Agri-Environmental Policy and Moral Hazard under Output Price and Production Uncertainty

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Abstract— **Several theoretical and empirical models have been developed to examine how risk aversion affects compliance with agri-environmental schemes under asymmetric information and uncertainty. However, none has examined the case where the level of compliance is a continuous variable and producers face simultaneous monitoring, output price and production uncertainty. Treating conservation effort as a continuous variable, we show that risk aversion can mitigate the moral hazard problem in most cases. However, if conservation effort has a risk-increasing impact on production the effect of risk aversion on compliance is ambiguous.**

Keywords— **Agri-environmental schemes, uncertainty, moral hazard**

I. INTRODUCTION

There is increasing interest in the use of agri-environmental programmes to improve environmental quality. Many existing schemes use fixed incentive payments and/or cost sharing to encourage farmers to reduce negative externalities associated with agricultural activities or to increase positive externalities and the supply of environmental public goods. Examples of such voluntary agri-environmental schemes include the Environmentally Sensitive Areas Scheme (ESAS), the Countryside Stewardship Scheme (CSS), and the German MEKA programme [1] in Europe. In the United States, the U.S. Department of Agriculture administers the Conservation Reserve Program (CRP), the Environmental Quality Incentives Program (EQIP), and several other programmes.

A key issue in the design of incentive-based agri-environmental schemes is asymmetric information - the agri-environmental agency (AEA) does not have access to information possessed by farmers and/or can only observe their actions imperfectly. This creates the potential for adverse selection and moral hazard. Adverse selection can result in overpayment and limited environmental benefits since farmers have an incentive to hide information about agri-environmental characteristics or, even worse, may misrepresent their potential contribution to environmental quality in order to obtain higher payments. Moral hazard occurs due to imperfect information on compliance. The AEA may only be able to monitor participating farmers incompletely due to budgetary limitations or may face difficulties in verifying compliance, some farmers may choose not to fulfil their contractual obligations while receiving payments. Since both hidden information and hidden action will result in reduced outcomes, addressing information asymmetry is indispensable to the design of agri-environmental schemes.

Several authors have addressed the issue of information asymmetry, focusing primarily on adverse selection (Spubler [1]; Chambers [2]; Bourgeon et al. [3]; Wu and Babcock [4]; Latacz-Lohmann and Van der Hamsvoort [5]; Moxey et al. [6]). As Choe and Fraser [7] observe, moral hazard and compliance monitoring have received far less attention. Economic inefficiencies due to moral hazard in agri-environmental policy are analysed by Ozanne et al. [8] through a framework based on work by Moxey et al. The authors conclude that the moral hazard problem may have been exaggerated due to the failure to consider the impact of risk aversion. In the context of land set-aside provisions, Fraser [9] shows that risk aversion can increase the likelihood of compliance with agri-environmental schemes under monitoring and output price uncertainty. He also demonstrates that non-compliance can be reduced by changing inversely the size of penalty and the probability of inspection, holding the expected penalty constant. Hart and Latacz-Lohmann [10] allow for variations in farmers' compliance costs and in their willingness to cheat. In these articles, however, discrete choice

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models (i.e., farmers can choose only two or three actions: non-participation, compliance or non-compliance) have been employed and a single stochastic variable (output price) is considered as a source of farm-income variability. The impact of production risk on compliance has not been examined. Fraser mentions production uncertainty, but does not incorporate it explicitly in his model. If both output price and production uncertainty exist, results obtained by previous studies may not hold.

Several authors have examined the impact of risk aversion on input use under production uncertainty (e.g., Feder [11]; Loehman and Nelson [12]). In more recent analysis, Isik [13] allows for both output price and production uncertainty within a production function originally specified by Just and Pope [14] to examine the impact of environmental policies on input use, but focuses on the case where the two stochastic variables are uncorrelated. When producers face production uncertainty, a risk-input relationship which captures how changes in the level of input use affects production risk is one of main factors influencing farmers' behaviour. An input is risk-reducing (increasing) if an increase in its use reduces (augments) the variance of output. If a change in usage does not affect these, then it is a risk-neutral input. Risk input relationships and risk aversion affect both the adoption of practices (participation) under agri-environmental programmes and compliance decisions. The former issues relate to the optimal size of subsidy for the adoption of specific practices. In this paper, we focus on the latter issue.

This paper provides a comprehensive framework for modelling farmers' compliance decisions in agri-environmental schemes incorporating continuous effort and simultaneous uncertainty. More specifically, we treat conservation effort (action taken by farmers to improve the environmental outcome under a programme) as a continuous variable and assume the existence of monitoring, output price and production uncertainty. One of the primary advantages of our model is that it can examine the effect of risk-input relationships on the likelihood of compliance. The possibility of correlation between the stochastic variables is included. Based on this general framework, we derive the optimal level of conservation effort and comparative static results under a range of scenarios.

Our results suggest that if conservation effort is either risk-decreasing or risk-neutral, optimal effort exerted by a risk-averse farmer is greater than that for a risk-neutral farmer. The greater the aversion to risk, the greater the effort exerted under monitoring, output price, and/or production uncertainty. If conservation effort is risk-increasing, however, the optimal level of effort can be lower than that exerted by a risk-neutral farmer. When conservation effort is risk-increasing, the effect of the degree of risk aversion on optimal effort is ambiguous. Finally, the covariance of stochastic variables affects equilibria for both risk-neutral and risk-averse farmers.

The next section presents the theoretical model. In section 3, we discuss the relationship between the degree of risk aversion and the optimal level of conservation effort, approximating the utility function by the second-order Taylor expansion. Section 4 summarizes our conclusions and their policy implications.

