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Abstract

This paper is entitled « Contracts For Regulating Environmental Damage From Farming: A Principal-Agent Approach » and explores the use of agency theory in the procurement of environmental public goods. The voluntary participation basis of many European agri-environmental schemes, combined with heterogeneity in the farm population and policy makers' lack of information about individual farms, poses a contract design problem. In particular, undifferentiated payment contracts and contracts that are amenable to « cheating » by farmers can lead to inefficiencies. Agency theory can assist in the design of contracts to overcome this situation. This paper presents a simple theoretical two-producer model, together with a simulated numerical example, to demonstrate the potential advantages of using agency theory in this manner. The results indicate how over-payment to farmers can be reduced. The increasing policy and funding importance of agri-environmental objectives suggest that further research in this field is merited.

Keywords: Principal-agent, mechanism design, agri-environmental policy; nitrate abatement.

Résumé

Des contrats pour maîtriser les atteintes à l'environnement par l'agriculture : une approche par la théorie de l'agence. *L'article étudie l'emploi de la théorie de l'agence dans les procédures administratives touchant à la fourniture de biens publics, ici l'environnement. La conception des contrats entre l'administration et les agriculteurs se heurte à trois facteurs : le principe de participation volontaire des agriculteurs qui caractérise un certain nombre de programmes agri-environnementaux européens, l'hétérogénéité de la population agricole, et le manque d'information disponible sur les exploitations individuelles. Deux types de contrats en particulier posent problème : ceux qui ne distinguent pas les différences entre agriculteurs et ceux qui permettent aux agriculteurs de « tricher ». La théorie de l'agence aide à formuler des contrats qui contournent ces difficultés. Les auteurs présentent ici un modèle théorique simple représentant deux types d'agriculteurs, et une simulation à partir d'un exemple numérique. L'intérêt potentiel d'une telle application de la théorie de l'agence est mis en évidence. En particulier, les résultats indiquent la possibilité de diminuer l'attribution de subventions excessives aux agriculteurs. L'importance grandissante accordée aux objectifs agri-environnementaux dans l'élaboration des politiques montre la nécessité de poursuivre des recherches dans ce sens.*

Mots-clés: *relations principal-agent, conception des mécanismes, politique agri-environnementale, réduction des nitrates*

1. Introduction

1.1. The nature of EU agri-environmental policy

European Council Regulation 2078/92 (sometimes known as the « agri-environment regulation ») required member states to implement a programme of measures to achieve aims including: reduction in the use of agri-chemicals; promotion of extensive forms of crop and livestock production; diverting farmland from production for 20 years or longer; and managing land for public access and leisure (EC, 1992). To reflect differences in environmental conditions and farming structures, member states were allowed discretion in the design and implementation of their own agri-environmental programmes. This has resulted in a variety of schemes across Europe. Many are based around the original Environmentally Sensitive Areas (ESAs) scheme pioneered in England during the 1980s, but others include Nitrate Sensitive Areas (NSAs), Heathland and Moorland regeneration schemes, and aid to organic farmers (Umstätter & Dabbert, 1996; EC, 1997).

Despite variation in specific aims and prescriptions, the majority of schemes share a common feature in that they are based on voluntary participation: rather than *requiring* farmers to participate, farmers are offered financial inducements as an encouragement to participate. This is the case for all seven schemes currently administered by the Ministry of Agriculture, Fisheries and Food (MAFF) in England, and reflects considerable success by the farming lobby in avoiding the imposition of mandatory regulatory controls that many other economic sectors endure (Cox *et al.*, 1990).

Payments offered to farmers are calculated « on the basis of the undertakings given by the beneficiary and of the loss of income and of the need to provide an incentive » (EC, 1992). That is, in return for agreeing to adhere to prescribed management practices under an agri-environmental scheme, farmers are offered payments as compensation for income foregone and costs, including some transaction costs, incurred. For example, farmers within an NSA have the freedom to choose whether or not to enter into a management agreement on their land. If they do enter into such an agreement, they must then adhere to specified agricultural practices in return for compensatory payments. If they decide not to enter a management agreement, they face no penalties. Moreover, constraints are typically binding only for a fixed period, not indefinitely. Thus, for example, management agreements run for a fixed period (usually five years) and are not automatically renewed, allowing farmers the option of withdrawing from the scheme after the initial period. This time-limited, voluntary framework poses a policy design problem since policy makers must balance the need to make schemes attractive, to entice farmers in, against the costs of compensatory payments, compliance monitoring efforts and administration.

