Environmental targets and shadow prices of bad outputs in organic and conventional farming

Anni Huhtala[1] and Per-Olov Marklund[2]

[1]MTT Agrifood Research Finland, Luutnantintie 13, FI-00410 Helsinki, Finland

[2]Department of Economics, Umeå University, S-901 87 Umeå, Sweden

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Environmental targets and shadow prices of bad outputs in organic and conventional farming

Anni Huhtala[1] and Per-Olov Marklund[2]

[1]MTT Agrifood Research Finland, Luutnantintie 13, FI-00410 Helsinki, Finland

[2]Department of Economics, Umeå University, S-901 87 Umeå, Sweden

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Abstract

We present a framework for deriving shadow prices for negative environmental impacts regulated in agriculture. The shadow prices can be used as indicators of the costs of environmental regulation imposed as reflected in alternative farming technologies adopted. We illustrate our analytical findings with implications of the Finnish water protection policy measures on conventional and organic livestock farms over the period 1994-2002. Generally, the representative organic farm is found to be more technically efficient relative to its own technology than is the conventional representative farm. However, there is no statistical indication of a difference between these two particular representative farms in valuing the costs of undesirable output (manure) at the margin.

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JEL Codes: H23, C21, Q12, Q21

1 Introduction

Organic farming has become an important option for policies promoting food safety and environmental quality of food production. By ruling out the use of synthetic fertilizers and other chemicals organic farming represents an environmentally 'clean' technology which can be viewed as a constrained version of conventional farming in agriculture. However its potential environmental friendliness does not come without a cost. Yields in organic farming are in general significantly lower than under conventional management, even though the yield differences vary between products and to a certain extent between countries. (Offerman and Nieberg, 2000; Zanoli and Gambelli 1999)

Depending on the farming strategies adopted also the environmental impacts will change accordingly. It is necessary to evaluate the existing measures of economic performance of conventional and organic farming technologies from a point of view of environment, since conventional economic indicators may be misguided. We provide an analytical framework for measurement of shadow prices for environmentally detrimental outputs for agricultural sector using the opportunity cost of production. In other words, we assume implicitly that abatement is only possible by adjusting agricultural production, or output/value added at the farm level.

The shadow pricing is based on a straightforward assumption that the current regulation reflects the environmental preferences of the society. What is important for our purpose is to draw a distinction between good and bad outputs which has been recognized, e.g., by Färe and Grosskopf (1998, 2004) and Smith (1998). Our empirical application of shadow pricing has its origin in Färe et al. (2001, 2004). By exploiting the duality theory, the shadow prices can be derived from the output distance function using the envelope theorem. Since the cost for reducing bad outputs is in terms of forgone revenue from good outputs, each bad output commands its own shadow price at the margin. Shadow prices, or social costs, of environmentally detrimental outputs such as runoff of nutrients to watercourses can be estimated.

To illustrate our analytical findings, we consider the implications of water protection policy measures in the Finnish agriculture. In purpose of alleviating leakage of nutrients to the waters, the authorities have imposed restrictions that limit the use of manure as a fertilizer. With certain exceptions, maximally 15 m^3 manure is allowed to be spread per hectare cultivated land annually. If this policy measure is restrictive, the performance of the farms change as the environment becomes a factor to be taken into account in the economic maximization problem. Furthermore, since an undesirable by-product is produced its effects on the environment have negative welfare consequences that should be accounted for in monetary terms. The shadow price implicitly reveals the value that the regulatory authorities put on the last unit manure spread on land causing environmental damages. If the authorities know the environmental preferences of the society and know how and to what extent undesirable output affects the environment, the shadow price is the correct value from a socially optimal point of view.

Our farm-level data are sampled from the Finnish FADN network. We have information on the technology chosen (organic vs. conventional), amounts of good output (value added) and bad output (manure) produced, and inputs of capital, labor, energy, land, and other materials used. Generally, our results indicate that the representative organic farm is more technically efficient relative to its own technological frontier than is the conventional representative farm. However, there is no statistical indication of a difference between these two particular representative farms in valuing bad output (manure) at the margin. That is, the marginal abatement costs are equal, somewhere between FIM 449 – 882. This means that we cannot reject the hypothesis of the Finnish authorities pursuing a cost efficient manure policy.

The paper is organized as follows. In section 2, we present a simple optimization problem in which organic nutrient surplus, or manure, is an environmentally detrimental by-product of all agricultural production to such extent that it is regulated by environmental standards. We compare two different types of technologies, organic and conventional farming from a social point of view. In section 3, the empirical framework, based on production frontiers, is outlined, including the shadow-pricing methodology, empirical specification, and a brief description of empirical data. The results are presented in section 4 and, finally, section 5 concludes.

