# Measuring External Effects of Agricultural Production: An Application for the Netherlands

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**Abstract:** Although the external effects of agricultural production receive considerable attention, the measurement of these effects is not well developed. In this paper, after introducing a theoretical approach, the methodology is applied to the Netherlands. The method used requires information about the quantities and the shadow prices of external effects. Different approaches were used to derive these shadow prices. Although many uncertainties still exist, incorporating the environmental effects of agricultural production reduces the gross value added by about 5–15 percent. Internalizing these external effects gives producers the opportunity to adjust inputs, output, and technology. It can thus be considered as a maximum effect.

## Introduction

Agricultural production technology has changed considerably during recent decades. Some technologies have been displaced completely by new ones; the substitution of labour by capital equipment and delivered inputs and services is the most impressive example of this. Although the literature shows that several studies have been devoted to these changes in technology, the measurement and explanation of technological change, and the effects of changing price relations between inputs and/or outputs, there has been very limited attention to the external effects.

Increased attention to the effects of agricultural production on the environment, landscape, and nature makes it clear that these external effects can play a very important role in the future development of prices, production technology, and level of production. There is a strong tendency to internalize the effects of undesirable outputs of present and new production technology and also of the scale and intensity of production. These changes will affect future gross and net production.

The external effects of agricultural production could be incorporated in a revised production measure. Such a procedure would throw some light on the importance of these effects of agricultural production in the long term. Two studies illustrate such external effects (RIVM, 1988; and Ministerie van Landbouw en Visserij, 1989):

- air pollution, either by well-known ingredients like ammonia, nitrogen oxide, etc., or due to smell;
- surface water pollution, due to minerals (such as chemicals) or organic material in the surface water;
- ground water pollution, due to leaking of minerals or other materials that have their origins directly or indirectly in agricultural production;
- soil pollution, which can mean that the soil attracts a certain amount of pollutants that could potentially enter the ground water, surface water, or air;[2]
- the visual attractiveness of the landscape, due to its composition and variety; and
- the conservation of nature, so that a large variety of different species are retained.[3]

The empirical analysis here will be limited to environmental effects due to manure, fertilizer, and pesticides resulting in pollution of the air and ground and surface water. These external effects might be considered as having a quantity component and a related price component. A difficulty with external effects is that the implicit price or shadow price is mostly unknown. Shadow prices of external effects (measured in quantity units) can depend heavily on the particular levels. But as this is comparable with economic markets, where prices depend on quantities, we should not be too concerned that the shadow prices are only given in a marginal sense.

Before starting on the empirical analysis, the measurement of external effects from a theoretical perspective and the difference between private and social output values are considered.

## Theoretical Aspects of Measuring External Effects

Here we start with a transformation function with two groups of output variables, normal outputs and external effects.[4] Input variables are divided into variable inputs and quasi-fixed inputs. The technology variable explicitly is retained in the transformation function:

(1) $F(Y, Z, X, U, T) = 0$

where $Y$ = the vector of normal outputs with elements $Y_i$ and prices $p_i$ ($i$=1, ..., $I$), $Z$ = the vector of positive or negative external effects with elements $Z_k$ and shadow prices $v_k$ ($k$=1, ..., $K$), $X$ = the vector of variable inputs with elements $X_j$ and prices $w_j$ ($j$=1, ..., $J$), $U$ = the vector of quasi fixed inputs with elements $U_h$ and prices $q_h$ ($h$=1, ..., $H$), and $T$ = a technology variable.

Short-term profit maximizing implies that the difference between the normal output value and the cost of variable inputs is maximized under the restriction of the transformation function. This gives the following Lagrange multiplier:

(2) $$\max_{Y, X} L = p'Y - w'X + \mu F(Y, Z, X, U, T)$$

where row vectors are given with a prime.

