Agri-Environmental Policy Effects at Producer Level - Identification and Measurement

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Effekte von Agrarumweltprogrammen auf Produzentenentscheidungen - Identifikation und Messung

Abstrakt

Die vorliegende empirische Studie untersucht die Effekte von Agrarumweltprogrammen auf individuelle Produzentenentscheidungen. Wir betrachten die Auswirkungen auf Produktionsintensität, -struktur und Wirtschaftlichkeit für ein Sample an Getreideproduzenten in England (2000 bis 2009). Die ökonometrische Methodik basiert auf einer direktionalen Distanzfunktion und den Einsatz von matching Schätzern. Die Ergebnisse zeigen u.a., dass ein Agrarumweltprogramm welches auf Freiwilligkeit beruht Produzentenverhalten deutlich effektiver beeinflusst. Der methodische Beitrag besteht aus der Verbindung eines produktionstheoretisch fundierten multi-output multi-input Ansatzes um verschiedene Masse zur Bewertung von Produktionserfolg und -struktur zu generieren. Letztere werden dann als Indikatoren für die robuste Treatment Analyse verwendet.

Schlüsselworte: Agrarumwelt Programme, PES, Direktionale Distanzfunktion, Matching Schätzers

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Abstract

This empirical study investigates the effects of different agri-environmental schemes on individual producer behaviour. We consider the effects on production intensity, performance and structure for a sample of UK cereal farms for the period 2000 to 2009 and use the policy examples of the Environmental Stewardship Scheme (ESS) and the Nitrate Vulnerable Zones (NVZ). The econometric methodology is based on a directional distance function framework as well as the application of matching estimators. We find that both schemes are effectively influencing production behaviour at individual farm level. However, agri-environmental schemes show only very minor effects on the technical and allocative efficiency of farms, hence, we can conclude that farms enrolled in agri-environmental schemes are efficiently adjusting their production decisions given the constraints by the respective scheme. Farms affected by these schemes indeed tend to become less specialised and more diversified with respect to their production structure. A voluntary type agri-environmental scheme seems to signficantly influence producer behaviour at a far higher scale than a non-voluntary agri-environmental scheme. The methodological novelty of this research lies in the use of a sound production theory based multi-output multi-input approach to disentangle measures for production performance and structure which are then used as indicators for the robust treatment effects' analyses.

Keywords: Agri-Environmental Policy, PES, Directional Distance Function, Matching Estimators

JEL: Q15, Q18, Q57, C23

1. Introduction

Policies to encourage the provision of agri-environmental goods have been introduced and developed since the 1980s as a consequence of rising concerns that agricultural support measures have led to a threatening level of land use intensity. Following standard economic theory, such agri-environmental goods (e.g. water quality or biodiversity) are unlikely to be provided through a market mechanism at their socially optimal levels because of externalities as well as the public good nature of the targeted goods. However, market based policy instruments are generally considered as a more cost-effective way to achieve environmental goals compared with command-and-control based policy instruments.

There is a considerable policy interest in the performance of agri-environmental measures. This is especially true with respect to voluntary agreement based agri-environmental schemes. Despite the widespread application of such agri-environmental schemes their cost-effectiveness and economic efficiency is only poorly understood. Given policy and fiscal needs (e.g. the current funding program for the UK agri-environment schemes is due to be revised in 2013, see e.g. Natural England 2010) there is an increasing debate among academics and policy makers as to whether schemes as currently implemented actually deliver the expected outcomes (see Ferraro and Pattanayak 2006, Butler et al. 2009, Hodge and Reader 2010, Sauer and Walsh 2010). This study aims to deliver empirical evidence on the impact of different agri-environment related regulatory instruments on farmers' production and investment decisions. We investigate the command-and-control based instrument of the Nitrate Vulnerable Zones Scheme (NVZ) and the voluntary agreement based instrument of the Environmental Stewardship Scheme (ESS). The analysis aims to disentangle the effects of those instruments on individual producer behaviour by measures of input intensities, production structure and farm performance.

In a first step input intensity indicators are calculated for the different farm type samples. In a second step partial performance measures and the individual farms' efficiency is estimated using a multi-output multi-input directional distance function approach as the dual to the profit function. A third analytical step consists of estimating the average change in these measures due to the effects of the policy schemes. This is done by using a matching estimator approach based on statistical propensity score analysis. Propensity score analysis is useful for evaluating policy instrument/program related treatment effects when using nonexperimental or observational data. As farm enterprises are economic phenomena defined by a multitude of different characteristics over space and time such a matching approach is needed to accurately determine the effect of agri-environmental policy instruments on these farms in a statistically robust way. The remaining paper is structured as follows: The next section outlines the policy instrument of agri-environmental schemes. Section 3 introduces the conceptual model of production behaviour including potential effects of agri-environmental schemes. Section 4 covers a brief introduction of the policy schemes considered whereas section 5 describes the datasets. Section 6 discusses the estimation results and finally section 7 concludes the study.

2. Agri-Environmental Schemes and Producer Behaviour

Considering instruments of economic policy at a very general level, economic instruments can be distinguished from traditional command-and-control instruments (see Hepburn 2006). In the area of agri-environmental policy economic instruments for conservation purposes (as e.g. market-based mechanisms such as eco-certification) are usually subsumed under the heading of payments for environmental services (PES). Following Wunder (2005) and Pagiola et al. (2007), payment schemes for environmental services generally have two common features: (1) they are voluntary agreements, and (2) participation involves a management contract (or agreement) between the conservation agent and the landowner. The latter agrees to manage an ecosystem according to agreed-upon rules (e.g. reducing fertiliser usage or stocking rates, or providing a public good by fencing to exclude stock from remnant bush) and receives a payment (in-kind or cash) conditional on compliance with the contract. Such contractual relationships are subject to asymmetric information between farmers and conservation agents.