2 Optimization framework for incorporating undesirable output in agricultural production

Formally, a first best optimal solution can be derived by setting up a social planner's utility maximization problem. The agricultural sector produces consumption goods *C* and *G* by using conventional and organic farming technology, respectively. Therefore, we posit two production functions which involve conventional production, $f(L_1;\overline{K_1})$ and organic production, $g(L_2;\overline{K_2})$. Both technologies utilize land (L_1,L_2), which is a variable input. The main difference in the production functions is the given technology, and sector specific capital denoted here by K[1]. Simultaneously with production of goods, a bad output, *b*, causing environmental deterioration is generated such that $b=\mu_1 f(L_1;\overline{K_1})+\mu_2 g(L_2;\overline{K_2})$, where μ_1 and μ_2 are non-negative coefficients. The environmentally undesirable output can be, e.g., manure generated in animal production as excessive amounts of manure spoil recreation possibilities due to odors or water pollution impacts. The by-product causing nuisance shows up as an argument in the society's objective function. The utility function takes the form *U(C,G,b)* with $U_C>0$, $U_G>0$, and $U_b<0$.

For the maximization problem of the social planner, we write the Lagrangian

$$\begin{aligned}(1)\qquad \ell &= U(C,G,b)+\lambda_1(f(L_1;K_1)-C)+\lambda_2(g(L_2;K_2)-G)\\ &+\varphi(b-\mu_1 f(\cdot)-\mu_2 g(\cdot))+\omega(\overline{L}-L_1-L_2)\end{aligned}$$

and the first order conditions

$$(2)\qquad \partial\ell/\partial C = U_C-\lambda_1=0$$

$$(3)\qquad \partial\ell/\partial G = U_G-\lambda_2=0$$

$$(4)\qquad \partial\ell/\partial b = U_b+\varphi=0$$

$$(5)\qquad \partial\ell/\partial L_1 = \lambda_1 f_{L_1}-\varphi\mu_1 f_{L_1}-\omega=0$$

$$(6)\qquad \partial\ell/\partial L_2 = \lambda_2 g_{L_2}-\varphi\mu_2 g_{L_2}-\omega=0$$

From (2), (4), and (5) the optimality necessitates that

$$(7)\qquad U_C=\frac{\omega}{f_{L_1}}+\varphi\mu_1=\frac{\omega}{f_{L_1}}-\mu_1 U_b$$

to guarantee efficient input use in conventional farming. In particular, the environmental deterioration is optimal up to the point where the marginal utility value of the good output equals the sum of the direct marginal disutility ($U_b<0$), which is proportional to the good output (by a factor μ_1), and the private production cost (ω/f_{L_1}).

Accordingly, equations (3), (4) and (6) determine optimal input use in organic farming

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[1] The capital stocks and technologies are given in our static analysis as we do not consider investment decisions. Distinguishing a separate production function for each technology reflects the fact that technologies are sector specific and two different types of capital stocks are used in different combinations of variable inputs. In fact, we cannot measure all inputs empirically, as the capital stocks include even know-how, or human capital including learning which can be critical for adopting new technologies (see, e.g., Sipiläinen et al 2005). In the analytical model, the differences in production technologies are simply captured by two distinct capital stocks, K_1 and K_2.

(8) $$U_G = \frac{\omega}{g_{L_2}} - \mu_2 U_b .$$

Hence, organic farming technology should be employed up to the point where both the direct production/input costs and disutility of an additional undesirable output is properly taken into account. Consequently, how much of each technology should optimally be adopted is determined by

(9) $$\frac{U_G + \mu_2 U_b}{U_C + \mu_1 U_b} = \frac{f_{L_1}}{g_{L_2}} .$$

As it is well-known from the environmental economics literature, the socially optimal solution can be attained in a market economy by using economic instruments that internalize the externality from the undesirable by-product of production. In the following, we show how government can use regulation imposing an environmental standard on the by-product. The standard becomes an implicit shadow price that corresponds to the value of the environmental externality, U_b. The shadow price also reflects the farm's marginal abatement cost and, therefore, how stringent the standard is perceived by the farm.

Assume that competitive farms are producing both conventional and organic products for market prices p_C and p_G, respectively. Production is regulated such that both technologies have a similar constraint for a maximum amount of environmentally detrimental output, $\bar{b}$, such that $\mu_1 f(L_1;\overline{K_1}) \le \bar{b}$ and $\mu_2 g(L_2;\overline{K_2}) \le \bar{b}$. Given these constraints, the two representative farms maximize profits

$$\pi_C = p_C f(L_1;\overline{K_1}) - rL_1 - q_C(\bar{b} - \mu_1 f(L_1;\overline{K_1}))$$
$$\pi_G = p_G g(L_2;\overline{K_2}) - rL_2 - q_G(\bar{b} - \mu_2 g(L_2;\overline{K_2}))$$

where r is land rent and q_C and q_G are shadow prices or Lagrangian multipliers. The optimality necessitates

(10) $p_C f_{L_1}(\cdot) + q_C \mu_1 f_{L_1}(\cdot) = r$ and (11) $p_G g_{L_2}(\cdot) + q_G \mu_2 g_{L_2}(\cdot) = r$

such that the (accounting) prices can be expressed as

(12) $p_C = \frac{r}{f_{L_1}(\cdot)} - q_C \mu_1$ and (13) $p_G = \frac{r}{g_{L_2}(\cdot)} - q_G \mu_2 .$