II. THEORETICAL MODEL[2]

Consider a farmer facing both output price and production uncertainty who participates in a voluntary agri-environmental scheme (i.e., the participation constraint is satisfied). Conservation effort is assumed to be costly[3], with the cost to the farmer determined by actual direct compliance costs represented by the function $m(e)$ and profit forgone represented through the production function $F(x,e;\nu)$, where $e \in [0, e_{\max}]$ represents the level of conservation effort, x is a variable input of production not related to conservation effort[4], and ν is a random variable associated with production with mean zero and variance σ_ν^2. Following Just and Pope, production uncertainty can be reflected by:

[2] Due to space limitations, complete mathematical derivations are not given. They are available from the authors on request.

[3] There may be private benefits from conservation effort so that the optimal level of effort is non-zero without compliance monitoring. Optimal effort depends not only on marginal costs but also on marginal private benefits. The inclusion of such benefits would not affect the principal conclusions of this paper.

[4] More elaborate specifications can be explored.

$$F(x,e;\nu) = f(x,e) + q(x,e)\cdot\nu\,. \qquad (1)$$

The deterministic component $f(x,e)$ relates to output level and the stochastic component $q(x,e)$ relates to variability of output. We assume that $f(x,e)>0$ for $\forall x,\forall e$, $q(x,e)>0$ for $\forall x,\forall e$ (without loss of generality) and the following properties:

$$m(0)=0\,,\partial m/\partial e = m_e > 0\,,\partial^2 m/\partial e^2 = m_{ee} > 0\,, \quad (2)$$

and

$$\partial f/\partial e = f_e < 0\,,\ \partial^2 f/\partial e^2 = f_{ee} < 0\,,\ f_e + q_e\nu < 0 \qquad (3)$$

and $f_{ee} + q_{ee}\nu < 0$.

The sign of $\partial q/\partial e = q_e$ depends on the nature of a conservation practice (effort). If conservation effort is risk-reducing input, $\partial q/\partial e<0$; if risk-neutral, $\partial q/\partial e=0$; and if risk-increasing, $\partial q/\partial e>0$. We also assume:

$$\partial f/\partial x = f_x > 0\,,\ \partial^2 f/\partial x^2 = f_{xx} < 0\,, \qquad (4)$$
$$f_x + q_x\nu > 0\,,\text{ and } f_{xx} + q_{xx}\nu > 0\,.$$

Again, the sign of the first derivative of q with respect to the variable input hinges on risk-input relationships.

In some cases, conservation effort affects the use of variable inputs directly (e.g., rates of fertiliser or manure use). Again, for mathematical convenience, we focus on the single input case. An alternative specification of the production function would be $F(x(e);\nu)$. In that case, equation (1) can be rewritten as:

$$F(x(e);\nu) = f(x(e)) + q(x(e))\cdot\nu\,. \qquad (5)$$

The sign of $\partial f/\partial e = f_e$ depends on $\partial f/\partial x$ and $\partial x/\partial e$. Similarly, $\partial q/\partial x$ and $\partial x/\partial e$ determine the sign of the first derivative of q with respect to conservation effort. For example, since pesticide is likely to be a risk-reducing input through its impact on yield (i.e., $\partial q/\partial x<0$), conservation effort that decreases the use of pesticide (i.e., $\partial x/\partial e<0$) can be regarded as risk-increasing (i.e., $\partial q/\partial e>0$). Let p denote the (exogenous) output price which is assumed to be uncertain and to have the form $p=\bar{p}+\varepsilon$, where $\bar{p}$ is the expected output price and ε is a stochastic variable with mean zero and variance σ_ε^2.

The scheme provides incentive payments to farmers to engage in conservation activities. After a contract is signed, a participating farmer may choose not to exert the level of effort, $\bar{e}\in[0,e_{\max}]$, required by the AEA due to the costs of doing so. We assume that a certain proportion of farmers enrolled in the scheme are inspected randomly during a given period (i.e., there is incomplete monitoring) and if non-compliance is detected, a penalty is imposed according to the penalty function, $\rho(\bar{e}-e,\mathbf{z})$, which is continuously differentiable at $[0,\bar{e}]$, decreasing in e (i.e., $\partial\rho/\partial e<0$), $\partial^2\rho/\partial e^2=0$, $\rho(.)>0$ for $e<\bar{e}$, and $\rho(0,\mathbf{z})=0$. $\mathbf{z}$ is a vector of parameters that determine the size of the penalty factor for non-compliance. We also assume that monitoring is perfect in that if a farmer is inspected, the level of conservation effort will be observed accurately[5]. Hence, the farmer faces monitoring uncertainty only due to incomplete monitoring (i.e., whether inspected or not inspected).

The farmer is assumed to have a von-Neuman-Morgenstern utility function, $U(\pi)$ defined for profit π and to seek to maximize expected utility. According to (2), (3) and the penalty factor function defined at $[0,\bar{e}]$, the farmer never exerts more effort than the required level, and thus faces inequality constraints implicitly. With these assumptions and denoting the probability of inspection [6] by $\theta\in(0,1]$ which is assumed to be independent of ε and ν, the farmer's

[5] In general, monitoring is likely to be imperfect (i.e., it is difficult to measure conservation effort accurately). We do not examine this issue in this paper.

