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Economic-Environmental Trade-offs and the Conservativeness of the Upper Partial Moment

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Probabilistic programming are typically used to model economic-environmental trade-when environmental outcomes are stochastic. Application of available probabilistic programming techniques such as the upper partial moment (UPM) is problematic due to the conservativeness of the estimated the compliance probability. Conservatively estimated trade-offs may result in overregulation of agricultural production practices. Although the conservativeness of the UPM is usually acknowledged by researchers, none of the researchers investigated the size of conservativeness of the UPM. An alternative non-linear trade-off model specification is developed to investigate the conservativeness of the UPM. Meta data from the validated Soil Water Balance (SWB) crop growth simulation model for irrigated maize in South Africa is used to show that the UPM is very conservative in the estimation of the trade-offs comparing to the new method. However, the size of the conservativeness is very situation-specific and varies due to differences in fixed resources, fertilizer application methods and conservativeness measures.

1. Introduction

Trade-off analysis applies the principle of opportunity cost to derive information about the sustainability of agricultural production systems. During trade-off analysis the inter-relationships among sustainability indicators implied by the underlying bio-physical processes and the economic behavior of producers are quantified. Stoorvogel *et al.* (2004) stated that trade-off curves are two-dimensional graphs representing the trade-off between two sustainability indicators. Crissman *et al*. (1998) stated that trade-offs are an essential component in setting research priorities and in designing and implementing the criteria of sustainable agriculture. The slope of a trade-off curve shows the opportunity cost of increasing agricultural production in terms of foregone environmental quality. The opportunity cost also represents the shadow prices for environmental quality and can be used as an economic incentive to achieve the environmental objective. The information generated with the trade-off analysis is critical for informed policy decision-making, as it allows policy makers and the public to assess whether a given improvement in environmental quality is worth the sacrifice in agricultural production (Stoorvogel *et al*., 2004). Since agriculture is still seen as one of the remaining major sources of water quality problems due to nutrient and sediment losses (Shortle et al., 1998; Peterson & Biosvert, 2001; Görgens, 2012), trade-off analysis to weight the regulation of agricultural production practices for improved environmental health with the reduced agricultural production is important. Moreover, it is of utmost importance that the trade-offs used to provide information for policy development is modeled correctly.

Trade-offs is typically modeled with the use of probabilistic programming due to the stochastic nature of the environmental outcomes. A potential problem with the application of probabilistic programming is that the available techniques such as the UPM (Qui *et al*., 2001) are conservative in the estimation of the compliance probability. The conservative estimation of the trade-offs can result in overregulation of agricultural production practices which will result in reduced agricultural production and losses in farm profit. Several researchers (Atwood *et al*., 1988; Qiu *et al*., 2001; Krokhmal *et al*., 2002; Kong, 2006) have raised their concern over the conservativeness of the UPM, however, none of the researchers investigated the size of the conservativeness of the UPM. The conservativeness of the UPM is due to the use of the partial moment inequality that generates a conservative probability limit. Due to the inequality the UPM estimate the economic indicator such that the environmental constraint is maintained at a higher compliance than that specified.

Atwood *et al*. (1988) indicated that the conservativeness of the UPM can be investigated using exogenously constrained or alternative nonlinear methods. An exogenous conservativeness is determined by comparing trade-off results of two UPM models. The first UPM model determines the trade-offs for a specified compliance probability, while the second model achieves the same level of compliance based on the exogenous calculation of the specified compliance probability. The calculation of the exogenous compliance probability requires information on the optimized distribution of the environmental outcome in the second optimization. The estimated exogenous conservativeness might, however, not give an indication of the true conservativeness of the UPM model. The endogenously determined probability limits that ensure compliance in the UPM are determined by the specified compliance probability and the distribution of the environmental variable. Any change in the specified compliance probability or the distribution of the environmental variable will therefore result in probability limit changes that will influence how strict the environmental constraint is enforced. The estimation of the true conservativeness, the endogenous conservativeness, is based on the fact that optimized trade-offs are different when producers face a conservative probability bound compared to a probability bound closer to the actual compliance probability. The estimation of the endogenous conservativeness requires the use of a trade-off model that can model compliance without the conservative probability bounds of the UPM. Currently no technique is available to model the trade-off with a smaller probability bound than that used by the UPM.

The objective of the article is to develop an alternative non-linear trade-off model that can be used to investigate the conservativeness of the UPM. The newly developed Upper Frequency Method (UFM) counts the number of deviations from the environmental goal in an effort to ensure that the deviations above the goal do not exceed the number of deviations allowed by the model.

The article proceeds by discussing the theoretical background to the conservativeness of the upper partial moment, the data and procedures, followed by the discussion of the results and finally the conclusions.

2. Conservativeness of the Upper Partial Moment

Safety-first rules are concerned with the probability of a variable falling above a critical or target level. Probabilistic safety-first constraints can be imposed using different approaches such as chance constraint programming and the Chebyshev stochastic inequality. Imposing the probabilistic constraints through the use of the Chebyshev's inequality generates highly conservative probability bounds (Atwood *et al*., 1988). Berck and Hihn (1982) introduced a semi-variance inequality that evaluates safety-first rules and is able to generate a smaller upper probability limit than the Chebyshev. Atwood (1985) extended Berck and Hihn's (1982) semi-variance inequality with a more general lower partial moment stochastic inequality to enforce such constraints. The Lower Partial Moment (LPM) developed by Atwood (1985) requires that the random variable be finitely discrete and uses the empirical distribution of the random variables. Atwood (1985) demonstrated that the LPM generates a smaller upper probability limit than the Chebyshev.