Rearranging we have

(14) $$\frac{p_G + \mu_2 p_G}{p_C + \mu_1 p_C} = \frac{f_{L_1}}{g_{L_2}} .$$

From (7) and (12) and (8) and (13), we have that u_C and u_G correspond to socially optimal prices if the externality, $-U_b$, is appropriately internalized or

(15) $$\frac{U_C - \frac{\omega}{f_{L_1}}}{-U_b} = \frac{p_C - \frac{r}{f_{L_1}}}{-q_C}$$ and (16) $$\frac{U_G - \frac{\omega}{g_{L_2}}}{-U_b} = \frac{p_G - \frac{r}{g_{L_2}}}{-q_G} .$$

These optimality conditions imply that regulation setting a constraint, $\overline{B}$, on the undesirable by-product from producing conventional and organic output, corresponds to the shadow price on this particular by-product, q_C and q_G, which should be equal when the regulator is striving for cost efficient policy.

This leads to a straightforward policy implication. If the negative environmental impacts, U_b, are not accounted for, the conventional measures of economic performance will be misleading indicators, and there will be no incentive to adopt a socially optimal amount of environmental friendly technology. However, we can "translate" the environmental targets to economic indictors through shadow prices that reflect how much the society value undesirable outputs.

We illustrate our analytical findings with implications of the Finnish water protection policy measures on agricultural production. In purpose of alleviating leakage of phosphorus and nitrogen to the waters, the Finnish authorities have imposed restrictions on animal farms that limit the use of manure (here it is assumed that one unit manure causes one unit compound bad output). With certain exceptions, maximally 15 m^3 manure is allowed to be spread per hectare cultivated land annually. If this policy measure is restrictive, the performance of the farms changes as the environment becomes a factor to be taken into account in the economic maximization problem. Furthermore, since this also means that the authorities hold the view that an undesirable by-product is produced its effects on the environment has negative welfare consequences that should be accounted for in monetary terms, which may be quantified using a shadow pricing approach. The environmental regulation on manure spreading and its implicit shadow pricing is illustrated in Figure1.

Initially, the farm maximizes profits subject to no environmental constraints and, therefore, chooses to operate at point A, where the produced good and bad output quantities are *y* and *b*, respectively. The farm has no concern about *b* affecting the environment, causing eutrophication, nuisance, etc. At point A the farm makes no effort to reduce emissions, i.e., there is no abatement cost and the shadow price of bad output equals zero. Therefore, to reduce the leakage quantity from *b* to *b',* the authorities introduce a policy measure that restricts the use of manure. Then, given that the farm still maximizes profits it has to adjust to point *A'*.

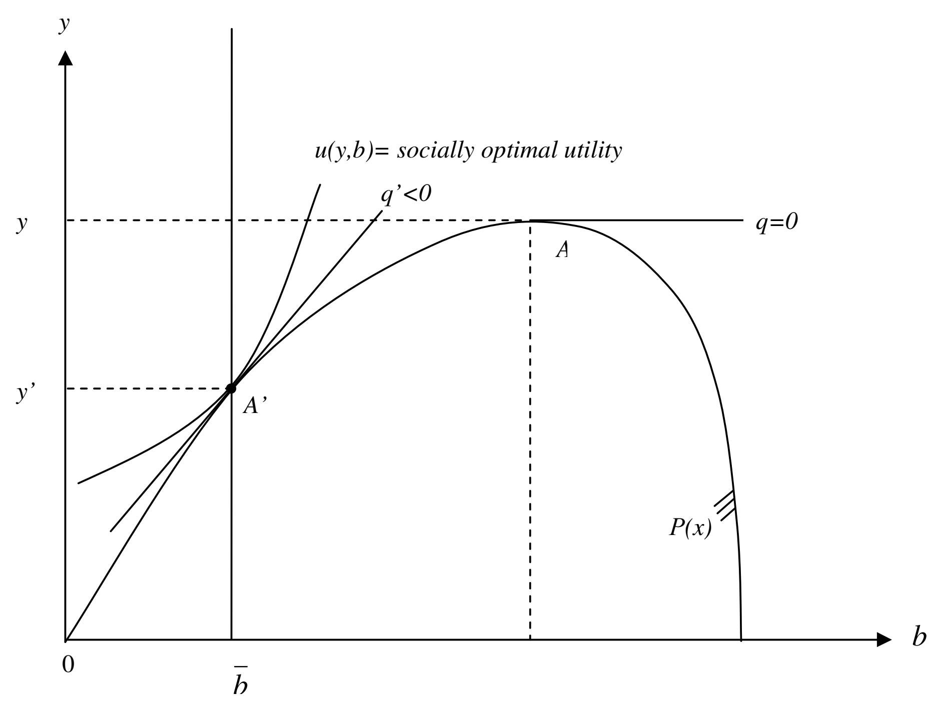

Figure 1.Illustration of environmental policy and its relation to shadow pricing

At point A', the relative shadow price of bad output is *q'/p*, which reflects the marginal rate of transformation between bad and good outputs. This means that the shadow price reflects the revenue forgone, $-(q'\cdot\partial b) = p\cdot\partial y$, due to the last reduced unit of bad output, $\partial b = -1$ As such, the shadow price τ can be interpreted as the marginal abatement cost at point *A'*.