Optimal variable input ($X^*$) and output ($Y^*$) levels are functions of prices, quasi-fixed inputs, and technology (Chambers, 1988, chap. 3, p. 7):

(3) $X_j^* = f_j(p, w, U, T) \quad (j=1, ..., n)$

(4) $Y_i^* = g_i(p, w, U, T) \quad (i=1, ..., m)$

Under the assumption of profit-maximizing producers in a competitive market for outputs and variable inputs where the external effects are not of concern, the optimal input and output levels do not depend on the shadow prices of external effects. These external effects only influence production decisions under the condition of technical or legal restrictions on the level of the external effects $Z$ (Pittman, 1983).

The resulting private rent for quasi-fixed inputs ($D_p$) is equal to:

(5) $D_p = p'Y^* - w'X^* \equiv q^{*\prime}U$

where $q^*$ is the vector of shadow prices of quasi-fixed inputs that results from an optimal choice of variable inputs and outputs.

For society, however, the external effects are important, and the resulting difference between output value and input value ($D_s$) is:

(6) $D_s = (p'Y^* + v'Z^*) - w'X^* = q^{*\prime}U + v'Z^*$

where $Z^*$ is the level of external effects that belongs to input level $X^*$, the output level $Y^*$, quasi-fixed inputs $U$, and technology T.

If, however, producers were confronted with prices of external effects, $v$, they would adjust their input level $X$ and output level $Y$, resulting in a new short-term equilibrium, derived from:

(7) $$\max_{X, Y, Z} L^+ = p'Y + v'Z - w'X + \mu F(Y, Z, X, U, T)$$

with optimal levels of outputs and variable inputs:

(8) $X_j^+ = f_j^+ (p, v, w, U, T) (j=1, ..., J)$

(9) $Y_i^+ = g_i^+ (p, v, w, U, T) (i=1, ..., I)$

(10) $Z_k^+ = h_k^+ (p, v, w, U, T) (k=1, ..., K)$

The resulting levels of private and social rent for quasi-fixed inputs ($D_p^+$ and $D_s^+$, respectively) are equal to:

(11) $D_p^+ = D_s^+ = p'Y^+ + v'Z^+ - w'X^+ = q^{+\prime}U + v'Z^+$

where $q^+$ is the vector of resulting shadow prices for quasi-fixed inputs.

Because producers can adjust their input and output levels to the new situation, $D_p^+ \geq D_s$. This approach gives a maximum difference between the social and private levels of remuneration for the quasi-fixed production factors.

## Data Description and Preliminary Analysis

### Data Description

The methodology is applied to the Netherlands. A long-term set of inputs and outputs for the Netherlands agricultural sector is used (Oskam, 1991). The data set is derived mainly from statistics compiled by the Central Bureau of Statistics (CBS) and the Agricultural Economics Institute. In addition, a number of aggregations, prices, and procedures are specifically developed for this data set.

### Quantity Component of External Effects

A second set of information is related to the external effects of agricultural production. Here a number of technical indicators are used, together with statistical information from the CBS, to calculate the quantity levels of each of these external effects. Because the analysis focuses on incorporating the external effects in productivity measurement, a short description is given of how these data were generated. A selection of these data is given in Table 1.

The levels of air, surface-water, ground-water, and soil pollution are derived entirely from the level of organic fertilization (manure), the level of use of chemicals (fertilizer and pesticides), minus the net use of these materials by plants. As this does not give the distribution of the net effects over the particular type of pollution, net losses of nitrate, phosphate, calcium, and ammonia were calculated.