[6] We assume that the probability of inspection is independent of prior behaviour (i.e., participating farmers who have previously been found not to be in compliance are no more likely to be inspected than other farmers). Harrington [15], Friesen [16], and Fraser [17] investigate state-dependent monitoring using dynamic game models. They find that state-dependent (two/three groups) audit schemes can provide cost savings for an AEA.

expected utility maximization problem based on equation (1) can be expressed as :

$$\max_{x,e} \quad E[U(\pi)] = (1-\theta)\, E_{\varepsilon\nu}[U(\pi^{NI})] + \theta\, E_{\varepsilon\nu}[U(\pi^{I})]$$
$$s.t.\ \ x \geq 0 \text{ and } 0 \leq e \leq \bar{e}\,, \qquad (6)$$

where E and $E_{\varepsilon\nu}$ are the expectation operator defined over θ, and ε and ν respectively,

$$\pi^{NI} = s + pF(x,e,\nu) - wx - m(e)\text{, and} \qquad (7)$$
$$\pi^{I} = s + pF(x,e,\nu) - wx - m(e) - s\rho(\bar{e} - e, \mathbf{z})\,. \quad (8)$$

The superscripts *NI* and *I* indicate "not inspected" and "inspected" respectively, and π^j for $j = \{NI, I\}$ denotes profit for each case; s represents a fixed incentive payment under the scheme; and w is a known input price. Although the Kuhn-Tucker conditions can be derived, because we are interested in how the optimal level of conservation effort is affected by changes in parameters in the objective function (e.g., risk aversion), we focus on e and its interior solution. The first-order necessary condition is[7]:

$$\frac{\partial E[U(\pi)]}{\partial e} = (1-\theta)E_{\varepsilon\nu}[U_{\pi^{NI}}((\bar{p}+\varepsilon)(f_e + q_e\nu) - m_e)]$$
$$+\theta E_{\varepsilon\nu}[U_{\pi^{I}}((\bar{p}+\varepsilon)(f_e + q_e\nu) - m_e - s\rho_e)] = 0\,, \quad (9)$$

where $U_{\pi^j} = \partial U / \partial \pi^j > 0$ for $j = \{NI, I\}$. Denote $(\bar{p}+\varepsilon)(f_e + q_e\nu) - m_e \equiv \Gamma^{NI}$ and $(\bar{p}+\varepsilon)(f_e + q_e\nu) - m_e - s\rho_e \equiv \Gamma^{I}$. Maximization of the objective function requires the following sufficient second-order condition be satisfied:

$$\frac{\partial^2 E[U(\pi)]}{\partial e^2} = (1-\theta)E_{\varepsilon\nu}[U_{\pi^{NI}\pi^{NI}}(\Gamma^{NI})^2 + U_{\pi^{NI}}\Gamma_e^{NI}]$$
$$+\theta E_{\varepsilon\nu}[U_{\pi^{I}\pi^{I}}(\Gamma^{I})^2 + U_{\pi^{I}}\Gamma_e^{I}] < 0\,. \qquad (10)$$

[7] If we employ (5) instead of (1), conservation effort is a control variable. However, the first-order condition with respect to conservation effort does not rely on the form of the production function, i.e., (1) or (5).

Since $\Gamma_e^j < 0$ for $j = \{NI, I\}$, $U_{\pi^j\pi^j} = \partial^2 U / \partial(\pi^j)^2 \leq 0$ for $j = \{NI, I\}$ is sufficient for (10) to hold. Applying the expectation operator in (7) and using the expression for the approximate covariance (Bohrnstedt and Goldberger [18]), the first-order necessary condition can be rewritten as:

$$-\theta s\rho_e \frac{E_{\varepsilon\nu}[U_{\pi^I}]}{\Phi} = m_e - \left[\bar{p} + \frac{(1-\theta)Cov(U_{\pi^{NI}};\varepsilon)}{\Phi} + \frac{\theta\, Cov(U_{\pi^I};\varepsilon)}{\Phi}\right] f_e$$
$$-\left[Cov(\varepsilon;\nu) + \frac{(1-\theta)\bar{p}Cov(U_{\pi^{NI}};\nu)}{\Phi} + \frac{\theta\,\bar{p}\,Cov(U_{\pi^I};\nu)}{\Phi}\right] q_e\,, \quad (11)$$

where $\Phi = (1-\theta)E_{\varepsilon\nu}[U_{\pi^{NI}}] + \theta E_{\varepsilon\nu}[U_{\pi^I}]$. We first focus on the risk-neutral farmer's optimal choice.

Lemma 1: *Suppose a farmer is risk-neutral, the optimal level of conservation effort satisfies the following condition*:

$$-\theta s\rho_e = m_e - \bar{p}f_e - Cov(\varepsilon,\nu)q_e\,.$$

Proof: If a farmer is risk-neutral, $U_{\pi^{NI}} = U_{\pi^I}$. Hence, $E_{\varepsilon\nu}[U_{\pi^I}]/\Phi = 1$. In addition, since $U_{\pi^{NI}}$ and U_{π^I} are constant, $Cov(U_{\pi^j};\varepsilon) = U_{\pi^j}E_{\varepsilon\nu}[\varepsilon] = 0$ for $j = \{NI, I\}$ and $Cov(U_{\pi^j};\nu) = U_{\pi^j}E_{\varepsilon\nu}[\nu] = 0$ for $j = \{NI, I\}$. Therefore, (11) reduces to the condition. *Q.E.D.*

From this lemma, if two stochastic variables affecting price and production are uncorrelated, the optimal level of effort exerted by a risk-neutral farmer is determined where the marginal reduction in the expected penalty (the marginal benefit of effort: MBE), $-\theta s\rho_e$ equals marginal total compliance costs (the marginal cost of effort: MCE), $m_e - \bar{p}f_e$. However, when the two stochastic variables are not independent and conservation effort has an effect on production risk, even a risk-neutral farmer will take account of the correlation between ε and ν, and risk-input relationships, which influence expected profit. Note that even if each producer is a price taker the output of individual producers could be correlated with output price due to a positive correlation between the

stochastic outputs of all producers (Grant [19]). For example, if bad weather or disease causes a reduction in aggregate output rather than the output of just some farmers, output price may increase. Thus the correlation between ε and ν is expected to be either zero or negative.