Additionally, and in line with the formal theoretical discussion above, it is assumed in Figure 1 that the authorities know the environmental preferences of the society, and know how and the extent to which undesirable output affects the environment. Therefore, the authorities introduce the socially optimal manure restriction, $\bar{b}$, which equalizes the marginal utility, U_b, with the marginal abatement cost, *q*, from reducing bad output. Then, by estimating *q*, we implicitly reveal that the last unit manure spread on land causes the society negative external effects, or environmental damages, at the value of of $q = U_b$. This follows from the externalities being fully (optimally) internalized by the restriction $\bar{b}$.

3 Empirical analysis

The shadow-pricing methodology

To calculate shadow prices of bad outputs, in our case manure, a shadow-pricing model originating from Färe et al. (2001), Färe and Grosskopf (2004), and Färe et al. (2004) is used.[2] Formally, let $y = (y_1,...,y_M) \in \Re_+^M$ and $b = (b_1,...,b_J) \in \Re_+^J$ be vectors of good and bad outputs, respectively, and let $x = (x_1,...,x_N) \in \Re_+^N$ be a vector of inputs. The technology of reference is the output possibilities set, $P(x)$, which for a given vector of inputs denotes all technically feasible output vectors. This output set is assumed to be convex and compact with $P(0) = \{0,0\}$. Furthermore, inputs and good outputs are assumed to be freely disposable and bad outputs only weakly disposable. Finally, good outputs are assumed to be null-joint with the bad outputs. This means that good outputs cannot be produced without producing bad outputs. The directional output distance function is defined on $P(x)$, as

$$(16) \quad D(x,y,b;g) = \max_{\beta}\{\beta : (y+\beta\cdot g_y, b-\beta\cdot g_b) \in P(x)\}, \qquad g_y \in \Re_+^M, \quad g_b \in \Re_+^J$$

which then inherits its properties from $P(x)$. The solution, β^*, gives the maximum expansion and contraction of good outputs and bad outputs, respectively. The vector $g = (g_y = 1, -g_b = -1)$ specifies the direction in which an output vector, $(y,b) \in P(x)$, is scaled so as to reach the boundary of the output set at $(y+\beta^*\cdot g_y, b-\beta^*\cdot g_b) \in P(x)$, where $\beta^* = D(x,y,b;g)$. This means that the producer becomes more technically efficient when simultaneously increasing good outputs and decreasing bad outputs. The distance function takes the value of zero for technically efficient output vectors on the boundary of $P(x)$, whereas positive values apply to inefficient output vectors below the boundary. The higher the value the more inefficient is the output vector. Finally, the directional output distance function satisfies the translation property

$$(17) \quad D(x, y+\alpha\cdot g_y, b-\alpha\cdot g_b; g) = D(x,y,b;g) - \alpha$$

where α is a positive scalar.

When deriving the output shadow-pricing model the duality between the distance function and the revenue function is exploited. Let $p = (p_1,...,p_M) \in \Re_+^M$ and $q = (q_1,...,q_J) \in \Re_-^J$ represent absolute

[2] Marklund (2003) provides an application of this model to the Swedish pulp industry, together with a thorough overview of the development of the estimations of bad output shadow prices. See also Marklund and Samakovlis (2003) and Marklund (2004).

prices of good and bad outputs, respectively. Then the relative shadow prices of bad outputs, in terms of the *m:th* good output, can be calculated from

$$(18)\qquad \frac{q_j}{p_m} = \left(\frac{\partial D(x,y,b;g)}{\partial b_j} \Big/ \frac{\partial D(x,y,b;g)}{\partial y_m} \right), \qquad j = 1,...,J$$

which is the marginal rate of transformation between the $j:th$ bad output and the $m:th$ good output, MRT_{jm}, where $\partial D(\cdot)/\partial y_m < 0$ and $\partial D(\cdot)/\partial b_j \geq 0$. The shadow price is then measured in terms of decreased production of y_m, which has to be met when reducing b_j marginally.

The empirical specification model

Following, e.g., Färe et al. (2004) the directional output distance function is parameterised by using a quadratic flexible functional form and estimated using an econometric, COLS estimating, procedure[3] This means that the distance function is first estimated by OLS and then 'corrected' by adding the largest residual to the intercept. The corrected distance function, *CD(.)*, takes non-negative values and can be written as