Table 1—Estimated Quantities of Emission of Different Chemicals in Netherlands Agriculture (1000 t/year)

| Year | Nitrogen (N) | Phosphate ($P_2O_5$) | Calcium ($K_2O$) | Ammonia ($NH_3$) | Pesticides (Active Ingredient) |
|---|---|---|---|---|---|
| 1950 | 39 | 53 | 108 | 98 | 3 |
| 1960 | 116 | 49 | 130 | 123 | 5 |
| 1970 | 349 | 78 | 218 | 162 | 9 |
| 1980 | 510 | 89 | 324 | 217 | 18 |
| 1985 | 543 | 92 | 375 | 238 | 20 |
| 1988 | 462 | 74 | 320 | 230 | 20 |

Levels for particular years were used to establish relations between the number of different types of animals and the particular nutrients in manure (CBS, 1989; RIVM, 1988; and Wijnands *et al.*, 1988). Efficiency factors and information on real livestock capital during 1949–88 were used. Ingredients from fertilizers were added, while net use of plants was related to a base year, size of arable land and grassland, and a factor for crop production per hectare. Some checks were used on available data for other years.

The use of pesticides is based on CBS (1989) and data for the use of pesticides on arable farms. No correction was introduced for the use of pesticides by plants.

## Price Component of External Effects

The price component of external effects (shadow prices) is the most difficult element in the whole analysis. Here, some heroic assumptions were made to prepare the statistics.

First, 1986 prices were sought for each type of external effect. In fact, these are meant to be marginal prices, representing the implicit damage of the last unit. Several sources were used. Three different methods are available to derive indications for shadow prices of external effects.

**Estimated costs per unit**. Because reductions of environmental pollution have been planned, a number of indications are given on marginal costs. A specific example is ammonia, where marginal costs per unit of reduction are available (Stolwijk, 1989, p. 18; and Oudendag and Wijnands, 1989, p. 9).

**Marginal costs of environmental measures in other parts of the economy**. This follows from the opportunity cost principle: the value of one unit of reduction follows from the costs of a similar unit of reduction in another part of the economy (Bressers, 1988).

**Direct valuation of environmental effects such as contingent valuation**. This method is often very specific and hardly any practical indications can be derived from empirical research in this area (Hanley, 1990; and Johansson, 1987).

In Table 2, the implicit marginal costs of 1 ton of average manure are given for three different levels of shadow prices.

Table 2—Calculated External Effects (guilders/kg) per Average Ton of Manure in 1986

| Ingredient | Quantity in kg/ton | Shadow Price/Value | | | | | |
|---|---|---|---|---|---|---|---|
| | | Low | | Medium | | High | |
| | | Price | Value | Price | Value | Price | Value |
| N | 4.98 | 0.5 | 2.49 | 1.2 | 5.98 | 2 | 9.96 |
| $P_2O_5$ | 2.63 | 1.0 | 2.63 | 1.8 | 4.73 | 3 | 7.89 |
| $K_2O$ | 6.10 | 0 | 0 | 0.1 | 0.61 | 0.3 | 1.83 |
| $NH_3$ | 2.50 | 1.5 | 3.75 | 2.5 | 6.25 | 4 | 10.00 |
| Total | | | 8.87 | | 17.57 | | 29.68 |

Sources: CBS (1989), Stolwijk (1989), Table 3, and own calculations.

In calculating prices of external effects for different quantities and in other years, the following general approach was used:

(12) $v = \alpha z^{\beta} y^{\sigma}$

where $v$ = the real shadow price of a particular external effect (e.g., N in the form of nitrate, phosphate, ammonium, and pesticides), $z$ = the quantity of the external effect, $y$ = the real net product of the Netherlands, $\beta$ = (shadow) price flexibility of the external effect, $\sigma$ = (shadow) price flexibility with respect to real net product, and $\alpha$ = constant equalizing Equation (12) in the year 1986.

The implicit income elasticity of an external effect ($e_y$) can be derived from Equation (12):

$$(13)\quad e_y = -\frac{\sigma}{\beta}$$

This income elasticity reflects the percentage of reduction of a negative external effect required to compensate for a 1-percent increase in real net product. Because external effects are considered to be luxury goods, $|e_y| > 1$ (Baumol and Oates, 1988). Here different values were used, but 1.25 was the central assumption.