The next question is how a negative covariance affects a risk-neutral farmer's choices. If $q_e > 0$, (i.e., risk-increasing), the last term of the right-hand side of the equation in Lemma 1, $-Cov(\varepsilon,\nu)q_e$, can be interpreted as the additional marginal cost of effort (expected profit decreases as effort increases). In this case, the optimal level of effort for a risk-neutral farmer decreases because the MCE increases while the MBE remains unchanged. Let e_0^N and e_c^N be the optimal conservation effort exerted by a risk-neutral farmer (N) when $Cov(\varepsilon,\nu)=0$ and when $Cov(\varepsilon,\nu)<0$ respectively. Assuming $q_{ee}=0$ figure 1 illustrates this situation. Meanwhile, if $q_e<0$ (i.e., risk-reducing), since expected profit increases as effort increases, $Cov(\varepsilon,\nu)q_e$ can be interpreted as the additional marginal benefit of effort (by rearranging the equation in Lemma 1 as: $-\theta s\rho_e + Cov(\varepsilon,\nu)q_e = m_e - \bar{p}f_e$). Thus, the optimal level of effort for a risk-neutral farmer increases because the MBE increases while the MCE remains unchanged. This case is depicted in figure 2.

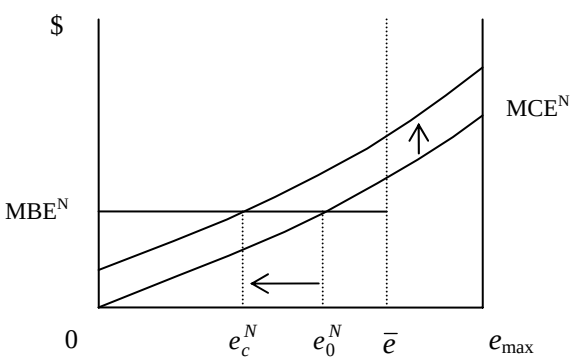

Figure 1: The impact of a negative covariance on the optimal level of effort if $q_e > 0$

Now, we shall discuss the optimal level of effort for a risk-averse farmer under uncertainty.

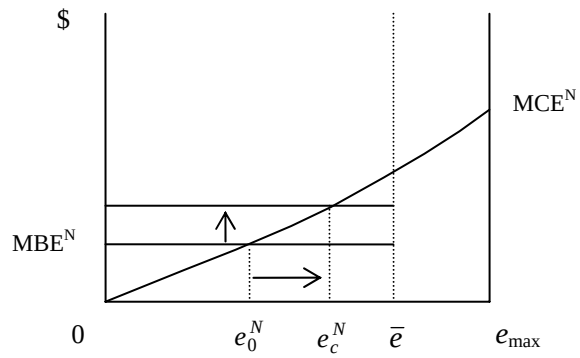

Figure 2: The impact of a negative covariance on the optimal level of effort if $q_e < 0$

Proposition 1: *Under monitoring and output price uncertainty, a risk-averse farmer exerts more conservation effort than a risk-neutral farmer*.

Proof: Under only price and monitoring uncertainty $Cov(\varepsilon,\nu)=0$. Therefore, as discussed above, the optimal level of effort exerted by a risk-neutral farmer is determined where the MBE, $-\theta s\rho_e$, equals the MCE $m_e - \bar{p}f_e$. Meanwhile, condition (11) reduces to

$$-\theta s\rho_e \frac{E_{\varepsilon\nu}[U_{\pi^I}]}{\Phi} = m_e - \left[\bar{p} + \frac{(1-\theta)Cov(U_{\pi^{NI}};\varepsilon)}{\Phi} + \frac{\theta Cov(U_{\pi^I};\varepsilon)}{\Phi}\right] f_e .$$

If a farmer is risk-averse, the utility function is concave in profit and $\pi^{NI} > \pi^I$, then we know that $U_{\pi^{NI}} < U_{\pi^I}$. Hence, $\Phi < (1-\theta)E_{\varepsilon\nu}[U_{\pi^I}] + \theta E_{\varepsilon\nu}[U_{\pi^I}] = E_{\varepsilon\nu}[U_{\pi^I}]$, and $E_{\varepsilon\nu}[U_{\pi^I}]/\Phi > 1$. Also, $Cov(U_{\pi^j};\varepsilon)$ for $j=\{NI,I\}$ is negative. Thus, the MBE for a risk-averse farmer (MBE^A) is higher than that for a risk-neutral farmer (MBE^N), and the MCE for a risk-averse farmer (MCE^A) is smaller than that for a risk-neutral farmer (MCE^N). This suggests that by taking account of a risk premium a risk-averse farmer exerts more conservation effort than a risk-neutral farmer under monitoring and output price uncertainty. *Q.E.D.*

Let e^N and e^A be the optimal conservation effort exerted by a risk-neutral farmer (*N*) and a risk-averse farmer (*A*) respectively. Figure 3 illustrates the situations identified by Proposition 1.