(19)

$$\begin{aligned} CD^{kt}(x^{kt}, y^{kt}, b^{kt}; g) = \{ & (\alpha_0 + \max(\varepsilon^{OLS})) + \sum_{n=1}^{N} \alpha_n x_n^{kt} + \sum_{m=1}^{M} \beta_m (y_m^{kt} + b_J^{kt}) + \sum_{j=1}^{J-1} \gamma_j (b_j^{kt} - b_J^{kt}) \\ & + \frac{1}{2} \sum_{n=1}^{N} \sum_{n'=1}^{N} \alpha_{nn'} x_n^{kt} x_{n'}^{kt} + \sum_{n=1}^{N} \sum_{m=1}^{M} \delta_{nm} x_n^{kt} (y_m^{kt} + b_J^{kt}) + \sum_{n=1}^{N} \sum_{j=1}^{J-1} \eta_{nj} x_n^{kt} (b_j^{kt} - b_J^{kt}) \\ & + \frac{1}{2} \sum_{m=1}^{M} \sum_{m'=1}^{M} \beta_{mm'} (y_m^{kt} + b_J^{kt})(y_{m'}^{kt} + b_J^{kt}) + \sum_{m=1}^{M} \sum_{j=1}^{J-1} \mu_{mj} (y_m^{kt} + b_J^{kt})(b_j^{kt} - b_J^{kt}) \\ & + \frac{1}{2} \sum_{j=1}^{J-1} \sum_{j'=1}^{J-1} \gamma_{jj'} (b_j^{kt} - b_J^{kt})(b_{j'}^{kt} - b_J^{kt}) \\ & + \kappa_k + \tau_t \}^{OLS} + b_J^{kt} \end{aligned}$$

where κ_k and τ_t are parameters representing farm and time specific effects, respectively. This is the expression to differentiate when calculating shadow prices of outputs, in accordance with equation (18). The functional form in (19) satisfies symmetry, $\alpha_{nn'} = \alpha_{n'n}$, $n \neq n'$, $\beta_{mm'} = \beta_{m'm}$, $m \neq m'$, and $\gamma_{jj'} = \gamma_{j'j}$, $j \neq j'$, and the translation property in equation (17).

Finally, the distance function in (19) is separately estimated on observations from conventional and organic farming, respectively. In the former case good output is denoted $y = C$ and in the latter case the notation is $y = G$. As for the rest, the same variables are included in both estimations. Manure is denoted b_1, and x_1 denotes capital, x_2 labour, x_3 energy, x_4 land, and x_5 other materials.

Data

The original farm level data are from Finnish bookkeeping farms that participated in the Farm Accountancy Data Network (FADN) during 1994-2002. The selected conventional and organic samples consist of farms that have a share of livestock return of total return that is at least 60 percent. They are considered to be livestock (milk and beef) specialized farms. Furthermore, farms for which there only is

[3] Regarding the COLS estimator, see, e.g., Greene (1993). The particular approach adopted is used in Lovell et al. (1994), where, e.g., a Shephard output distance function is estimated. The COLS procedure applied on the directional output distance function is in more detail described in Marklund and Samakovlis (2003).

one single observation are excluded. This results in unbalanced panels, extending over the period 1994-2002 and consisting of 2094 observations for 261 conventional farms and 224 observations for 51 organic farms.[4] The directional output distance function is estimated on input and output variables constituting these panels. Following Färe et al. (2004, p. 12), the input and output variables are mean normalized before estimation. Descriptive statistics for the variables are provided in Appendix, Table A1.

4 Results

The directional output distance function is estimated on mean normalized data, using a COLS procedure. From the theory section we know that for the distance function to be well-behaved certain properties need to be fulfilled. In the particular COLS estimating procedure used the properties of translation, symmetry, and the function being non-negative are imposed, but null-jointness and monotonicity are only tested for afterwards. Our results from the estimations show that null-jointness is satisfied for 57 and 85 percent of the observations on conventional and organic farms, respectively. Monotonicity in good and bad outputs is fully satisfied for both types of farms. The parameters of the estimated distance functions are provided in Appendix, Table A2.[5]

In Table 1 the results for the representative farm in the conventional and organic farming sectors are provided. In both cases, at these particular points of evaluation, the estimated directional output distance function satisfies all the theoretical assumptions made (except for the monotonicity condition in some inputs, i.e., the derivatives with respect to the input show a negative sign).[6]

Table 1. Figures at mean of data for representative animal farms.[7]

	Conventional farms			
	Point estimate	*Standard error*	*t-value*	*Confidence interval*
q_1/p_1	-686.35	31.33	-21.90	-747.76 … –624.93
CD(.)	0.53	0.005	111.83	0.52 … 0.54

$\bar{y}_1$ = 354097 FIM, $\bar{b}_1$ = 623 m^3

	Organic farms			
	Point estimate	*Standard error*	*t-value*	*Confidence interval*
q_1/p_1	-635.33	95.17	-6.68	-821.86 … -448.80
CD(.)	0.17	0.03	6.11	0.12 … 0.23

$\bar{y}_1$ = 304248 FIM, $\bar{b}_1$ = 665.56491 m^3

During 1994-2002, the representative conventional animal farm was significantly technically inefficient. It could have increased the good output production from FIM 354097 to 354097 + 0.529829*354097 = FIM 541708 (52.9829 %), using the same technology, and without using larger input quantities. Similarly, the manure production could have been reduced from 623 m^3 to 623 - 0.529829*623 = 293 m^3. Furthermore, when having reached the frontier, this particular farm could have reduced the emissions of

[4] As some farms switch from conventional to organic production, and vice versa, during the period in study, the may show up in both samples, but not in the same year.