1.2. Problems with voluntary schemes

Problems arise with these voluntary agri-environment schemes for two, related reasons. First, variation in factors such as farm size and structure, natural resource endowment, site history and site position lead to considerable heterogeneity in the farm population. This means that the cost (i.e. income foregone) of compliance with an agri-environment scheme may vary across farms, *and* that the environmental gains from compliance may also vary across farms (Moxey *et al.*, 1995a; Weaver *et al.*, 1996). In this situation, the use of a single, standard payment mechanism for all farms participating in a scheme leads to some (low cost of compliance) farms being over-compensated, whilst other (high cost of compliance) farms are not tempted into the scheme. This problem is categorised in the agency theory literature as the problem of adverse selection. Adoption of a differentiated payment mechanism could, potentially, address these problems by offering different payment levels to different farms and is appealing to policy makers concerned with achieving budgetary efficiency and « tax-payer value for money » (Webster & Felton, 1993; Colman, 1994; Colman, 1997). Second, however, heterogeneity in costs of compliance is generally not directly observable by policy makers, at least not without the latter incurring considerable administrative costs. That is, information asymmetry exists such that farmers know more about their costs of compliance than the policy makers do. To date, this has led to a tendency to opt for the administrative ease of a standard, undifferentiated payment mechanism, even though it leads to the adverse selection problem, rather than engage in costly identification and monitoring of farm situations. Policy makers are, however, now rethinking their approach (e.g. EC, 1996), and consideration of mechanisms for payment differentiation is appropriate.

1.3. Scope for Differentiated Payments

In the extreme, differentiated payments would take the form of individually negotiated contracts with each and every farmer. This should ensure that all farmers in a given scheme receive exactly the payment level required to tempt them into voluntary participation. The administrative costs would, however, be very high. In some cases, this might be acceptable if the environmental good in question was highly site-specific, that is, had a scarce, discrete spatial distribution such that its protection or production could only occur on a limited number of circumscribed farms: the ecological feature is rare, its loss is irreversible and there are not clear substitutes. In these situations the farmer is effectively a monopoly supplier of the public good and the regulator a monopsonist. Here, the administrative costs of negotiation, monitoring and enforcement might be justified by the relative uniqueness of the environmental outcome.

Yet the majority of environmental gains sought by agri-environmental schemes are not entirely site-specific and potential exists for « substitution » between sites. For example, ESAs or NSAs operate over a broadly defined geographical area and seek to achieve provision of environmental goods, such as landscape features or non-point pollution abatement, that have a less discrete, diffuse spatial distribution. Provided that, in aggregate, sufficient farms within the defined area participate such that the environmental good is provided adequately in total, the policy maker is not too concerned with the precise spatial distribution of farm participation. In this case, individually negotiated contracts may offer little benefit in terms of environmental good provision and the additional administrative costs incurred will probably outweigh any savings achieved through avoidance of over-compensation. Nevertheless, some degree of payment differentiation may be desirable given the unacceptable level of over-compensation associated with a single, standard payment mechanism. Clearly, there is a trade-off between the degree of differentiation offered in order to reduce over-compensation levels, and the additional administrative costs incurred.

Debates on the design of payment mechanism in the face of information asymmetries regarding individual producer type have been informed by theoretical developments in the new regulatory economics[1]. In particular, agency theory has been suggested as a means of designing a range, or menu, of contract options in such a way that not only are producers enticed into voluntary participation, but that they also simultaneously reveal some of their hidden information (Spulber, 1988; Bourgeon *et al.*., 1992; Latacz-Lohmann & Van der Hamsvoort, 1997).

This paper explores further the potential for this approach to mechanism design for agri-environmental schemes by using a simple numerical example based on the abatement of agricultural nitrate pollution. The remainder of this section introduces agency theory and reviews the literature. Section 2 introduces the two producer type model. Section 3 gives a simulated numerical case study of the use of mechanism design to

[1] For an introduction to this area, see Laffont & Tirole, (1993) or Mas-Colell *et al.* (1995).

reduce the costs of environmental contracts for nitrogen abatement. Section 4 offers a discussion, including consideration of data availability, and draws some conclusions.

1.4. The Principal Agent Approach

Since its origins in labour economics, the principal-agent model, or agency theory, has become an important paradigm in the economics of procurement and contracting, notably in the defence (Wolfson, 1985) and energy sectors (Reichelstein, 1992). Agency theory recognises that the regulator is less well informed than the participating agent about some critical parameter set which defines the agent's type. Typically the hidden information concerns the cost of compliance with the regulators' contract. These are games of incomplete information where one player is unsure about the preferences of his opponent (see Fudenberg & Tirole, 1991, Chapter 6).

To avoid the complications of the principal and agent engaging in a complex signalling game, the solution for the equilibrium of games of incomplete information relies upon the revelation principle (Dasgupta *et al.*, 1979; Myerson, 1979). This states that if a game of incomplete information has an equilibrium solution it can be replaced by a direct mechanism which induces truth-telling: that is when faced with a set of contracts the producer chooses the contract intended for their type and thereby truthfully reveals their true preferences. In practice the direct solution is implemented by a policy which includes a combination of a performance parameter, for instance the level of abatement, and a transfer (compensation) payment.

