Compared to CAFOs, pig farms are considerably smaller in size. A farm is considered a mixed farm if the primary commodity produced accounts for less than 60% of the total output.

27. Grassland was associated with dairy farming, cropland with arable farming and silage corn with CAFOs and pig farms. Silage corn was predominantly grown as a waste disposal crop on the latter farm types. For mixed farms land use was weighed.

28. The entire data set is available from the authors upon request.


Table 1  Statistical analysis of income effects with implementation of a nitrogen standard

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R-Square 0.86  R-Square 0.85

* Significant at P < 0.10;  ** Significant at P < 0.005.
Figure 2 Excess on-farm manure nitrogen as a share of recoverable nitrogen, continental United States by county, 1997

Excess manure nitrogen as a percent of recoverable

- 0 - 10
- 10 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- excess < 1 ton

Some counties are combined to meet disclosure criteria.

Source: Economic Research Service, USDA.
Figure 3  Conditions and processes determining nutrient emissions from agriculture
Figure 4 Efficiency and innovation offsets as consequences of the implementation of an environmental standard.
Table 5  Potential expansion path following the implementation of an environmental standard