[5] Additionally, to check for possible multicollinearity problems the condition number (see e.g., Greene, 2000) of conventional and organic farming data matrixes are calculated, revealing the test statistic values 225 and 396, respectively. Even though Kmenta (1997) suggests that values larger than 30 should be interpreted as multicollinearity being present, the test results are fairly good, considering that flexible functional forms are representing the farm technologies.

[6] Descriptive statistics for estimated shadow prices and efficiency scores are provided in Appendix, Table A3.

[7] The test statistics have been obtained by applying the Delta test procedure, which is based on Taylor series approximation. A thorough description of this test is given in, e.g., Greene (2000).

one unit (m^3) manure by reducing good output at the value of FIM 686.349. Furthermore, also the representative organic animal farm was significantly technically inefficient. It could have increased good output production from FIM 304248 to 304248 + 0.170394*304248 = FIM 356090 (17.0394 %), using the same technology, and without using larger input quantities. The manure production could have been reduced from 666 m^3 to 666 - 0.170394*666 = 552.5176 m^3. In this case, the organic farm could have reduced the emissions of one unit manure by reducing good output at the value of FIM 635.332, after having reached the frontier.

In general, the representative organic farm is found to be more technically efficient relative to its own technological frontier than is the conventional representative farm. This is statistically confirmed, as the confidence intervals for the efficiency point estimates do not overlap, and in line with the results in Oude Lansink et al. (2002).[8] However, there is no statistical indication of a difference between these two particular farms in valuing manure at the margin. This means that there is no difference regarding marginal abatement costs, and that we cannot reject the hypothesis of the Finnish authorities pursuing a cost-efficient manure policy. Improved environmental quality from reducing the use of one m^3 manure is as valuable irrespective of which type of farm that is accomplishing the reduction. The result indicate that this particular value is by the Finnish authorities set somewhere at FIM 449-882. Finally, the conclusions generally drawn on the representative farms would also be drawn from the average figures of shadow prices and efficiency scores, provided in Appendix, Table A3.

5 Conclusions

The purpose of this paper is to provide an analytical framework that gives guiding principles about the stringency of environmental standards, imposed on farmers in the agricultural sector. Basically, we show that all the information needed can be obtained from estimating production technology on farm performance generated data.

To illustrate our analytical findings, we consider the implications of water protection policy measures in the Finnish agriculture. The use of manure is a source of environmentally undesirable by-products, e.g., leakage of phosphorous and nitrogen to the waters and, therefore, farms are allowed to spread maximally 15 m^3 phosphorus per hectare cultivated land. If the farmers perceive the measure as restrictive they experience marginal abatement costs, and the higher these costs the more stringent the environmental demand.

The marginal abatement costs are estimated using a shadow-pricing model that is derived from farm production technology, approximated by the estimated directional output distance function. This particular function measures technical efficiency, which tells us how efficient the farmers use their resources. Furthermore, if it includes undesirable by-products, the environment is counted for among these resources.

The shadow-pricing is based on a straightforward assumption that the current environmental regulation reflects the environmental preferences of the society. This assumption originates from the very basic result within economic theory, that marginal abatement costs from reducing environmentally detrimental by-products should equal the marginal utility from the resulting environmental improvement. Therefore, the estimated marginal abatement costs implicitly reveals the value, or the shadow price, that the regulatory authorities put on the environmental improvement when imposing restriction on undesirable emissions. As such, shadow-pricing, as suggested in this paper, provides a tool for evaluating the stringency of current environmental regulation, as it makes it possible to compare the society's revenue from improved environmental quality with the cost (reduced farm revenue) that is associated with this particular improvement. The shadow-pricing approach adopted also makes it possible to evaluate whether pursued environmental policy is cost efficient.

[8] Oude Lansink et al. (2002) use an input based data envelopment analysis (DEA) approach to study efficiency and productivity of Finnish crop and livestock farms during 1994-1997.

The results show that the representative organic farm used the resources more efficiently relative to its own conditions than the representative conventional farm did during 1994-2002. This result is in line with earlier research on Finnish agriculture. However, there is no indication of a difference between these two particular farms in valuing manure at the margin, i.e., marginal abatement costs. This means that we cannot rule out that the Finnish regulatory authorities pursued a cost-efficient manure policy during the period in study. The results further indicate that the authorities valued the environmental damages from one m^3 manure spread on land to somewhere at FIM 449-882 (2000 constant prices).

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Appendix

Table A1. Descriptive statistics per year for variables in the output distance function, representing conventional farm technology; mean and standard deviations (in parentheses).