1.5. Context and Assumptions

It is important to be clear about the context in which agency theory is applied. First it can be applied to contracts between an individual agent and the regulator (Laffont & Tirole, 1993) or a large number of agents and the regulator (Bourgeon *et al.,* 1992). The contracts proposed in the next section are between an individual producer and the regulator, although, there is no reason why the regulator should not sign contracts with a large number of individuals collectively.

Individual contracts may be socially optimal when there are substantial differences between producers in terms of the social benefits of input abatement. This arises due to different spatial distributions of ecological habitats and, in the case of non-point pollution, different locations and physiographic features. Individual contracts may also be optimal when the transactions costs of establishing and monitoring a quota market are prohibitive. It is notable that the current UK agri-environmental policy is based upon individual contracts either negotiated, in the case of SSSIs, or fixed in the case of ESAs and NSAs.

It is also important to be clear what information is held by the regulator and by the producer. In the case of perfect information, the regulator knows the abatement benefit for a producer, the compliance cost function and observes the producer's actions *ex post*. All of this information is known costlessly. The only distinction between the perfect information and the asymmetric information case defined here is that, for the latter, the regulator only has a prior distribution for the parameter that determines producer type. In our example this parameter measures the producer's land productivity which, in turn, defines the compliance cost function. Although other definitions of producer type could be used[2], there are well-established methods of measuring land productivity in agriculture, offering a tractable approach to applying agency theory to the design of real agri-environmental contracts (Van Diepen *et al.*, 1991; Bourgeon *et al.*., 1992; Wu & Babcock, 1996). It is assumed that whilst the regulator knows the *range* of land productivity types and the compliance cost functions associated with these types, only an individual producer knows which compliance cost function applies to him. The validity of this approach,

[2] For example, Latacz-Lohmann & Van der Hamsvoort (1997) use attitude to risk.

and data constraints on is operationalisation, are discussed briefly in section 4.

Solutions to contracting problems may be of two forms. The first-best solution for the regulator is that where the producers only receive their compliance cost. This solution is only attainable under perfect information. The second-best solution applies where the regulator offers contracts which take account of the potential for a producer to declare himself to be a type other than their true type. The optimal second-best solution considered in the next section induces truth-telling, that is each producer selects a contract from a menu of contracts which is intended for their type.

The sequence in which contracts are offered and accepted is also critical. On the basis of information available, the regulator announces a menu of contracts which consist of different combinations of a transfer payment, b_i, and an input quota, x_i. Each contract may be intended for a particular producer type and can be offered without negotiating directly with the producer. When the menu is announced, the regulator must make a commitment to accept an eligible producer's choice of a contract. This commitment is essential because by choosing a contract the producer is revealing information about his type which may provide the regulator with an incentive to withdraw the contract and, in its place, offer the producer the perfect information alternative. If the producer anticipates that this will occur, he will respond by disguising his true type when selecting a contract. This process has the potential to reduce the efficiency of second-best « truth-telling » contracts under asymmetric information.

2. Methods

2.1. The Regulator's Problem for the Two-Producer Case

Agri-environmental goods are a heterogeneous assortment, ety. This heterogeneity demands a variety of agricultural land management pncompassing, for example, amenity landscape features, habitat mosaics and water qualiractices which, for ease of presentation, will be defined here in terms of input usage, such that abatement of input usage (i.e. deintensification) from existing levels, via input quotas, will, at least potentially, deliver the desired agri-environmental goods.[3] To further simplify the presentation, consideration is restricted to only two farm types distinguished by their profitability : low profitability type i=1 and high profitability type i=2. It is assumed that the target group has already been selected and that monitoring activities will be decided upon separately from the contract design process.

In reaching an agreement with each individual farmer, the utilitarian regulator aims to maximise the following social welfare function[4]:

$$z_i = v\, a_i + (b_i - c_i(x_i)) - (1+e)b_i \qquad (1)$$

The function has three components. The parameter v gives the benefit derived per unit of input abatement a_i. Abatement is defined as $a_i = (x^{*,i} - x_i)$ where $x^{*,i}$ is the optimal unconstrained input for farm type i, and x_i is an input quota for farm i, such that $x^{*,i} - x_i \geq 0$. Thus the linear abatement benefit function, which is assumed to be identical across farms, can be given as $v(x^{*,i} - x_i)$. The farmer's monetary utility or rent is given by $U_i = (b_i - c_i(x_i))$, as the excess of the transfer payment, b_i, over the costs of abatement $c_i(x_i)$. Finally the term $(1+e)b_i$

[3] This is intuitively reasonable for many classes of agri-environmental goods, such as clean rivers, but may need careful interpretation for cases involving positive management rather than simply reductions in harmful management, as with, for example, haymeadow preservation. Benefits are only potential since scientific uncertainty and the stochastic nature of many environmental systems means that there are no guarantees that prescribed management practices will indeed deliver the desired agri-enviornmental outcomes.