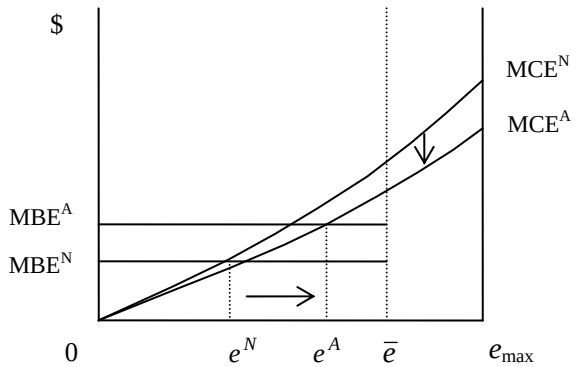

Figure 3: The impact of changes in risk aversion on the optimal level of effort under monitoring and output price uncertainty

Proposition 2: *Under simultaneous monitoring, output price and production uncertainty with* $Cov(\varepsilon,\nu)=0$*, if conservation effort is risk-neutral or risk-reducing, a risk-averse farmer with a Just and Pope production function exerts more effort than a risk-neutral farmer. However, if conservation effort is risk-increasing, the impact of risk aversion on the optimal level of conservation effort will be reduced. Compared to the risk-neutral case, the optimal level of conservation effort exerted by a risk-averse farmer can be higher, the same or lower.*

Proof: If $Cov(\varepsilon,\nu)=0$, $-\theta s\rho_e = m_e - \bar{p}f_e$ should hold for a risk-neutral farmer. Condition (11) reduces to:

$$-\theta s\rho_e \frac{E_{\varepsilon\nu}[U_{\pi^I}]}{\Phi} = m_e$$
$$-\left[\bar{p} + \frac{(1-\theta)Cov(U_{\pi^{NI}};\varepsilon)}{\Phi} + \frac{\theta Cov(U_{\pi^I};\varepsilon)}{\Phi}\right]f_e$$
$$-\left[\frac{(1-\theta)\bar{p}Cov(U_{\pi^{NI}};\nu)}{\Phi} + \frac{\theta\,\bar{p}\,Cov(U_{\pi^I};\nu)}{\Phi}\right]q_e .$$

If $q_e \le 0$, then since $Cov(U_{\pi^j};\varepsilon)$ and $Cov(U_{\pi^j};\nu)$ for $j=\{NI,I\}$ are negative, again the MBE^A is higher than MBE^N, and MCE^A is smaller than MCE^N. Thus, if $Cov(\varepsilon,\nu)=0$ and $q_e \le 0$, the optimal level of conservation effort exerted by a risk-averse farmer facing output price, production and monitoring uncertainty is higher than that exerted by a risk-neutral farmer (it is also equal to or higher than that exerted by a risk-averse farmer facing only monitoring and output price uncertainty because the MBE^A curve in figure 3 shifts upwards). However, if $q_e > 0$ (risk-increasing):

$$-\left[\frac{(1-\theta)\bar{p}Cov(U_{\pi^{NI}};\nu)}{\Phi} + \frac{\theta\,\bar{p}\,Cov(U_{\pi^I};\nu)}{\Phi}\right]q_e > 0 .$$

Therefore, the optimal level of conservation effort exerted by a risk-averse farmer facing simultaneous monitoring, output and price uncertainty is at a maximum equal to that exerted by a risk-averse farmer facing only monitoring and output price uncertainty because the MCE^A curve in figure 3 shifts upwards. We can not conclude that the optimal effort for a risk-averse farmer is higher than that for a risk-neutral farmer. There is a possibility that a risk-averse farmer will exert less effort than a risk-neutral farmer. *Q.E.D.*

Proposition 3: *Under simultaneous monitoring, output price and production uncertainty with* $Cov(\varepsilon,\nu)<0$*, if conservation effort is risk-neutral, a risk-averse farmer exerts more effort than a risk-neutral farmer. If conservation effort is risk-reducing, the optimal effort exerted by a risk-averse farmer facing* $Cov(\varepsilon,\nu)<0$ *is greater than that exerted by a farmer facing* $Cov(\varepsilon,\nu)=0$ *. In addition, if conservation effort is risk-increasing, the optimal conservation effort of a farmer facing* $Cov(\varepsilon,\nu)<0$ *is smaller than a farmer facing* $Cov(\varepsilon,\nu)=0$.

Proof: If $q_e = 0$, the optimal condition for a risk-averse farmer is as in Proposition 1. If $q_e < 0$ and $Cov(\varepsilon,\nu)<0$,

$$\left[\frac{(1-\theta)\bar{p}Cov(U_{\pi^{NI}};\nu)}{\Phi}+\frac{\theta\,\bar{p}\,Cov(U_{\pi^{I}};\nu)}{\Phi}\right]q_e$$
$$<\left[Cov(\varepsilon;\nu)+\frac{(1-\theta)\bar{p}Cov(U_{\pi^{NI}};\nu)}{\Phi}+\frac{\theta\,\bar{p}\,Cov(U_{\pi^{I}};\nu)}{\Phi}\right]q_e$$
.

Compared to the case when random variables are independent, the optimal level of conservation effort exerted by a risk-averse farmer is increased because the MBE^{A} curve shifts upwards. In addition, if $q_e > 0$ and $Cov(\varepsilon,\nu) < 0$:

$$-\left[\frac{(1-\theta)\bar{p}Cov(U_{\pi^{NI}};\nu)}{\Phi}+\frac{\theta\,\bar{p}\,Cov(U_{\pi^{I}};\nu)}{\Phi}\right]q_e$$
$$<-\left[Cov(\varepsilon;\nu)+\frac{(1-\theta)\bar{p}Cov(U_{\pi^{NI}};\nu)}{\Phi}+\frac{\theta\,\bar{p}\,Cov(U_{\pi^{I}};\nu)}{\Phi}\right]q_e$$
.