The price flexibility of the external effect is more difficult to establish. There are critical values where an increase in the quantity of an external effect will have a large influence on the shadow price of this effect, while in other ranges, (e.g., under a particular level), changes in quantities have no or nearly no influence on shadow prices.

Because the analysis relates to the agricultural sector, which generates important negative external effects, we are in a situation where quantities influence shadow prices. The quantity effect therefore has to be incorporated; values of β of 0.4, 0.2, and 1 are used as three guesses for the particular quantity effect of environmental goods.

## Empirical Analysis

Because of the uncertainty about the shadow prices of environmental effects, three series of measures were generated using the price levels and additional parameters, as given in Table 3. Gross value added was used as measure for the quasi-fixed inputs.

Table 3—Different Guesses of Shadow Prices (guilders/unit) and Parameters of Environmental Effects of Agricultural Production in 1986

| Variable/Parameter | Unit | Medium | Low | High |
|---|---|---|---|---|
| Nitrogen | kg N | 1.2 | 0.5 | 2 |
| Phosphate | kg $P_2O_5$ | 1.8 | 1 | 3 |
| Calcium | kg $K_2O$ | 0.1 | 0 | 0.3 |
| Ammonia | kg $NH_3$ | 2.5 | 1.5 | 4 |
| Pesticides | kg active ingredient | 10 | 5 | 25 |
| β[1] | | 0.4 | 0.2 | 1 |
| σ[1] | | 0.5 | 0.2 | 1.5 |

[1]These parameters influence the development of the shadow price (see Equation 12).

Focusing first on the medium guess of shadow prices, the resulting difference between private and social rent for quasi-fixed inputs ($D_p^+ - D_s$) cannot be neglected (Table 4). This is due to two different elements. One is the increasing levels of environmental damage by the agricultural sector. This element consists of a quantity component and a price component: more pollution increases the shadow costs per unit of pollution—the quantity effect. The other element is an increasing level of real net product, generating higher shadow costs per unit of pollution—the income effect.

Both effects increased considerably during 1949–88. But their cross effect is also important: a higher level of pollution will be perceived as more damaging at a higher income level. Negative environmental effects of agricultural production increased from about 1 percent in 1949 to more than 11 percent at the beginning of the 1980s. Later on they levelled off somewhat. This is due to the approach used, where emissions directly affect the environment.

Table 4—External Effects of Agricultural Production in the Netherlands, Starting from Three Sets of Shadow Prices and Parameters

| Year | Low | | Medium | | High | |
|---|---|---|---|---|---|---|
| | External Effect (million guilders) | Gross Value Added (percent) | External Effect (million guilders) | Gross Value Added (percent) | External Effect (million guilders) | Gross Value Added (percent) |
| 1949 | 19 | 1.0 | 18 | 1.0 | 4 | 0.2 |
| 1955 | 36 | 1.2 | 40 | 1.4 | 13 | 0.4 |
| 1960 | 55 | 1.5 | 66 | 1.8 | 28 | 0.8 |
| 1965 | 91 | 1.9 | 123 | 2.6 | 72 | 1.5 |
| 1970 | 182 | 2.8 | 296 | 4.6 | 274 | 4.2 |
| 1975 | 354 | 3.7 | 630 | 6.6 | 763 | 8.0 |
| 1980 | 631 | 5.6 | 1,214 | 10.7 | 1,866 | 16.5 |
| 1985 | 821 | 5.0 | 1,635 | 9.9 | 2,782 | 16.8 |
| 1988 | 749 | 4.5 | 1,452 | 8.7 | 2,552 | 15.2 |

Incorporating the uncertainty about shadow prices of environmental effects leads to a rather wide range: 5–15 percent of gross value added in 1988.