[4] This specification is standard in the literature (e.g. Laffont & Tirole, 1993). Substituting a budgetary cost-minimisation objective, for a given environmental standard, would yield similar results.

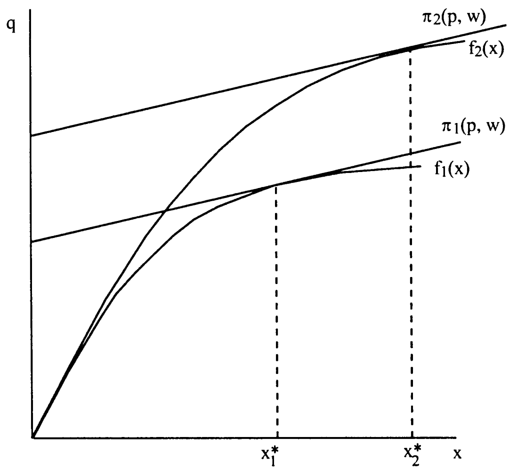

Figure 1: optimal Input Use

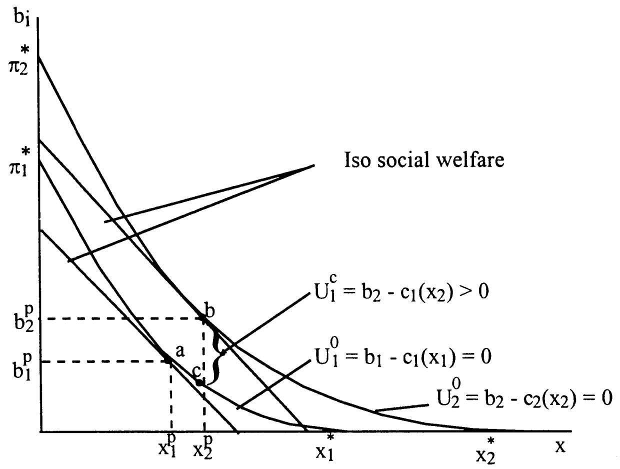

Figure 2: Optimal Contracts Under Perfect Information

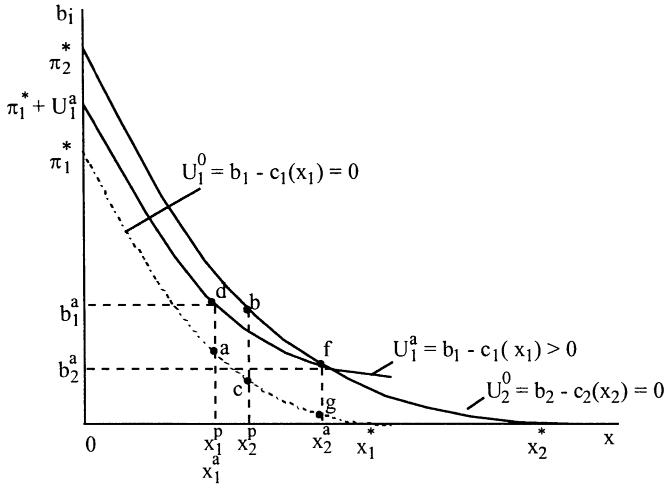

Figure 3: Optimal Contracts Under Asymmetric Information

is the cost of the transfer payment where e represents the shadow costs of public funds in terms of the distortionary effects of taxation, (Laffont and Tirole, 1993: p55).[5] Note that if e=0 then b_i, as a transfer payment, drops out of the social net benefit function. The compliance cost term in the social welfare function, which should represent the resource costs of complying with regulation, may need to be adjusted to account for agricultural output and input subsidies.

At the farm level, the abatement cost function, $c_i(x_i)$, is defined as the difference between the unconstrained and the constrained profit function:

$$c_i(x_i) = \pi_i(p, w) - \pi_i(p, w, x_i) \qquad x^{*,i} \geq x_i \qquad (2)$$

The properties regarding the profit function are those of Chambers (1988, p124) namely, $\pi_i(p, w)$ is convex in output and input prices, p and w. The implications of defining farmer types in terms of efficiency in the single input/output case are illustrated in Figure 1. Note that the high profitability type, type 2, uses a higher input than the low profitability type, type 1. It is assumed that the production functions of the two farmer types differ only in their efficiency parameter, thus: $f_2(x) = \lambda f_1(x)$ where $\lambda>1$ is a scale parameter.