Thus, compared to the independent (zero covariance) case, the optimal level of effort exerted by a risk-averse farmer is decreased because the MCE^{A} curve shifts upwards. *Q.E.D.*

However, when $Cov(\varepsilon,\nu) < 0$ and $q_e \neq 0$, we can not conclude that a risk-averse farmer exerts more effort than a risk-neutral farmer. Nevertheless, we find that for both risk-neutral and risk-averse farmers, when $q_e < 0$ the optimal level of effort is greater than when $q_e > 0$ (except for a risk-neutral farmer with $Cov(\varepsilon,\nu) = 0$). This suggests that the AEA should target enforcement efforts to farmers who are required to adopt risk-increasing conservation practices under agri-environmental schemes. For risk-decreasing practices, moral hazard is less problematic.

III. THE DEGREE OF RISK AVERSION AND OPTIMAL LEVEL OF CONSERVATION EFFORT

To investigate how the degree of risk aversion affects the optimal level of conservation effort, we assume that expected utility can be approximated by a second order Taylor's expansion. Again we focus on *e* and its interior solution.

The Taylor's expansion of the utility function around expected profit is:

$$U(\pi)=\sum_{t=0}^{\infty}\frac{U^{(t)}(E\pi)}{t!}\cdot(\pi-E\pi)^{t}, \qquad (12)$$

where $t!$ is the factorial of t and $U^{(t)}(E\pi)$ denotes the *t*th derivative of the utility function at the point $E\pi$. For a second-order expansion the function is:

$$E(U(\pi))=U(E\pi)+\frac{1}{2}U''(E\pi)\cdot\sigma_{\pi}^{2}, \qquad (13)$$

where σ_{π}^{2} denotes the variance of profit. Expected profit can be expressed as:

$$E\pi=(1-\theta)[\iint_A \pi^{NI}\zeta(\varepsilon,\nu)d\varepsilon d\nu] + \theta[\iint_A \pi^{I}\zeta(\varepsilon,\nu)d\varepsilon d\nu], \qquad (14)$$

where A is a set in two-dimensional space, $(\varepsilon,\nu)\in A$, and $\zeta(\varepsilon,\nu)$ is the joint probability density function of ε and ν . Equation (14) can be rewritten as:

$$E\pi=s+\bar{p}f(x,e)+q(x,e)Cov(\varepsilon,\nu) - wx-m(e)-\theta s\rho(\bar{e}-e,\mathbf{z}). \qquad (15)$$

The variance of profit can be expressed as:

$$\sigma_{\pi}^{2}=\iint_A(1-\theta)\{\pi^{NI}-E\pi\}^{2}\zeta(\varepsilon,\nu)d\varepsilon d\nu + \iint_A\theta\{\pi^{I}-E\pi\}^{2}\zeta(\varepsilon,\nu)d\varepsilon d\nu. \qquad (16)$$

This expression can be also rewritten as:

$$\sigma_{\pi}^{2}=f^{2}\sigma_{\varepsilon}^{2}+\bar{p}^{2}q^{2}\sigma_{\nu}^{2}+2\bar{p}q^{2}E[\varepsilon\nu^{2}]+q^{2}E[\varepsilon^{2}\nu^{2}] - q^{2}[r\sigma_{\varepsilon}\sigma_{\nu}]^{2}+2\bar{p}fq[r\sigma_{\varepsilon}\sigma_{\nu}]+2fqE[\varepsilon^{2}\nu] + (\theta-\theta^{2})(\rho s)^{2}, \qquad (17)$$

where $f=f(x,e),\ q=q(x,e),\ r\sigma_{\varepsilon}\sigma_{\nu}=Cov(\varepsilon,\nu)$ (r is the correlation coefficient between ε and ν), and $\rho=\rho(\bar{e}-e,\mathbf{z})$.

Lemma 2 (Anderson [20]): *Let a,b,c and d be jointly distributed random variables. Then,*

$$E[(\Delta a)(\Delta b)(\Delta c)(\Delta d)] = Cov(a,b)Cov(c,d) + Cov(a,c)Cov(b,d) + Cov(a,d)Cov(b,c),$$

where $a - E(a) = \Delta a, b - E(b) = \Delta b, c - E(c) = \Delta c$ *and* $d - E(d) = \Delta d$.

From Lemma 2, we obtain:

$$E_{\varepsilon\nu}[\varepsilon^2\nu^2] = E_{\varepsilon\nu}[\varepsilon\varepsilon\nu\nu] = Cov(\varepsilon,\varepsilon)Cov(\nu,\nu) + 2Cov(\varepsilon,\nu)Cov(\varepsilon,\nu) = \sigma_\varepsilon^2\sigma_\nu^2 + 2[r\sigma_\varepsilon\sigma_\nu]^2, \quad (18)$$

and equation (14) becomes:

$$\sigma_\pi^2 = f^2\sigma_\varepsilon^2 + \bar{p}^2q^2\sigma_\nu^2 + 2\bar{p}q^2E_{\varepsilon\nu}[\varepsilon\nu^2] + q^2\sigma_\varepsilon^2\sigma_\nu^2 + q^2[r\sigma_\varepsilon\sigma_\nu]^2 + 2\bar{p}fq[r\sigma_\varepsilon\sigma_\nu] + 2fqE_{\varepsilon\nu}[\varepsilon^2\nu] + (\theta-\theta^2)(\rho s)^2. \quad (19)$$