Information asymmetries in the design of such contracts relate to hidden information and hidden action. Hidden information (leading to adverse selection) arises when the service contract is negotiated: Farmers hide information about their opportunity cost structure with respect to supplying the environmental service and, hence, are able to claim higher costs of provision and finally higher payments. Hidden information has been the subject of numerous theoretical analyses in the context of agri-environmental payment schemes (see e.g. more recently Ozanne et al 2001, Peterson and Boisvert 2004, Ozanne and White 2008, Russell and Sauer 2011). Hidden action (or moral hazard) arises after the contract has been negotiated leading to costly monitoring and enforcement in the case of non-compliance on the side of the conservation agent. The agent might not be able to perfectly monitor and/or enforce compliance or might choose not to monitor and/or enforce compliance. Hence, the farmer has an incentive to avoid the fulfillment of the contractual responsibilities and to seek rent through non-compliance (see e.g. more recently Ozanne and White 2008, Yano and Blandford 2009, Zabel and Roe 2009, Russell and Sauer 2011).

Pullin and Knight (2009) stress that the problems of environmental change and biodiversity loss have entered the mainstream political agenda. It seems likely that conservation biologists and environmental managers will be asked about the effectiveness of conservation interventions. Hence, managers and policy actors require an interim product (an evidence-base) to underpin their current decision-making. Green accounting matrices or input-output accounting systems (IOA) have been developed in countries with intensive agricultural production to facilitate voluntary improvements in farm environmental performance. These systems are to be used for the assessment of farm input use and efficiency in areas with intensive agricultural production as a response to an increased interest in the environmental performance of different farming systems. Halberg et al (2005) conclude that such systems need further development and standardization. Only a few studies so far have attempted to empirically measure the actual impact of being subject to agri-environmental schemes on producer behaviour at individual farm level using statistical or econometric tools. Brady et al (2009) assess the long-term effects of the 2003 CAP reform on farm structure, landscape mosaic and biodiversity using a spatial agent-based model for a sample of EU countries. Mosnier et al (2009) employ a bio-economic modelling approach to estimate the effect of decoupled payments and cross-compliance measures for typical farms in the Southwest of France. Pufahl and Weiss (2009) find that agri-environmental schemes significantly reduced the purchase of fertiliser and pesticide of individual farms in Germany. Sauer and Walsh (2010 and 2011) most recently attempt to measure the relative cost-effectiveness of agri-environmental schemes using a farm level approach based on large panel data sets and taking into account farms' compliance behaviour. We try to contribute to this evolving empirical literature by providing a sound production theory based analysis which satisfactorily addresses the problem of identification with respect to behavioural changes at farm level (see also Rosenzweig and Wolpin 2000).

3. Conceptual Model

We start our empirical investigation by modelling an individual cereal farm i focusing on the production decisions at time t. As the typical cereal farm produces more than one output (e.g. arable output, livestock output, other output) using more than one input (e.g. land, labor, fertilizer, chemicals) we employ the conceptual framework of a multi-output multi-input distance function.

Directional Technology Distance Function

The set of all technologically possible input-output combinations for cereal farm i can be described by the following production technology:

(1) $T = \{(x, y) \colon x \text{ can produce } y\}$

where $x \in R_+^N$ is a vector of inputs and $y \in R_+^M$ is a vector of outputs (see Chambers et al 1998). The directional technology distance function (DTDF) provides a complete functional representation of the production technology and a measure for production (in)efficiency (Faere and Grosskopf 2000). The DTDF represents a variation of the shortage function (Luenberger

1992) and is related to the well known Shephard (1953) input and output distance functions. It measures the distance from a particular observation to the efficient boundary of technology and its value depends on a mapping rule (or a directional vector) by which the direction is determined in which the inputs are to be contracted and the outputs are to be expanded (see also Guarda et al 2011). For a given direction $g = (g_x, g_y)$ with $g_x \in R_+^N$ and $g_y \in R_+^M$ the DTDF is given by

(2) $\vec{D}_T(x, y; g_x, g_y) = sup\{\varphi: (x - \varphi g_x, y + \varphi g_y) \in T\}$

and takes values in the interval $[0, +\infty]$. The directional distance function equals zero for technically efficient observations and takes a positive value for inefficient observations (for the functional properties see in detail e.g. Chambers et al 1998). For every observation k, k = 1, …, K

(3) $\omega_k = \vec{D}_T(x, y; g_x, g_y) + \varepsilon_k$

where $\omega_k \sim |N(0, \sigma_\omega^2)|$ is a nonnegative error component representing the distance function value and $\varepsilon_k \sim N(0, \sigma_\varepsilon^2)$ is a conventional two-sided disturbance term accounting for specification errors. The translation property of the DTDF allows for its empirical estimation (Faere and Grosskopf 2000)

(4) $\vec{D}_T(x_k - \lambda g_x, y_k + \lambda g_y; g_x, g_y) = \vec{D}_T(x_k, y_k; g_x, g_y) - \lambda$

with $\lambda \in R$ and is the additive analog of the homogeneity property of the Shephard distance function. This property implies that the translation of the input-output vector from (x, y) to $(x - \lambda g_x, y + \lambda g_y)$ leads to a decrease in the distance function value by the scalar λ. Hence, by substituting (3) into (4) we obtain

(5) $-\lambda = \vec{D}_T(x_k - \lambda g_x, y_k + \lambda g_y; g_x, g_y) - \omega_k + \varepsilon_k$