2.2. First-Best Solution under perfect information

If the regulator were able to observe the farm's type, then the objective function (1) is maximised subject to the individual rationality constraints:

$$b^{p,i} - c_i(x^{p,i}) \geq U^{0,i} \qquad i=1,2 \qquad (3)$$

That is the utility earned from a contract must be greater than the farmer's reserve utility, $U^{0,i}$. In what follows it is assumed that $U^{0,i} = 0$. That is, farmers are willing to accept compensation which just covers their compliance cost. The terms $b^{p,i}$ and $x^{p,i}$ give the transfer and the input quota for the first-best solution, where the superscript p indicates perfect information.

The optimal solution to (1) subject to (3) is

$$-(1 + e)c'^{,i}(x^{p,i}) = v \qquad i=1,2 \qquad (4)$$

the incentive compatibility constraints are binding $b_i = c_i(x_i)$; in other words there is no incentive for the regulator to give any rent away to the farmer. Thus in the first-best solution, the marginal social cost of abatement is equal to the marginal social benefit. The optimal contracts are defined by a transfer payment coupled with an input restriction, $\{b^{p,i}, x^{p,i}\}$. It follows immediately from (4) and the properties of the compliance cost function that $x^{p,2} > x^{p,1}$.

The optimal solution under perfect information is illustrated in Figure 2, in which the curves $U^{0,i}=0$ correspond to the vertical displacement between the isoprofit lines $\pi_i(p,w)$ in Figure 1: the lines $U^{0,i}=0$ represent indifference curves between transfer payments and the level of input quota. These indifference curves meet the vertical axis at the unconstrained profit level, $\pi^{*,i}$ and the horizontal axis at the optimal unconstrained input, $x^{*,i}$.

The regulator's objective function is represented by iso-social welfare lines. Interior equilibrium solutions can be identified at points of tangency between the iso-social welfare lines and the farmer's indifference curves. However, it should be pointed out that two types of corner point solutions may also occur: one where the abatement benefits are relatively high and one or both of farms are given a zero quota; the other where the abatement benefits are relatively low and one or both farms have a quota set at the unconstrained profit maximising input level.

2.3. Second-best Solution under Asymmetric Information

If the regulator is unable to observe the farmer's type directly there is an incentive for the low profitability farmer to declare himself as the high profitability

[5] Evidence from Alston and Hurd (1990) indicates values of e for the USA vary between 0.2 and 0.5.

type. This is illustrated in Figure 2, where the distance « bc » represents a positive rent, $U^{c,1}$, to the low profitability farmer who receives the higher compensation payment, $b^{p,2}$ and an increased input quota, $x^{p,2}$, thereby accruing a rent:

$$U^{c,1} = b^{p,2} - c_1(x^{p,2}) > b^{p,1} - c_1(x^{p,1}) = 0 \quad (5)$$

This is costly to the regulator because overall abatement is reduced, yet the transfer payment outlay is increased.

If the regulator has a subjective prior probability for the two farmer types within the target group and is able to observe the farmer's actions *ex post* then the regulator's expected social welfare is given by:

$$z = \gamma\{v(x^{*,1} - x^{a,1}) + (b^{a,1} - c_1(x^{a,1})) - (1+e)b^{a,1}\} + (1-\gamma)\{v(x^{*,2} - x^{a,2}) + (b^{a,2} - c_2(x^{a,2})) - (1+e)b^{a,2}\} \quad (6)$$

where γ gives the probability of the farm being low profitability, that is of type 1 and superscript a indicates asymmetric information. Given the assumed shape of the profit function, and therefore of the compliance cost functions, a unique separating solution exists. This is ensured by the incentive compatibility constraints which remove the incentive for one type of farmer to declare himself untruthfully to be another type of farmer:

Incentive Compatibility 1:

$$b^{a,1} - c_1(x^{a,1}) \geq b^{a,2} - c_1(x^{a,2}) \quad (7a)$$

Incentive Compatibility 2:

$$b^{a,2} - c_2(x^{a,2}) \geq b^{a,1} - c_2(x^{a,1}) \quad (7b)$$

In addition the individual rationality constraints still apply where the farmer must at least be compensated for his reduction in profit.

Individual Rationality 1:

$$b^{a,1} - c_1(x^{a,1}) \geq 0 \quad (8a)$$

In*dividual Rationality 2:*

$$b^{a,2} - c_2(x^{a,2}) \geq 0 \quad (8b)$$

By optimising (6) subject to constraints (7) and (8) we obtain the first-order conditions for a second-best solution:

$$-(1+e)c'^{,1}(x^{a,1}) = v \quad (9)$$

In other words, the solution requires the low profitability type to abate optimally. The case with the high profitability type is more complex since the first order conditions lead to

$$-(1+e)c'^{,2}(x^{a,2}) = v + \{ EQ \backslash f(\gamma,1-\gamma) \} e[c'^{,2}(x^{a,2}) - c'^{,1}(x^{a,2})] < v \quad (10)$$

since $c'^{,2}(x^{a,2}) - c'^{,1}(x^{a,2}) < 0$. From (4), (9) and (10) it follows that $x^{a,1} = x^{p,1}$, $x^{a,2} > x^{p,2}$ and $x^{a,2} > x^{a,1}$.