For mathematical convenience, we assume that ε and ν have a bivariate normal distribution. All third moments vanish (Bohrnstedt and Goldberger [18]) and $E_{\varepsilon\nu}[\varepsilon\nu^2] = E_{\varepsilon\nu}[\varepsilon^2\nu] = 0$. Finally, the variance of profit is:

$$\sigma_\pi^2 = f^2\sigma_\varepsilon^2 + \bar{p}^2q^2\sigma_\nu^2 + q^2\sigma_\varepsilon^2\sigma_\nu^2 + q^2[r\sigma_\varepsilon\sigma_\nu]^2 + 2\bar{p}fq[r\sigma_\varepsilon\sigma_\nu] + (\theta-\theta^2)(\rho s)^2. \quad (20)$$

When ε and ν are independently distributed (i.e., $r = 0$), the variance of profit is:

$$\sigma_\pi^2 = f^2\sigma_\varepsilon^2 + \bar{p}^2q^2\sigma_\nu^2 + q^2\sigma_\varepsilon^2\sigma_\nu^2 + (\theta-\theta^2)(\rho s)^2. \quad (21)$$

The expected utility maximization problem can be expressed as:

$$\max_e \; E(U(\pi)) = U(E\pi) + \frac{1}{2}U''(E\pi)\cdot\sigma_\pi^2 \quad (22)$$
$$s.t. \; x \ge 0 \text{ and } 0 \le e \le \bar{e}.$$

We assume that the utility function is a power function which exhibits constant relative risk aversion (CRRA):

$$U(W) = W^{1-\delta}/(1-\delta),\; U'(W) = W^{-\delta}, \quad (23)$$
$$\text{and } U''(W) = -\delta W^{-\delta-1}.$$

The Arrow-Pratt coefficient of constant relative risk aversion is $-U''(W)W/U'(W) = \delta$, and $\delta \in [0,1]$. Assuming an interior solution, the first-order condition with respect to e is:

$$\frac{\partial E(U(\pi))}{\partial e} = U'(E\pi)\cdot\frac{\partial E\pi}{\partial e} + \frac{1}{2}\left[\left(U'''(E\pi)\cdot\frac{\partial E\pi}{\partial e}\right)\cdot\sigma_\pi^2 + U''(E\pi)\frac{\partial\sigma_\pi^2}{\partial e}\right] = 0. \quad (24)$$

Rearranging equation (24) we obtain:

$$-\theta s\rho_e = m_e - \bar{p}f_e - q_e r\sigma_\varepsilon\sigma_\nu + \Psi(\delta)\frac{\partial\sigma_\pi^2}{\partial e}, \quad (25)$$

where

$$\Psi(\delta) = \frac{(1/2)\delta(E\pi)}{(E\pi)^2 + (1/2)\delta(\delta+1)\sigma_\pi^2}, \text{ and} \quad (26)$$

$$\frac{\partial\sigma_\pi^2}{\partial e} = 2ff_e\sigma_\varepsilon^2 + 2qq_e\bar{p}^2\sigma_\nu^2 + 2qq_e\sigma_\varepsilon^2\sigma_\nu^2 + 2qq_e[r\sigma_\varepsilon\sigma_\nu]^2 + 2\bar{p}r\sigma_\varepsilon\sigma_\nu[f_eq + fq_e] + 2(\theta-\theta^2)s^2\rho\rho_e. \quad (27)$$

If a farmer is risk-neutral ($\delta = 0$) then (25) reduces to $-\theta s\rho_e = m_e - \bar{p}f_e - q_e r\sigma_\varepsilon\sigma_\nu$. If a farmer is risk-averse ($\delta > 0$), the optimal level of conservation effort should satisfy (25).

A. Comparative Static Analysis

Proposition 4: *Suppose that the utility function can be approximated by a second-order Taylor series expansion about the mean, and constant relative risk aversion represents attitude to risk (the power utility function), under monitoring and output price*

uncertainty, as a farmer becomes more risk-averse, ceteris paribus, the optimal level of conservation effort increases if the following condition is satisfied: $E\pi > (1/2)^{1/2}\sigma_\pi\delta$.

Proof: If there is no production uncertainty, (27) reduces to:

$$\frac{\partial\sigma_\pi^2}{\partial e} = 2\,ff_e\sigma_\varepsilon^2 + 2(\theta-\theta^2)s^2\rho\rho_e < 0\,.$$

Thus, if $\partial\Psi/\partial\delta > 0$ (the right side of the equation (25) becomes smaller), the optimal level of conservation effort becomes larger with increasing aversion to risk:

$$\frac{\partial\Psi(\cdot)}{\partial\delta} = \frac{(1/2)(E\pi)[(E\pi+(1/2)^{1/2}\sigma_\pi\delta)(E\pi-(1/2)^{1/2}\sigma_\pi\delta)]}{[(E\pi)^2+(1/2)\delta(\delta+1)\sigma_\pi^2]^2}$$

.

Therefore, if $E\pi > (1/2)^{1/2}\sigma_\pi\delta$, $\partial\Psi/\partial\delta > 0$ and as the Arrow-Pratt coefficient of constant relative risk aversion increases, the optimal level of conservation effort also increases. *Q.E.D.*

Proposition 4 is consistent with the result in Fraser [9]. It seems that $(1/2)^{1/2}\sigma_\pi\delta$ is small relative to expected profit, particularly when δ is close to zero. Also, if $E\pi < (1/2)^{1/2}\sigma_\pi\delta$ applies, then:

$$\frac{\sigma_\pi}{CV_\pi} < (1/2)^{1/2}\sigma_\pi\delta\,, \tag{28}$$

where CV_π is the coefficient of variation of profit. The inequality (28) can be rewritten as:

$$\frac{1}{(1/2)^{1/2}\delta} < CV_\pi\,. \tag{29}$$

Since $(1/2)^{1/2}\delta < 1$, the coefficient of variation of profit becomes greater than unity, which is infeasible.