Assuming a simultaneous expansion of all outputs and a contraction of all inputs we set $g = (g_x, g_y) = (1,1)$ which implies that the amount by which a farm could increase outputs and decrease inputs will be $\vec{D}_T(x, y; 1,1)$ units of x and y. For a farm that is technically efficient, the value of the directional distance function would be zero whereas values of $\vec{D}_T(x, y; g_x, g_y) > 0$ would indicate inefficiency in production. If such a mapping rule is used with $\lambda = x_1$ we obtain

(6) $-x_{1k} = \vec{D}_T(0, x_{2k}^*, \ldots, x_{Nk}^*, y_{1k}^*, \ldots y_{Mk}^*) - \omega_k + \varepsilon_k$

where $x_{2k}^* = x_{2k} - x_{1k}, \ldots, x_{Nk}^* = x_{Nk} - x_{1k}, y_{1k}^* = y_{1k} + x_{1k}, y_{Mk}^* = y_{Mk} + x_{1k}$.

Duality and Nerlovian Profit Efficiency

An essential property of the directional technology distance function is that it is dual to the profit function. Profit maximisation requires the simultaneous adjustment of outputs and inputs, which is also a characteristic of the DTDF. Denote input prices by $w_N \in R_+^N$, ouput prices by $p_M \in R_+^M$ and technology T, we can define the profit function $\Pi(p, w)$ as:

(7) $\Pi(p, w) = \max\{py - wx: (x, y) \in T\}$

which is homogeneous of degree 1 in prices, convex and continuous in positive prices. The Luenberger inequality can be used to derive the decomposition of profit efficiency giving the following duality theorem (Faere and Grosskopf 2000)

(8) $\Pi(p, w) = \max\{py - wx + \vec{D}_T(x_k, y_k; -g_x, g_y)(pg_y + wg_x)\}$

$$\vec{D}_T(x_k, y_k; -g_x, g_y) = \max\left\{\frac{\Pi(p, w) - (py - wx)}{pg_y + wg_x}\right\}$$

Rearranging (8) and adding an allocative inefficiency term (AE) closes the inequality and gives the Nerlovian profit efficiency measure (Chambers et al 1998)

(9) $\frac{\Pi(p,w) - (py - wx)}{pg_y + wg_x} = \vec{D}_T(x_k, y_k; -g_x, g_y) + AE$

Hence, in addition to the technical efficiency measures provided by the DTDF, AE measures the residual inefficiency due to failure to choose the profit maximizing input-output bundle given relative prices. Profit efficiency is the ratio of the difference between maximal and observed profit normalized by the value of the direction vector.

Second Order Elasticities

The directional distance function allows for the measurement of substitution or complementarity relations between different inputs and outputs via the Morishima shadow price output and input elasticities of substitution (MES). The MES measure changes in relative output and input quantities as a consequence of changes in relative prices. MES can be interpreted as a measure of the percentage change in relative factors/outputs for a percentage change in price (Stern 2011). Following Blackorby and Russell (1989) and Färe et al (2005) the ratio of shadow output prices e.g. are derived from the DTDF as leading to the Morishima elasticity as

$$(10)\qquad M_{y_2 y_1} = y_1^* \left[\frac{\frac{\partial^2 \vec{D}_T(x_k,y_k;-g_x,g_y)}{\partial y_2 \partial y_1}}{\frac{\partial \vec{D}_T(x_k,y_k;-g_x,g_y)}{\partial y_2}} - \frac{\frac{\partial^2 \vec{D}_T(x_k,y_k;-g_x,g_y)}{\partial^2 y_1}}{\frac{\partial \vec{D}_T(x_k,y_k;-g_x,g_y)}{\partial y_1}} \right]$$

with $y_1^* = y_1 + \partial \vec{D}_T(x_k, y_k; -g_x, g_y)$.

Hence, we approximate the production behaviour and performance of a cereal farmer i at time t by using the concept of a directional distance function and derivable first and second-order measures. These measures indicate in how far farms participating in a voluntary management agreement type agri-environmental scheme and/or affected by a non-voluntary command-and-control type scheme alter their production behaviour as a consequence of these schemes. However, farms differ with respect to their characteristics and compliance behaviour reflecting differences in managerial skills, technology, location but also individual attitudes and experiences. The need for a robust empirical identification of the policy instruments' related treatment effects with respect to the farms production behaviour, hence, leads to crucial modelling implications.

4. Schemes and Data

For the modelling of the production technology we use individual farm data for the period 2000 to 2009 based on the UK Farm Business Survey (FBS) annually collected and released by Defra. We extract a representative subsample of cereal farms (FBS robust type 1) using stratified sampling techniques with a total sample size of more than 4,000 observations. The dataset includes information on outputs and inputs as well as various farm and farmer characteristics (due to space limitations, more descriptive information can be obtained from the authors). For the agri-environmental schemes we use the examples of the Environmental Stewardship Scheme (ESS) and the Nitrate Vulnerable Zones (NVZ) in the UK. Whereas the first scheme is a typical agreement type instrument, the latter scheme is based on a command-and-control structure.

The Environmental Stewardship Scheme (ESS)

The UK Environmental Stewardship Scheme (ESS) has been launched in mid 2005 and replaces the previous UK agri-environment schemes. It consists of an entry-level (ELS) and a higher-level (HLS) scheme, whereas the entry-level scheme has also an organic strand. The ESS is an example of the 'wide-and-shallow' approach replacing the more targeted schemes that were in place since the mid eighties (Dobbs and Pretty 2004 and 2008, Defra 2005). As part of the Environmental Stewardship Scheme, agricultural producers agree to modify their production activities to benefit the environment and are compensated for the costs they so incur. Most modifications imply a reduction in the intensity of production and the loss is usually conceived as income foregone by profit-maximizing producers. The level of compensation offered must be sufficient to persuade producers to forgo production options and to replace the income they lose.