The solution is represented in Figure 3 which should be considered in conjunction with Figure 2. The first-best solutions, at point « a » for type 1 and point « b » for type 2, are not feasible due to the rental gain « bc » derived by the low profitability farmer (i=1) declaring himself to be high profitability (i=2). The second-best solution is found by increasing the quota to the high profitability farmer up to $x^{a,2}$ whilst increasing the transfer payment to the low profitability farmer by « ad ». This optimal solution under asymmetric information is one which ensures the low profitability farmer to be indifferent between telling the truth and cheating. From Figure 3 the optimal contract for the high profitability farmer is at « f » and for the low profitability farmer at « d » where the low profitability farmer retains a rent represented by « ad ». The point « f » is where the incentive compatibility constraint for the low profitability farmer crosses the individual rationality constraint for the high profitability farmer. This illustrates the single-crossing property, where indifference curves only cross once. The single-crossing property is ensured by the fact that $c'^{,2}(x) - c'^{,1}(x) < 0 \ \forall x$.

3. Results

3.1. A simulation example

To illustrate numerically the potential for reducing producer rents by using agency theory in the design of contracts, a simple simulation example is offered here. The example considers two producers facing a single input, single output cobb-douglas production function, $q_i = A_i x^{\beta}$. The producers are differentiated in terms of productivity (A_i) by the quality of land that they farm: the producer on the better quality land (i=2) is more productive in that, for a given level of input and output prices, he uses more of the input (x_i) and produces more output (q_i) than the producer on the poorer quality land (i=1). The input (x) could be characterised as, for example, number of sheep or cattle, form of grass conservation, or quantity of nitrogen fertiliser applied - all of which are specified in one or more agri-environment schemes. For the purposes of this example, quantity of nitrogen fertiliser applied will be used.

3.2. NSAs

NSAs are a policy response to concerns over the levels of agricultural nitrate pollution in water. Concern arises partly because of human-health worries over drinking water, but also partly because of environmental concern over ecological damage, particularly through eutrophication. Although a pilot scheme of 10 NSAs existed in 1990, 32 NSAs are now administered by MAFF in England under regulation 2078/92 (MAFF, 1995). Producers farming within the 35,000 hectares (ha) of land designated as NSA, are eligible to enter into five-year contracts designed to reduce the degree of nitrate leaching from their land. Essentially, three forms of contract exist: one concerns the conversion of arable land to grassland, the other two concern reductions in intensity of nitrogen usage on grassland and arable land. In these latter cases, the contracts specify limits to the quantities of nitrogen fertiliser that can be applied. These limits are standard across all participating farms within an NSA and are set below application levels considered to be privately optimal according to « good agricultural practice ».[6] If farmers adhere to these limits, they receive standard compensatory payments per hectare. This use of standard limits (i.e. quotas) and payments disregards heterogeneity in the farm population, thereby offering a convenient example for the application of agency theory .

3.3. Land quality and yield data

For the purposes of this simulation example, data on land quality and yields are taken from previously published work by the authors on the estimated distribution of land classes and associated cropY yields under different levels of fertiliser application within the catchment of the River Tyne in northern England (Allanson *et al.*, 1993; Moxey & White, 1994; Moxey *et al.*, 1995b). Table 1 below reports estimated yields for winter wheat under four different fertiliser application levels on low and high productivity land.

	Nitrogen Kg/ha			
Land Class	50	100	150	200
Low	3.53	4.68	5.34	5.54
High	4.43	5.88	6.88	7.23

Table 1: Estimated Winter Wheat Yield (tonnes/ha) by Land Class

These yield data were used to estimate the following (linearised) cobb-douglas production (or nitrogen response) function for use in the simulation:

$$\log \text{yield} = -0.100 + 0.244DA_h + 0.350 \log(x)$$
$$R_{adj} = 98.0$$

where x is the nitrogen input in kg/ha and DA_h is a dummy variable for high productivity land. This production function was used to simulate three

6 A separate scheme of larger Nitrate Vulnerable Zones (NVZs) exists under the EC Nitrate Directive (91/676/EEC). Under this scheme, farmers are required to adhere to good agricultural practice, and receive no compensatory payments.