## Concluding Remarks

The inclusion of environmental effects in measuring agricultural production gives some idea of possible changes in future rents of quasi-fixed factors, due to the incorporation of external effects. These estimates generate an upper bound because producers will use more efficient technologies after the introduction of quantity restrictions or taxes/levies (Pearce and Turner, 1990). Moreover, an increase in the prices of agricultural products due to the introduction of quantity restrictions or taxes/levies can partly or completely offset these effects. Here, either the Netherlands should be an important producer of a particular product or other countries should introduce similar regulations. As a last factor, the government might bear a part of the costs of incorporating external effects in the production decisions of the agricultural sector. This is, however, only a shift of the burden from the agricultural sector to the taxpayer.

Due to an increasing level of real net production in the economy, shadow prices of most external effects will increase. This will boost the (negative) value of the environmental effects unless quantities are sufficiently reduced.

The methodology is applied to the most important environmental effects of agricultural production over the past 40 years. The methodology is not very different from the earlier work of Hueting (1974) developed for a national economy. Empirical estimates of external effects of agricultural production are very scarce, which makes it difficult to compare these results with other research. This analysis focused on a limited number of external effects. More effects could be included, but the environmental effects are currently receiving the most attention.

## Notes

[1]Wageningen Agricultural University.

[2]There are two stages in this process, where the soil is still "attracting" these materials and where there is already leakage. Here, the other types of pollution are already mentioned.

[3]This can embrace direct impact on nature itself, as well as indirect effects, due to potential living circumstances for wildlife and birds.

[4]One could also add a set of input variables in the category of external effects, but these effects seem to be less important and are discarded in this analysis.

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## Discussion Opening—*Zhigang Chen* (Université Laval)

Oskam takes on a very ambitious task, that of measuring the environmental effect of agricultural production at the industry level. He makes the provisional assumption that monetary values can generally be placed on given physical changes in the environment. This assumption is extremely convenient, since it implies that environmental losses or gains and the cost of averting or creating them are measurable in the same dollar unit, and thus one can determine how much can justifiably be spent on environmental control.

A very interesting result of the paper is that incorporating the environmental effects of agricultural production reduces the gross value added in the Netherlands by 5–15 percent. However, the significance of this result depends on the reliability of the calculation and, unfortunately, there are reasons for questioning the accuracy and relevance of these calculations, given the method used to construct the quantity and shadow price of the environmental effects. Since estimating the shadow price of the environmental effect is an essential part of the paper, as is the whole measurement issue, more explanation is needed.

The difficulties inherent in quantifying the environmental impact of agricultural production may be conveniently summarized in a Coasian framework. Let us assume that the world consists of two groups—farmers and the rest of society. As farmers increase their production, their marginal net benefit falls to zero at some point beyond which they will not rationally wish to produce. Meanwhile, society must bear increasing marginal external costs related to the level of production. In practice, the shape and location of these marginal curves is unlikely to be known, and they will move under the impact of changing prices and available technology, so that it is extremely difficult to measure the amounts. Given the diversity of the resource base (i.e., soil type) and underlying technology in agriculture, it is likely that substantial survey and estimation work will be needed before marginal external benefits can be estimated with any accuracy. One may suggest the use of farm-gate prices, but this could result in an over-estimate if the social value of the extra output is less than the private value. This is especially important for agricultural products where price or production is subsidized.

The uncertainty in estimating marginal external benefits is probably insignificant compared to that related to the estimation of marginal external costs. There are several methods available, such as contingent valuation and hedonic prices, each with its own merits and shortcomings. Fortunately, agricultural and resource economists have been working on these problems for a number of years, so there is a considerable body of literature to consult.

Despite its simplification of the issues, Oskam's paper does provide some useful indications of the appropriate methodological direction to take and points towards future research needs. For example, the environmental impact of agricultural production is simply overlooked in the current analysis of agricultural productivity and comparisons across national boundaries, probably due to the difficulty of incorporating environmental effects in productivity measurement. Oskam's paper provides some ideas on how to deal with this problem as well as with other issues relating to agriculture and the environment.

*[Other discussion of this paper and the author's reply appear on page 143.]*