Year	**Number of obs**	**Variables**						
		C	b_1	x_1	x_2	x_3	x_4	x_5
1994	251	324.92 (128.40)	602.45 (265.67)	342.84 (275.18)	4848.27 (1455.27)	27.27 (12.71)	31.45 (15.07)	153.49 (84.52)
1995	248	308.61 (132.25)	608.02 (259.51)	354.40 (267.97)	4935.88 (1508.50)	31.26 (15.24)	33.29 (16.44)	159.29 (75.22)
1996	247	344.26 (147.19)	627.85 (268.80)	387.88 (280.08)	4913.66 (1486.50)	29.53 (14.27)	35.11 (17.68)	158.25 (75.64)
1997	237	361.21 (15.82)	656.47 (278.92)	426.21 (314.98)	4945.83 (1516.07)	28.18 (14.30)	35.97 (17.64)	167.33 (88.06)
1998	241	322.01 (146.24)	676.34 (306.58)	474.29 (338.27)	5064.13 (1617.25)	27.02 (19.07)	38.29 (20.08)	189.07 (112.79)
1999	235	343.65 (162.22)	692.39 (303.50)	538.84 (375.28)	4927.40 (1479.63)	25.69 (15.81)	39.59 (19.76)	203.34 (111.40)
2000	226	383.99 (191.10)	556.25 (299.21)	583.96 (428.78)	5050.85 (1591.97)	24.04 (14.06)	41.20 (20.81)	220.26 (125.02)
2001	220	393.76 (201.07)	575.65 (318.44)	626.16 (468.33)	4874.15 (1615.70)	27.39 (15.24)	43.69 (21.97)	250.76 (141.27)
2002	189	428.47 (232.48)	603.99 (340.08)	676.70 (530.15)	4843.77 (1563.94)	28.78 (16.09)	45.21 (23.38)	256.91 (153.96)
99-02	2094	354.10 (170.48)	623.15 (295.24)	482.01 (384.06)	4935.30 (1534.88)	27.71 (15.37)	37.89 (19.64)	192.76 (114.74)
Min	-	3.83	96.00	7.99	988.00	4.33	8.52	31.80
Max	-	1173.48	2292.00	2938.44	11921.00	163.64	135.44	1025.86

y = C = outputs, except direct payments, 1000 FIM (2000 constant prices)
b_1 = manure, m3
x_1 = capital, machinery and buildings, 1000 FIM (2000 constant prices)
x_2 = labour, hours
x_3 = energy, fuel and electricity, 1000 FIM (2000 constant prices)
x_4 = land, arable area, hectare
x_5 = other material, 1000 FIM (2000 constant prices)

Table A1 (continuing). Descriptive statistics per year for variables in the output distance function, representing organic farm technology, mean and standard deviations (in parentheses).

Year	**Number of obs**	**Variables**						
		G	b_1	x_1	x_2	x_3	x_4	x_5
1994	20	299.33 (143.90)	629.17 (313.72)	335.41 (175.31)	4436.55 (1067.49)	28.13 (14.18)	36.47 (17.81)	150.08 (85.74)
1995	23	253.90 (143.93)	577.77 (312.11)	320.00 (197.84)	4368.30 (1217.00)	29.29 (12.78)	37.49 (17.17)	147.17 (70.41)
1996	27	300.93 (172.21)	647.33 (370.86)	368.02 (233.34)	4594.52 (1494.39)	30.20 (14.13)	39.92 (23.75)	158.17 (96.46)
1997	30	254.01 (143.41)	623.90 (362.52)	399.21 (269.25)	4197.77 (1577.12)	27.72 (14.92)	43.03 (29.57)	145.82 (96.81)
1998	18	229.40 (111.69)	629.51 (299.91)	458.76 (366.01)	4595.28 (1349.59)	29.87 (20.99)	47.02 (36.94)	144.21 (63.89)
1999	25	286.90 (198.45)	734.20 (434.02)	584.90 (419.56)	4753.80 (1684.95)	26.30 (13.67)	51.85 (39.53)	188.34 (155.07)
2000	25	351.75 (290.47)	659.43 (399.21)	725.81 (473.65)	4564.44 (1987.56)	30.08 (21.50)	55.87 (41.14)	222.07 (209.41)
2001	28	359.54 (268.38)	728.39 (466.57)	778.37 (446.99)	4556.61 (2012.58)	28.86 (17.99)	54.92 (33.93)	257.52 (191.52)
2002	28	372.05 (289.11)	730.46 (457.71)	796.92 (413.59)	4482.04 (1981.66)	30.37 (14.78)	58.82 (37.15)	263.66 (220.59)
99-02	224	304.25 (212.97)	665.56 (387.27)	540.69 (394.34)	4499.73 (1639.17)	28.97 (16.01)	47.70 (32.56)	189.65 (153.71)
Min	-	1.51	140.50	49.95	1159.00	5.74	12.30	21.42
Max	-	1418.05	2234.00	1622.71	10855.00	98.58	178.41	1016.71

$y = G$ = outputs, except direct payments, 1000 FIM (2000 constant prices)
b_1 = manure, m3
x_1 = capital, machinery and buildings, 1000 FIM (2000 constant prices)
x_2 = labour, hours
x_3 = energy, fuel and electricity, 1000 FIM (2000 constant prices)
x_4 = land, arable area, hectare
x_5 = other material, 1000 FIM (2000 constant prices)

Table A2. Parameter estimates of the mean normalized output distance function, representing animal farm technology.[9]