Parameter:	Symbol:	Value:
Marginal benefit of abatement	v	1.1
Shadow value of public funds	e	0.1
Land productivity Parameter:		
Low productivity land	A_1	0.905
High productivity land	A_2	1.155
Production function 'slope'		0.350
Output price	p	100
Input price	w	1.4
Profit maximising Input:		
Low productivity land	$x^{*,1}$	121.30
High productivity land	$x^{*,2}$	176.56
Probability of type i=1		0.5

Table 2: Simulation Parameters

	Input Quotas:		Transfer Payment:		Rent:	
Scenarios	x_1	x_2	b_1	b_2	U_1	U_2
1. First - best Perfect Information	52.93	77.05	26.51	38.59	0	0
2. Asymmetric Information: - 'cheating'	77.05	77.05	38.59	38.59	29.28	0
3. Second-best Asymmetric Information: - truth-telling	52.93	79.39	54.59	36.30	28.07	0

Table 3: Numerical Solution for the Two Producer Type

policy scenarios: the perfect information case where the policy maker can tailor contracts precisely; the asymmetric information with « cheating » case where a farmer can opt for a contract designed for another farm type; and the asymmetric information case with « truth-telling » where the incentive for cheating has been removed through redesign of the contracts. In all cases, the contract design involves an input quota on the amount of fertiliser that can be applied and a transfer payment as compensation for the profit foregone by adhering to this restrictive quota. Parameter values used for the simulations are reported in Table 2, with the results presented in Table 3. Reference to Figs. 2 and 3 may assist interpretation of the results.

3.4. Simulation results

The solution under perfect information, where the policy maker knows each farm's type and therefore compliance cost, is a first-best solution. The transfer payments exactly compensate each farmer for the profit foregone through adherence to the restrictive input quota: neither farmer earns any rent. This is the benchmark against which the other two scenario results should be compared.

The solution under asymmetric information with cheating reveals one change. Whilst the high profitability farmer on productive land (i=2) continues to earn zero rent, the low profitability farmer on unproductive land (i=1) has gained a positive rent by opting for the same contract as the productive farmer, thereby receiving a higher transfer payment and a higher input quota. This scenario can also be interpreted as an outcome of a single, undifferentiated payment mechanism. The farmer on unproductive land (i=1) is able to earn the positive rent because the policy maker can not observe the true farm type.

The solution under asymmetric information with truth-telling demonstrates the impact of redesigning the contract. Here, the input quota to the high profitability farmer on productive land (i=2) has been increased, although remaining well below the profit-maximising input usage reported in Table 2. Concomitantly the associated transfer payment has been reduced, to reflect the lower profits foregone. This has the effect of removing any incentive for the low profitability farmer on unproductive land (i=1) to cheat. In terms of reductions in over-compensation, this solution is superior to the situation under asymmetric information with cheating, but is second-best compared to the perfect information case.

4. Discussion

4.1. Gains from Agency Theory

Advances in agency theory have led to an emerging research agenda in the field of contract design for public procurement in the face of information asymmetries. This has been driven by theoretical developments in game theory, but also by the political drive for privatisation and market testing of public services during the 1980s and 1990s. The attraction of agency theory lies in its potential to replace a standardised payment mechanism with a menu of contracts such that the rents earned by producers are reduced, without recourse to expensively negotiated individual agreements. If the shadow-price of exchequer funds is greater than one, such contract differentiation offers the possibility of improved efficiency in the procurement of public goods under taxpayer funded schemes and has been applied with some success in the defence and energy sectors.

Potentially, the application of agency theory to the procurement of public goods in the agricultural sector also offers significant efficiency gains. The sector is characterised by considerable heterogeneity in the costs of complying with policy restrictions. Consequently, standardised payment mechanisms can lead to significant rents accruing across the farm population. Although policy makers may be aware of this heterogeneity, individual farm costs of compliance are, however, typically unknown.

This means that reducing aggregate rents by tailoring contracts to different farm types is hindered by the possibility of farmers declaring themselves to be of a type (e.g. high cost of compliance) different to their true type (e.g. low cost of compliance) in order to continue receiving rent. Agency theory can assist here by designing contracts such that the incentive for farmers to cheat in this manner is reduced.

This paper has explored the potential gains from employing agency theory in this manner through a simple model applied to the procurement of an environmental good in the agricultural sector. Although the empirical focus was on the abatement of nitrate pollution through restrictions on the use of nitrogen fertiliser, the results are interpretable in broader terms for a range of agri-environment schemes and serve to highlight the potential gains of employing agency theory: whilst the solution under asymmetric information can only be second-best relative to that achievable under perfect information, contracts designed with the aid of agency theory can reduce the rents earned relative to those earned under undifferentiated contracts. It should be noted, however, that any immediate, direct policy application is hindered by both data constraints and the need for further theoretical model extensions, as discussed briefly below.