The Nitrate Vulnerable Zones (NVZ)

The Nitrate Pollution Prevention Regulations 2008 have been introduced to implement the ECs Nitrates Directive and to reduce nitrogen losses from agriculture to water. Areas where nitrate pollution is a problem are designated - known as Nitrate Vulnerable Zones (NVZs). Rules are set for certain farming practices to be followed in these zones. In 2006 the agricultural area designated as NVZs has been increased to about 68%. The owner or occupier of any land or holding within an NVZ is responsible for complying with the rules whereas the Environment Agency is responsible for assessing farmers' compliance with these regulations, accomplished by random farm visits. Compliance with these rules is a requirement for cross compliance under SPS. Nitrate Vulnerable Zones rules concerning e.g. the storage of organic manures, the limiting of livestock manure, the planning of nitrogen use, the limiting of N requirements with respect to crop production, the management of spreading periods for organic manures and manufactured fertiliser, the nitrogen impact on surface water, and different field application techniques.

5. Empirical Identification and Econometric Modelling

Farm enterprises and their production behaviour are economic phenomena defined by a multitude of different characteristics over space and time. Hence, the accurate determination of the behavioural effects of agri-environmental policy instruments in a statistically robust way remains a methodological challenge (Rosenzweig and Wolpin 2000 or Rubin 1997). With respect to agricultural policy analysis e.g. Kirwan (2009) used regression analysis to investigate the effects of US federal farm programs on land rental values whereas Pufahl and Weiss (2009) applied propensity score matching to evaluate the effects of the German agri environmental programme on production decisions. Petrick and Zier (2011) most recently estimate the effects of various CAP measures on labor use in German agriculture. Different recent contributions in the area of econometric policy program evaluation point to the weak theoretical foundation of these empirical studies highlighting that structural models of economic behaviour (i.e. demand or supply structures) are missing (e.g. Heckman and Vytlacil 2007 or Heckman 2010). However, linkages to such underlying structural models of individual economic behaviour are crucial if agricultural production patterns are to be empirically modelled.

Beside simple partial indicators of production intensity based on the green accounting approach, the following empirical analysis is informed by sound production theory as well as takes into account methodological issues of behaviour identification and quantitative impact evaluation. We address problems of latent heterogeneity and potential endogeneity with respect to the observed farms by a two-stage estimation strategy to avoid the estimation of spurios policy effects (Imbens and Wooldridge 2009). The general research set-up of our study is as follows: In a first step input intensity indicators are calculated for the different observations in our cereal farm type sample. In a second step partial performance measures and the individual farms' efficiency is estimated using a multi-output multi-input directional distance function approach (see section 3). This distance function is estimated as a frontier type function to obtain relative measures of individual farms' efficiency. A third analytical step consists of estimating the average change in these measures due to location in a NVZ scheme relevant area and/or participation in the ESS scheme. This is done by using a bias-corrected and robust variance based matching estimator (see e.g. Guo and Fraser 2010, Abadie and Imbens 2002 and 2006, Abadie et al 2004).

Econometric Estimation of Technology

We parameterize the DTDF in (6) via a flexible transcendental-exponential functional form which we linearize as initially suggested in Blackorby et al. 1978 (see Blackorby et al 1978). It represents a second-order Taylor series approximation which is linear in parameters and sufficiently flexible to adequately approximate the true production technology (Faere et al 2010). The parameterized DTDF takes the form

$$(11)\quad exp\left[\vec{D}_T\left(x,y;g_x,g_y,\theta\right)\right] = \sum_{i=1}^{N}\sum_{j=1}^{N}\alpha_{ij}exp\left(\frac{x_i}{2}\right)exp\left(\frac{x_j}{2}\right)+\sum_{k=1}^{M}\sum_{l=1}^{M}\beta_{kl}exp\left(-\frac{y_k}{2}\right)exp\left(-\frac{y_l}{2}\right)+\sum_{i=1}^{N}\sum_{k=1}^{M}\gamma_{ik}exp\left(\frac{x_i}{2}\right)exp\left(-\frac{y_k}{2}\right)+\varepsilon$$

with $\theta=(\alpha,\beta,\gamma,\delta)$ as a vector of parameters to be estimated and ε is a random error assumed to be independendly and identically distributed with mean zero and variance σ_ε^2. The output vector y consists of cereal output and other (non-cereal) output; the input vector x includes labor, land, capital, fertilizer, chemicals, intermediate inputs whereas the latter is used as the scalar λ following (4) above. To obtain the dtdf specification we use the mapping rule: $(x - \lambda g_x, y + \lambda g_y)$, i.e. $(g_x, g_y) = (1,1)$. All monetary values are deflated as is common practice. To measure individual farms' efficiency we use a parametric stochastic frontier approach in a panel data specification applying the Battese and Coelli (1995) random effects estimator. The corresponding likelihood function and efficiency derivations are given in Coelli et al. (2005).