Coefficient	**Variable**	**Organic Estimate (t-value)**	**Conventional Estimate (t-value)**
α_0	**Intercept**	0.02 (0.14)	-0.22 (-3.85)
α_1	x_1	-0.02 (-0.17)	0.03 (1.41)
α_2	x_2	-0.03 (-0.15)	-0.02 (-0.28)
α_3	x_3	-0.25 (-2.13)	0.04 (1.65)
α_4	x_4	-0.42 (-2.74)	-0.05 (-1.21)
α_5	x_5	0.07 (0.59)	0.04 (1.27)
β_1	y_1	-0.37 (-3.47)	-0.38 (-13.85)
$\gamma_1=\beta_1+1$	b_1	0.63	0.62
α_{11}	x_1x_1	-0.11 (-1.52)	0.01 (0.60)
α_{12}	x_1x_2	0.09 (1.20)	-0.12 (-5.81)
α_{13}	x_1x_3	0.03 (0.53)	-0.002 (-0.22)
α_{14}	x_1x_4	-0.10 (-1.82)	0.05 (3.39)
α_{15}	x_1x_5	0.16 (1.63)	-0.07 (-6.50)
δ_{11}	x_1y_1	-0.03 (-0.51)	0.05 (5.41)
$\eta_{11}=\delta_{11}$	x_1b_1	-0.03	0.05
α_{22}	x_2x_2	-0.10 (-0.33)	-0.01 (-0.14)
α_{23}	x_2x_3	0.20 (1.81)	-0.12 (-4.43)
α_{24}	x_2x_4	0.04 (0.43)	0.17 (4.48)
α_{25}	x_2x_5	0.01 (0.08)	-0.04 (-1.64)
δ_{21}	x_2y_1	-0.08 (-0.72)	0.09 (3.77)
$\eta_{21}=\delta_{21}$	x_2b_1	-0.08	0.09
α_{33}	x_3x_3	0.24 (2.42)	0.02 (2.40)
α_{34}	x_3x_4	-0.15 (-2.02)	0.02 (1.41)
α_{35}	x_3x_5	0.06 (0.64)	-0.02 (-1.19)
δ_{31}	x_3y_1	-0.12 (-1.91)	0.02 (1.78)
$\eta_{31}=\delta_{31}$	x_3b_1	-0.12	0.02
α_{44}	x_4x_4	0.63 (4.84)	-0.01 (-0.31)
α_{45}	x_4x_5	-0.12 (-1.56)	0.02 (0.89)
δ_{41}	x_4y_1	-0.04 (-0.59)	-0.10 (-6.79)
$\eta_{41}=\delta_{41}$	x_4b_1	-0.04	-0.10
α_{55}	x_5x_5	-0.08 (-0.67)	-0.11 (-5.13)
δ_{51}	x_5y_1	-0.02 (-0.25)	0.12 (8.20)
$\eta_{51}=\delta_{51}$	x_5b_1	-0.02	0.12
β_{11}	y_1y_1	0.12 (1.77)	-0.12 (-7.62)
$\mu_{11}=\beta_{11}$	y_1b_1	0.12	-0.12
$\gamma_{11}=\beta_{11}$	b_1b_1	0.12	-0.12

[9] The parameter estimates of the farm and time effects are left out.

Table A3. Descriptive statistics per year for shadow prices and efficiency scores in the animal farming sector; mean and standard deviations (in parentheses).

Year	**Conventional farms**			**Organic farms**		
	obs	*CD(.)*	q/p_C	*obs*	*CD(.)*	q/p_G
1994	251	0.51224 (0.070433)	-687.42304 (181.0388)	20	0.26252 (0.061473)	-735.12760 (284.08037)
1995	248	0.51224 (0.079838)	-708.23887 (173.50215)	23	0.26252 (0.067701)	-635.49979 (175.10245)
1996	247	0.51224 (0.080657)	-655.35017 (167.34997)	27	0.26252 (0.060012)	-680.68317 (195.31854)
1997	237	0.51224 (0.071300)	-643.52064 (173.46114)	30	0.26252 (0.076635)	-655.15216 (163.06504)
1998	241	0.51224 (0.086699)	-710.25169 (191.24356)	18	0.26252 (0.072487)	-593.74175 (196.15436)
1999	235	0.51224 (0.081015)	-704.83961 (189.91634)	25	0.26252 (0.069189	-699.65931 (277.07233)
2000	226	0.51224 (0.097851)	-778.28325 (197.65626)	25	0.26252 (0.10795)	-703.10685 (459.74301)
2001	220	0.51224 (0.099568)	-816.39407 (249.83025)	28	0.26252 (0.075920)	-894.63667 (1304.36948
2002	189	0.51224 (0.098094)	-776.19692 (220.09811)	28	0.26252 (0.075410)	-847.74530 (1061.9017)
99-02	2094	0.51224 (0.084908)	-717.08707 (201.03786)	224	0.26252 (0.074256)	-722.74669 (634.83996)
Min	-	0.00000	-2286.22217	-	0.00000	-7491.56348
Max	-	1.14533	-41.23663	-	0.44128	-178.43460

CD(.) = efficiency scores

q/p_C = shadow price of manure in terms of FIM good output in the conventional animal sector (in 2000 constant prices)

q/p_G = shadow price of manure in terms of FIM good output in the organic animal sector (in 2000 constant prices)