4.2. Data constraints

G.A. Carlson *et al.*. (1983: p3) note that « The ability of economists to improve both understanding and the practical management of the natural resource base rests on.....an adequate data base... ». Unfortunately, extant databases rarely conform to theoretical ideals, particularly in the environmental sector where data have not been collected routinely (Magnuson, 1990). Thus, in the context of this paper, observed nitrate emissions from individual farms are virtually non-existent[7] whilst knowledge of the shape of the distribution of compliance costs across farms is rather vague. This paucity of agri-environmental data weakens the applicability of agency theory. Either: resources have to be devoted to compiling baseline data, thereby reducing the cost savings offered by the « arms-length » approach; or recourse has to be made to some, inevitably less accurate, proxy measures or indicators. Currently, the latter are gaining in popularity with policy makers across a range of sectors including agriculture and the environment (e.g. OECD, 1997).

For compliance costs, such indicators might reasonably take the form of known farm types and/or location. That is, various farm typologies and sources of farm enterprise profitability data do exist within the UK, at both national and regional levels (e.g. Nix, 1997; SAC, 1997; Challinor & Scott, 1997) and could be used to estimate the probability of a given farm having a high or low cost of compliance.[8] Estimates for nitrate emissions might be based on a formal bio-physical model requiring detailed site information such as soils and topography (as in this paper), or more simply derived using a « rule-of-thumb » based on observed land use, perhaps from remote sensing or farm records[9], and extant spatial datasets mapping susceptibility to leaching (Cook & Norman, 1996). Arguably, current policies already employ (albeit weakly) the latter approach in the areal designation of NSAs.

4.3. Model extensions

Notwithstanding data constraints on the current model form, several theoretical extensions also need to be made. In particular, four areas of investigation may be identified. First, although the

[7] Although the pilot NSAs were subject to an intensive monitoring programme.

[8] Indeed, the authors are currently exploring the potential for using routinely collected annual Farm Business Survey Data collected by the UK's Ministry of Agriculture, Fisheries and Food to estimate compliance costs for different farm types.

[9] Land use data supplied under the Integrated Administration and Control System operated in conjunction with current elements of the Common Agricultural Policy is already used to monitor agri-environmental schemes (EC, 1996).

two-type case serves to illustrate the principles, it needs to be extended to consider the continuum of producer types more typically observed in the real world (White & Ozanne, 1997). Second, the production function also needs to be extended to the multi-input, multi-output technology more realistic of agricultural production. This will entail consideration of functional forms more complex than the simple cobb-douglas production function presented in this paper.

Third, and perhaps more problematically, environmental damage needs to be incorporated more explicitly into the model. Whilst heterogeneity in costs of compliance has been addressed as a means of reducing excessive transfer payments, policy makers are (presumably) also interested in environmental benefits achieved. That is, there is a tradeoff between payment levels and, in this case, reductions in nitrate pollution: zero payments would be required if zero abatement was an acceptable outcome. Unfortunately, incorporating an environmental damage function into the model is a non-trivial exercise. Heterogeneity of environmental conditions, such as soils and typography, mean that on-site environmental damage varies between farms undertaking similar management actions, whilst connectivity (e.g. streams) between sites means that environmental damage at a given site is partially conditional upon management actions off-site (Moxey & White, 1994). Yet scientific understanding of these relationships remains incomplete (Jakeman *et al.*, 1995). Thus, whilst the use of an identical damage function for both farm types in this paper is clearly unrealistic, obvious alternative formulations are not readily apparent: there is a continuing need for scientific research into environmental linkages and damage functions, and dialogue with economists and policy makers to inform contract design.

On a different note, further consideration also needs to be given to the transaction costs embodied in the design and redesign of contracts. Although the simulation example presented here demonstrates that rents vary under different policy scenarios, the administrative costs of implementing, monitoring and enforcing the different contracts are not examined. It may be that variation in these costs outweighs variation in the rents paid under the different scenarios. Unfortunately, empirical data to explore this possibility are scarce. Thus, fourth, further exploration of administrative and other transaction costs of different contracts is highly desirable (Falconer & Whitby, 1997).

5. Conclusions

Given heterogeneity in the farm population and policy makers' lack of information about individual farms, the voluntary basis of many agri-environmental schemes poses a problem for the efficient procurement of environmental goods. The appeal of applying agency theory to this problem is that it offers an « arms-length » approach that potentially avoids some administrative costs and unnecessary transfer payments by enticing « truth telling » behaviour. Although the simple results presented here are merely illustrative of potential gains that could be reaped, and are subject to data and conceptual limitations, further research is merited by the increasing integration of environmental and agricultural policies and the attendant increase in public expenditure on agri-environment schemes.

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