To obtain measures of allocative efficiency via the Nerlovian profit efficiency formula (see equation (8) above) we estimate the dual profit function which we parameterize also by a flexible transcendental-exponential functional form corresponding to the functional form chosen for the DTDF. This function is approximated using also a random effects estimator with the output and input price vectors corresponding to the quantities chosen for the DTDF specification as outlined above using a common Toernquist price formula where aggregated values are needed. To measure finally changes in output and input related production decisions at farm level we use the second order dual Morishima Elasticities of Substitution (MES) as outlined by equation (10). Unlike in the case of the quadratic function the estimation of the parameters of the transcendental-exponential function does not require the imposition of additional parameter restrictions. The estimation of (11) using maximum-likelihood methods is, however, subject to the endogeneity problem (see Guarda et al 2011, Faere et al 2005) as it will result in inconsistent results, since all of its nonzero right-hand side variables are endogenous (see also Atkinson et al 2003) and hence, are correlated with the composite error term. To ensure consistency in estimation we first regress all right-hand side variables in (11) on their lagged values using all other regressors as instruments and then secondly use the so generated fitted values in the maximum-likelihood estimation of (11).[1]

Econometric Estimation of Treatment Effects

In a second step a matching estimation technique is used to accurately identify the treatment effects of the policy schemes on farms' production behaviour. As we use survey based nonexperimental data collected through the observation of farming systems as they operate in normal practice (see Rubin 1997) this type of method allows to reduce multi-dimensional covariates to a one-dimensional score called a propensity score. The underlying framework of analysis refers to Neyman and Rubin's counterfactual framework (Guo and Fraser 2010) where farms selected into treatment and nontreatment groups have potential outcomes (Y_0, Y_1) in both states (W=0,1): the one in which the outcomes are observed ($E[Y_1|W=1]$, $E[Y_0|W=0]$) and the one in which the outcomes are not observed ($E[Y_1|W=0]$, $E[Y_0|W=1]$). Unobserved potential outcomes under either condition are missing data. A matching estimator directly imputes the missing data at the unit level by using a vector norm. Specifically it estimates the values of $Y_i(0)|W_i = 1$, i.e. the potential outcome under the condition of control for the treatment participant, and $Y_i(1)|W_i = 0$ as the potential outcome under the condition of treatment for the control participant. The central challenge is the dimensionality of covariates or matching variables, as their number increases the difficulty of finding matches for treated farms increases also. Matching estimators use the vector norm to calculate distances on observed covariates between treated case and each of its potential control cases (i.e. counterfactuals). Let the unit-level treatment effect for farm observation i be

$$(12) \qquad \tau_i = Y_i(1) - Y_i(0)$$

As one of the outcome is always missing, the matching estimator (ME) imputes this missing value based on the average outcome for farms with "similar" values on observed covariates. A simple ME is

$$(13) \qquad \hat{Y}_i(0) = \begin{cases} Y_i & if\ W_i = 0 \\ \frac{1}{\#J_M(i)} \sum_{l \in J_M(i)} Y_l & if\ W_i = 1 \end{cases} \quad ; \quad \hat{Y}_i(1) = \begin{cases} \frac{1}{\#J_M(i)} \sum_{l \in J_M(i)} Y_l & if\ W_i = 0 \\ Y_i & if\ W_i = 1 \end{cases}$$

[1] An alternative solution is to estimate the DTDF frontier using the generalized method of moments (GMM) approach (see e.g. Atkinson et al 2003). This approach would yield more efficient estimates, however, beside being computational intense GMM estimates are often sensitive to the choice of instruments and finally the finite sample properties of the estimator are unknown (see O'Donnell 2003).

where $J_M(i)$ as the set of indices for the matches for farm observation i and $\#J_M(i)$ as the number of elements of $J_M(i)$. In the case of more than one observed covariate the ME uses the vector norm to calculate distances between treated case and each of its multiple possible control cases. Consequently, M matches are chosen using the vector norm based on the condition of nearest distances applying

(14) $J_M(i) = \{l = 1, \dots, N | W_l = 1 - W_i, \|X_l - X_i\|v \leq d_M(i)\}$

with $d_M(i)$ as the distance from the covariates for unit i, X_i, to the Mth nearest match with the opposite treatment. Then point estimates for various treatment effects are obtained e.g. by the sample average treatment effect (SATE)

(15) $\hat{\tau}^{average} = \frac{1}{N}\sum_{i=1}^{N}\{\hat{Y}_i(1) - \hat{Y}_i(0)\} = \frac{1}{N}\sum_{i=1}^{N}(2W_i - 1)\{1 + K_M(i)\}Y_i$

where $K_M(i)$ are the number of times farm observation i is used as a match, with M matches per unit i, and W_i as the treatment condition for unit i. Abadie et al (2004) recommend using four matches for each unit as the drawback of using only one match is that the process uses too little information in matching. As we use continuous covariates a bias-corrected matching estimator (Abadie and Imbens 2002) is needed which uses a least square regression to adjust for potential bias. Further, the assumption of a constant treatment and homoscedasticity may not be valid for certain types of covariates. To also account for such potential heteroscedasticity we use a 2nd matching procedure matching treated to treated and control to control cases (see Abadie et al 2004).

Model 1 aims to measure the treatment effects by the different agri-environmental schemes with respect to production intensity using simple partial indicators. Model 2 measures the schemes' gradual treatment effects with respect to both production intensity and performance/structure whereas model 3 finally estimates the treatment effects with respect to production performance and structure approximated by the directional distance function application outlined before.

6. Results and Discussion

We have estimated more than 100 different distance frontier and matching models for our sample of about 4,000 observations on cereal farms in the UK for the period 2000 to 2009. Due to space limitations we do not report the individual model parameters here, only those that are necessary for interpretation. However, all estimates can be obtained from the authors upon request. The overall model quality of the estimated distance frontiers are evaluated using the value of the log-likelihood functions, the Lagrange Multiplier test statistics, the Akaike Information Criterion and the R-Squared test values. The statistical quality of the estimated matching models is judged by the values of the standard errors for the estimated sample average treatment effect estimates.