Proposition 5: *Suppose the utility function can be approximated by a second-order Taylor series expansion about the mean, and the constant relative risk aversion represents attitude to risk (the power utility function), under monitoring, price and output uncertainty with* $Cov(\varepsilon,\nu)=0$, *as a farmer becomes more risk-averse, ceteris paribus, the optimal level of conservation effort increases if* $q_e \le 0$ *and* $E\pi > (1/2)^{1/2}(\sigma_\pi^2)^{1/2}\delta$.

Proof: If $Cov(\varepsilon,\nu)=0$ and $q_e \le 0$, (27) becomes:

$$\frac{\partial\sigma_\pi^2}{\partial e} = 2\,ff_e\sigma_\varepsilon^2 + 2qq_e\bar{p}^2\sigma_\nu^2 + 2qq_e\sigma_\varepsilon^2\sigma_\nu^2 + 2(\theta-\theta^2)s^2\rho\rho_e < 0\,.$$

According to Proposition 4, if $E\pi > (1/2)^{1/2}(\sigma_\pi^2)^{1/2}\delta$, $\partial\Psi/\partial\delta > 0$. Thus, if $q_e \le 0$ and $E\pi > (1/2)^{1/2}(\sigma_\pi^2)^{1/2}\delta$, a more risk-averse farmer exerts more conservation effort. *Q.E.D.*

Proposition 6: *Suppose the utility function can be approximated by a second-order Taylor series expansion about the mean, and the constant relative risk aversion represents attitude to risk (the power utility function, under monitoring, price and output uncertainty with* $Cov(\varepsilon,\nu)=0$, *if* $q_e > 0$ *and* $E\pi > (1/2)^{1/2}(\sigma_\pi^2)^{1/2}\delta$, *a more risk-averse farmer exerts more conservation effort if:*

$$[\bar{p}^2+\sigma_\varepsilon^2]qq_e\sigma_\nu^2 < -[ff_e\sigma_\varepsilon^2+(\theta-\theta^2)s^2\rho\rho_e]\,,$$

and less conservation effort if:

$$[\bar{p}^2+\sigma_\varepsilon^2]qq_e\sigma_\nu^2 > -[ff_e\sigma_\varepsilon^2+(\theta-\theta^2)s^2\rho\rho_e]\,.$$

The optimal level of conservation effort is not affected by the degree of risk aversion if:

$$[\bar{p}^2+\sigma_\varepsilon^2]qq_e\sigma_\nu^2 = -[ff_e\sigma_\varepsilon^2+(\theta-\theta^2)s^2\rho\rho_e]\,.$$

Also if the equality holds, the optimal level of effort is the same as that for the risk-neutral farmer.

Proof: If $Cov(\varepsilon, \nu) = 0$, (27) reduces to:

$$\frac{\partial \sigma_\pi^2}{\partial e} = 2\, ff_e \sigma_\varepsilon^2 + 2qq_e \overline{p}^2 \sigma_\nu^2 + 2qq_e \sigma_\varepsilon^2 \sigma_\nu^2 + 2(\theta - \theta^2) s^2 \rho \rho_e .$$

Let $[\overline{p}^2 + \sigma_\varepsilon^2] qq_e \sigma_\nu^2 = A$ and $-[ff_e \sigma_\varepsilon^2 + (\theta - \theta^2) s^2 \rho \rho_e] = B$. If $A < B$, $\partial \sigma_\pi^2 / \partial e < 0$. Therefore, if $E\pi > (1/2)^{1/2} (\sigma_\pi^2)^{1/2} \delta$, the optimal level of conservation effort becomes larger as δ increases. Similarly, when $A > B$, optimal conservation effort decreases. In addition, if $A = B$, the last term of the right-hand side of (25) vanishes. *Q.E.D.*

Proposition 6 implies that if conservation effort is risk-increasing but the randomness associated with production is sufficiently small, then an increase in the degree of risk aversion can ameliorate the problem of moral hazard. However, if the variance of ν is high, as δ increases, optimal conservation effort becomes smaller. Therefore, the AEA should be particularly concerned about moral hazard when random variation in production is expected to be high. This is particularly relevant for the use of agri-environmental programmes in more marginal production areas.

IV. CONCLUSIONS

Risk aversion has been viewed as being likely to diminish the moral hazard problem in agri-environmental schemes. However, the model developed in this paper predicts that the impact of risk aversion on compliance varies. We explore this for monitoring, output price and production uncertainty.

If the only sources of uncertainty are in monitoring and output price, the optimal level of conservation effort of a risk-averse farmer is higher than that for a risk-neutral farmer. But under monitoring, output price and production uncertainty, the relationship between a conservation practice and production risk plays an important role in determining the impact of risk aversion on compliance. If conservation effort has risk-reducing or risk-neutral effects on production, risk aversion can increase the optimal level of conservation effort, and an increase in the degree of risk aversion can reduce the problem of moral hazard. However, when conservation effort is risk-increasing, the effect of risk aversion on optimal effort is, at a minimum, reduced. If random variation in production is high, risk aversion may decrease the optimal level of conservation effort.

The implications of these results are that an AEA needs to pay attention to the amount of uncertainty that producers face and the degree of risk aversion, and in particular, how the practices required under agri-environmental programs affect risk. Conservation practices which are risk-increasing, for example, by requiring reductions in the use of inputs that reduce yield variation seem to be especially problematic. Moreover, when random variation in production is high, as may be the case in more marginal production areas, monitoring farmers' compliance with requirements of agri-environmental schemes becomes increasingly important.

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