Production Intensity

Table 2 gives a descriptive overview of the different intensity measures with respect to cereal producers in the period 2000 to 2009 whereas table 3 summarizes the treatment effects at sample average based on model 1 (see appendix). This sample average treatment effect (SATE) allows to judge whether the particular instrument was "successful" (in terms of the indicators used). Considering the statistical significance of the individual estimates we are able to judge if the sample average for the particular measure is significantly different from zero or not. Given the particular modelling assumptions and estimator used, these estimates suggest that the SATE is significantly different from zero for all partial intensity indicators and all treatments considered. The treatment effect for the usage of fertilizer is about the same magnitude for all three treatments investigated (i.e. a reduction in expenditure per ha of about 45-50%). The sample average treatment effect for the usage of chemicals shows to be a bit higher for farms that participate in the ESS scheme and are located in an NVZ designated area (i.e. a reduction in expenditure per ha of about 49-51%). For the total variable costs of production the estimates suggest again the highest reduction in production intensity for farms that participate in the ESS scheme and are located in an NVZ designated area (i.e. a reduction in variable costs per ha of about 40-63%). In total these results indicate that both schemes – management-agreement type as well as command-and-control type – are effective in influencing production behaviour at individual cereal farm level with respect to the environmental intensity of production.

Production Intensity - Dosage

Table 4 reports the results of the matching estimation of model 2 for the ESS scheme (see appendix). The estimates for the dosage model suggest with respect to the ESS scheme that the SATE is significantly different from zero for all treatment dosages and intensity indicators considered. The highest average treatment effects are found for farms that generate about 15 to 20 TGBP per year which amounts to about 8.4% of their total annual income. However, it has to be noted that only 39 observations in our sample fall in this dosage class, whereas the majority of farms (670) generate not more than 5 TGBP income by their ESS scheme participation per year. In general it can be concluded that a higher dosage of ESS participation (in terms of income points which amount to GBP) results in a higher effectiveness of the scheme.

Table 5 reports the results of the matching estimation of model 2 for the NVZ scheme (see appendix). The estimates for the dosage model suggest with respect to the NVZ scheme that the SATE is the highest with respect to fertlizer usage for those farms that have more than 75% of their area in an NVZ scheme. However, with respect to chemicals the scheme seems to be most effective for farms that have only up to 25% of their area under the scheme. For the intensity indicator variable cost it seems that farms with an NVZ area of between 25-50% show the highest treatment effect. Apparently, the dosages of the NVZ scheme significantly vary in their treatment effects. Nevertheless, farms with about 25 to 50% of their area affected by the NVZ scheme seem to show the highest treatment effects overall. However, these are only about 37 observations in our sample, whereas the majority of farms has between 75 and 100% of their agricultural area located in an NVZ area.

These empirical findings partly confirm simple survey data on the usage of different chemicals on farms located in NVZ areas versus farms located in non-NVZ areas (here especially with respect to phospor and kalium application rates). This descriptive data clearly shows that the application rates for those two chemicals are lower for farms in NVZ areas than for farms in non-NVZ areas for the period 2004 to 2009. These are only partial ratios not taking into account the multi-dimensional nature of farm businesses and farmers' decision making. Such behavioural complexities are, however, taken account of by our multivariate matching extimation which is able to disentangle in a statistically robust way the marginal impact of being located in an NVZ area on individual production decisions over time and space for a particular type of farms (here cereal producers).

Production Performance and Structure

Table 6 gives a descriptive overview of the different partial and total performance measures with respect to cereal producers in the period 2000 to 2009 (see appendix, column 2). These estimates are either simple productivity ratios or based on the estimation of the distance frontier outlined above. It gets clear from the estimates that both agri-environmental schemes lead to significant effects on productivity measured by partial productivity ratios. The sample average treatment effect on land productivity as well as capital productivity is for both schemes significantly negative whereas the SATE for labor productivity is significantly positive for both schemes. The NVZ scheme has a higher impact (i.e. leads to more pronounced changes) on partial productivity for land and labor compared to the ESS scheme. Farms that are affected by both agri-environmental schemes show, however, the highest treatment effect for labor and capital productivity.

The estimation results consistently show that the – voluntary and/or mandatory – enrolment in agri-environmental schemes leads to a significantly lower productivity with respect to the usage of land and capital. On the other hand, both schemes lead to a higher productivity with respect to the input labor. It is well known that extensive agronomic practices involve more labor input, probably substituting for machinery. A higher labor productivity could simply point to the fact that these farms use their labor input now more efficiently especially if their labor supply is constrained. Furthermore, many of the management options included in the ESS scheme relate to complementary type services as e.g. the maintenance of buffer strips. Labor already working on the field could simply also do some extra scheme related labor intensive work at the field boundaries. Chemical input on the NVZ related field is substituted by labor leading also to a higher productivity of labor (due to spacelimitatins, the parameter estimates can be obtainedfrom the authors). The much lower intensiveness of production on agri-environmental related areas inherently results in a lower land and capital productivity which is compensated for by scheme related payments in the ESS scheme.

The estimated technical efficiency (about 95%) is relatively high for the cereal farms in our sample and the estimated Nerlovian allocative efficiency measure (about 59%) indicates a relatively modest price related efficiency of production decisions. Whereas the SATE related to both schemes is slightly positive for the technical efficiency component, it is not significant for the allocative efficiency component only in the case where the farm is affected by both schemes. Overall the treatment effects for technical and allocative efficiency are rather small, hence, we can conclude that farms enrolled in agri-environmental schemes are efficiently adjusting their production decisions given the requirements under the scheme. Even very minor efficiency improvements are possible as a result of entering such a scheme.

The estimated dual Morishima elasticities of substitution indicate the magnitude and direction of substitution between the different outputs and inputs used for production. The MES measures changes in relative output and input quantities as a consequence of changes in relative prices and is asymmetric by definition. The estimates for MES1a and 1b indicate that cereal and other outputs (e.g. livestock related, non-agricultural etc.) are substitutes i.e. as the price for cereal increases more inputs are devoted to the production of cereal at the expense of the production of other outputs and vice versa. However, the values indicate that the shift to the production of more cereals (i.e. as the price for cereals increaes by 1%, the production of other output decreases by about 0.32%) is twice as pronounced as the shift from the production of cereals (i.e. as the price for other output(s) increaes by 1%, the production of cereals decreases by about 0.16%). This indicates the high degree of specialisation of the farms in the sample as the marginal cost of producing one more unit cereals are much lower than the marginal cost of producing one more unit non-cereal output.

The estimated sample average treatment effects (SATE) summarize the treatment effects by the respective agri-environmental schemes. The SATEs for MES1a and 1b suggest the following: the voluntary ESS scheme leads to a lower substitutional effect as the price for non-cereal output(s) changes and only a very minor increase in the substitutional effect as the price for cereal changes. The treatment effect by the non-voluntary NVZ scheme is much lower but positive for both measures. In total, we find that farms subject to treatment by agri-environmental schemes respond to output price changes by less specialisation / more diversification compared to farms that are not subject to such a treatment.

The individual input-input relationships and estimated treatment effects highlight that nearly all estimated input-input relationships are of substitutional nature, i.e. that as the price for one input increases the farmer responds by an increase in the use of the other input to substitute for the more expensive input. The highest MES were found for the input pair relationships between labor and land (a 0.58 to 0.59% increase for both price increases) followed by the relationship between capital and chemicals (a 0.36% increase in capital use to substitute for more expensive capital) and the relationship between fertilizer and land (a 0.13% increase in the use of land to substitute for more expensive fertilizer). Only the relationship between the inputs land and capital has been found to be a complementary one, i.e. a 0.01% decrease in the use of land as a response to a 1% increase in capital prices. The latter could be a consequence of the relatively fixed nature of the input land and the fact that capital remains a key input to a more productive cereal production.

With regard to the various treatment effects by the different agri-environmental schemes the following findings have to be noted: (i) The voluntary type ESS scheme seems to signficantly influence producer behaviour at a far higher scale than the non-voluntary type NVZ scheme (for

19 out of 20 versus 4 out of 20 input-input relationships). The ESS related treatment effect has been found to weaken substitutional relationships between inputs for 11 cases (see “c+”), to enforce substitutional relationships between inputs for 7 cases (see “s+“) and to enforce complementary relationships between inputs for 1 case (relationship land/capital). (ii) The non-voluntary type NVZ scheme seems to influence producer behaviour at a much lower scale than the voluntary based agri-environmental scheme. The related treatment effect has been found to work significantly enforcing for only one case (fertilizer/labor relationship) but significantly weakening for 3 cases (land/labor, fertilizer/land, land/chemicals). (iii) For farms that are subject to both schemes’ treatment effects the findings are following those for the ESS scheme for 11 input-input relationships. Only for one case the findings for the NVZ scheme were also found for the joint treatment perspective. Hence, it might be the case that the effects on producer behaviour by voluntary agri-environmental schemes are much more significant than those by non-voluntary agri-environmental schemes.
The empirical analysis suggests that the voluntary type agri-environmental scheme indeed significantly influences individual producer behaviour with respect to crucial structural decisions. Most importantly the ESS treatment for the farms in our sample leads to a lower use of fertilizer and chemicals (i.e. less substitution of labor by fertilizer and/or chemicals, less substitution of land by chemicals, and less substitution of chemicals by fertilizer and vice versa). It further seems to result in higher labor use (as per substituting more labor for chemicals) and mixed effects with respect to capital intensity (substituting less of it for more expensive land but more of it for fertilizer and/or chemicals). On the other hand, the finding of substituting less land for fertilizer and/or chemicals may reflect the compensation payments received for agreeing to certain management options under the ESS scheme.
The empirical analysis suggests further that the non-voluntary type NVZ scheme influences individual producer behaviour far less significantly with respect to structural production decisions. Most importantly the NVZ treatment for the farms in our sample leads to a lower substitution of land for labor and of fertilizer for land. These effects are contrary to those observed for the ESS treatment and the joint effects for farms enrolled in both schemes are insignificant. For the substitutional relationship between fertilizer and capital we even find that a substitution enforcing ESS treatment effect turns into a substitution weakening effect for the joint ESS and NVZ treatments. Hence, these findings might suggest that the joint treatment by both agri-environmental schemes could lead to counterproductive production effects at individual farm level. On the other hand, we also observe mutually enforcing treatment effects: both schemes show a lowering substitution effect of land for chemicals which is significantly higher for the joint case.
The estimation results for the production structure measures are in line with the findings for the treated farms’ productivity: A lower capital productivity for those farms affected by agri-environmental schemes corresponds to a lower substitutional relationship of capital for labor and for land. A lower land productivity for those farms corresponds to a lower substitutional relationship of land for fertilizer and of land for chemicals. Finally, a higher labor productivity corresponds to a higher substitutional relationship of labor for chemicals.

7. Conclusions

Both schemes are effectively influencing production behaviour at individual farm level with respect to intensity, productivity and the structure of production. However, agri-environmental schemes show only very minor effects on the technical and allocative efficiency of farms, hence, we can conclude that farms enrolled in agri-environmental schemes are efficiently adjusting their production decisions given the constraints by the respective scheme. Farms affected by these schemes indeed tend to become less specialised and more diversified with respect to their production structure. A voluntary type agri-environmental scheme seems to signficantly influence producer behaviour at a far higher scale than a non-voluntary agri-environmental scheme. The joint effect of both agri-environmental schemes on structural production decisions at individual farm level is, however, not clear: the analysis suggests mutually enforcing but also conflicting effects. The major contribution of this research project, however, is its methodological approach: We employ a propensity score analytical approach in the form of a robust matching estimation technique to identify the marginal effects of agri-environmental schemes on individual producer behaviour. The novelty lies in the use of a theoretically developed multi-output multi-input approach based on sound production theory to disentangle measures for production performance and structure which are then used as indicators for the analyses of policy treatment effects. Hence, the suggested framework of empirical analysis can be readily applied on other types of farms and/or policy schemes to generate useful policy measures as it is based on sound economic and statistical tools.

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Appendix

Table 2 Farming Intensity Indicators at Sample Averages

measure	fertilizer per ha mean [min, max]	chemicals per ha mean [min, max]	variable cost per ha mean [min, max]
mean expenditure[1] per ha (GBP/ha)	122.877 [0; 1,438.18]	145.099 [0; 1,516.37]	861.151 [1.081; 11,410.0]

1: all monetary figures are deflated with respect to the base year 2000.

Table 3 Sample Average Treatment Effect (SATE) - Model 1

measure *treatment effect at sample mean in mean expenditure per ha (GBP/ha)*	fertilizer per ha mean [min, max]	chemicals per ha mean [min, max]	variable cost per ha mean [min, max]
ESS Scheme	-57.914*** [-90.094; -25.733]	-72.683*** [-112.694; -32.673]	-345.589*** [-549.071; -142.107]
NVZ Scheme	-58.101*** [-96.776; -19.425]	-71.244*** [-118.993; -23.495]	-419.061*** [-654.497; -183.624]
ESS and NVZ Schemes	-58.777*** [-91.424; -26.131]	-74.561*** [-118.989; -38.133]	-541.569*** [-803.236; -279.902]

*, **, *** - significant at 10, 5, 1%-level.

Table 4 Sample Average Treatment Effect (SATE) - Model 2 ESS

measure *ESS treatment effect at sample mean in mean expenditure per ha (GBP/ha)*	fertilizer per ha mean [min, max]	chemicals per ha mean [min, max]	variable cost per ha mean [min, max]
> 0 <= 5,000 GBP ESS income p.a. (= 3.2% of total income)	-50.112*** [-82.116; -18.109]	-58.063*** [-98.005; -18.121]	-288.109*** [-504.371; -71.848]
> 5,000 <= 10,000 GBP ESS income p.a. (= 4.1% of total income)	-52.368*** [-84.619; -20.116]	-71.431*** [-111.406; -31.454]	-344.178*** [-542.542; -145.813]
> 10,000 <= 15,000 GBP ESS income p.a. (= 5.2% of total income)	-66.082*** [-100.554; -31.611]	-79.803*** [-120.929; -38.676]	-349.175*** [-555.026; -143.325]
> 15,000 <= 20,000 GBP ESS income p.a. (= 8.4% of total income)	-106.840*** [-143.684; -69.997]	-80.670*** [-124.443; -36.897]	-573.409*** [-807.667; -339.153]
> 20,000 GBP ESS income p.a. (= 13.4% of total income)	-55.822*** [-89.857; -21.769]	-66.409*** [-106.585; -26.233]	-353.496*** [-556.744; -150.247]

*, **, *** - significant at 10, 5, 1%-level.

Table 5 Sample Average Treatment Effect (SATE) - Model 2 NVZ

measure *NVZ treatment effect at sample mean in mean expenditure per ha (GBP/ha)*	fertilizer per ha mean [min, max]	chemicals per ha mean [min, max]	variable cost per ha mean [min, max]
> 0 <= 25% of area under NVZ	-40.684** [-73.385; -7.982]	-90.625*** [-128.816; -52.433]	-204.883* [-427.449; 17.685]
> 25 <= 50% of area under NVZ	-54.387*** [-89.634; -19.141]	-74.681*** [-116.333; -33.029]	-478.094*** [-694.668; -261.521]
> 50 <= 75% of area under NVZ	-36.623** [-75.641; 2.395]	-71.367*** [-113.352; -29.381]	-436.859*** [-667.149; -206.568]
> 75 <= 100% of area under NVZ	-59.278*** [-96.211; -22.345]	-72.381*** [-118.004; -26.756]	-414.034*** [-636.746; -191.322]

*, **, *** - significant at 10, 5, 1%-level.

Table 6 Performance Indicators and Sample Average Treatment Effect (SATE) - Model 3

measure	*performance measure at sample mean*	ESS Scheme *treatment effect at sample mean*	NVZ Scheme *treatment effect at sample mean*	ESS and NVZ Schemes *treatment effect at sample mean*
land productivity (output in GBP per land in ha)	1253.934 [15.313; 720941.6]	-392.043*** [-657.547; -126.540]	-538.297*** [-848.586; -228.008]	-498.223*** [-34.806; -261.64]
labor productivity (output in GBP per labor in awu)	110682.4 [631.764; 1.02e+07]	30255.73*** [8991.682; 51519.78]	38130.55*** [13548.16; 62712.94]	103304.4*** [55219.94; 151388.9]
capital productivity (output in GBP per total assets in GBP)	0.236 [0.007; 2.712]	-0.039** [-0.073; -0.006]	-0.024*** [-0.039; -0.007]	-0.071*** [-0.122; -0.019]
technical efficiency (in %)	94.71*** [81.17; 99.49]	0.012*** [0.011; 0.013]	0.001** [-1.115e-04; 0.002]	0.004*** [0.002; 0.006]
allocative efficiency (in %)	59.05*** [0.08; 0.65]	8.82e-04 [-0.001; 0.003]	-4.85e-04 [0.002; 9.91e-04]	-0.009*** [-0.013; -0.004]

*, **, *** - significant at 10, 5, 1%-level; MES: Morishima Elasticity of Substitution.