Qui *et al*. (2001) stated that the Upper Partial Moment (UPM) is parallel to the LPM. Like the LPM approach the UPM requires a finite discrete sample and uses the empirical distribution of the random environmental variables.

The UPM is defined as:

$$\rho(\alpha,t)=\sum\left(x_j-t\right)^{\alpha}f\left(x_j\right), \qquad x_j\geq t \tag{1}$$

for a discrete case and for a continuous case as:

$$\rho(\alpha,t)=\int_{-\infty}^{+\infty}(x-t)^{\alpha}f(x)dx \tag{2}$$

Where:

α	constant greater than zero
t	reference pollution level
x_j	pollution variable
$f(x_j)$	relative frequency distribution of the pollution variable x_j
$f(x)$	probability density function

The upper partial moment ($\rho(\alpha, t)$) is the integral of the deviation from the target $(x_j - t)$ multiplied by the relative frequency distribution of the pollution variable. α places an upper limit on the probability of x being more than $p\theta(\alpha, t)$ units above t. Setting $\alpha = 1$ expresses the inequality in terms of absolute deviations from t. Fishburn (1977) proved that a model that examines the trade-off between t and $\rho(\alpha, t)$ would generate solutions that are a subset of the second-degree stochastically dominant set if $\alpha \geq 1$. If $\alpha \geq 2$ the solution will be a subset of the third degree stochastically dominant set. The use of absolute deviation can provide less conservative estimates for the probability (Kim *et al.*, 1990).

Assume $\theta(\alpha, t) = [\rho(\alpha, t)]^{1/\alpha}$, which would be greater than or equal to zero since $\rho(\alpha, t) \geq 0$ and given a positive number p, then:

$$t + p\theta(\alpha, t) \geq t \tag{3}$$

The integral in Eq. 2 can then be expressed as the sum of two integrals

$$\rho(\alpha, t) = \int_{t}^{+\infty} (x - t)^{\alpha} f(x)dx + \int_{t+p\theta(\alpha,t)}^{+\infty} f(x)dx \tag{4}$$

Since $\int_{-\infty}^{t+p\theta(\alpha,t)} (x - t)^{\alpha} f(x)dx \geq 0$, then

$$\rho(\alpha, t) \geq \int_{t+p\theta(\alpha,t)}^{+\infty} (x - t)^{\alpha} f(x)dx \tag{5}$$

Over the interval $[t + p\theta(\alpha, t), +\infty]$, the expression $(x, t) \geq [t + p\theta(\alpha, t), +\infty]$ holds since $\theta(\alpha, t) = [\rho(\alpha, t)]^{1/\alpha}$. Therefore, the term $p^{\alpha}\rho\theta(\alpha, t)$ can replace $(x - t)^{\alpha}$ in Eq. 5 with no loss of generality, which gives

$$\begin{aligned} \rho(\alpha, t) &\geq \int_{t+p\theta(\alpha,t)}^{+\infty} p^{\alpha}\rho(\alpha, t) f(x)dx \qquad (6) \\ &= p^{\alpha}\rho(\alpha, t) \int_{t+p\theta(\alpha,t)}^{+\infty} f(x)dx \end{aligned}$$

The integral $\int_{t+p\theta(\alpha,t)}^{+\infty} f(x)dx$ is the probability that x is larger than $t + p\theta(\alpha, t)$, $Pr[x \geq t + p\theta(\alpha, t)]$. Rearranging Eq. 6 generates:

$$Pr[x \geq t + p\theta(\alpha, t)] \leq (1/\rho)^{\alpha} \qquad (7)$$

Let g be the standard that should be achieved for x and $g = t + p\theta(\alpha, t)$ then Eq. 7 holds

$$Pr(x \geq g) = Pr[x \geq t + p\theta(\alpha, t)] \leq (1/\rho)^{\alpha} \qquad (8)$$

Where $p = (g - t)/\theta(\alpha, t)$

With $\theta(\alpha, t) = [\rho(\alpha, t)]^{1/\alpha} \geq 0$ and $p = (g - t)/\theta(\alpha, t)$, where g is the standard set for the pollution variable x. Equation 8 places a lower limit on the probability of x increasing more than $p\theta(\alpha, t)$ units above t. In Eq. 8 the choice of some level of t between g and the population mean will often result in probability limits close to the actual probability limits (See Atwood, 1985). However, the distribution of the environmental variable determines the size of $\theta(\alpha, t)$ which influences the choice of p and therefore the choice of t. Since $p\theta(\alpha, t)$ represents the allowable deviation from t an increase in the size of the allowable deviation will result in the choice of a lower environmental target, t which is maintained. As a result the distribution of the environmental variable may determine the magnitude of the conservativeness of the UPM.

A sufficient condition to guarantee that $\Pr(x \geq g) = \Pr[x \geq t + p\theta(\alpha, t)] \leq (1/\rho)^{\alpha} \leq (1/q^{*})^{\alpha}$, is derived as follows. Note $(1/\rho)^{\alpha} \leq (1/q^{*})^{\alpha}$ requires $\rho \geq q^{*}$. Since $p = (g-t)/\theta(\alpha, t)$, $\rho \geq q^{*}$ implies

$$(\mathrm{g}-\mathrm{t})/\theta(\alpha, \mathrm{t}) \geq \mathrm{q}^{*} \tag{9}$$

Given that $\theta(\alpha, t)$ is greater than zero, rearranging Eq. 9 generates

$$t + q^{*}\theta(\alpha, t) \leq g \tag{10}$$

By enforcing Eq. 10 the following constraint is possible.

$$Pr(x \geq g) \leq (1/p)^{\alpha} \leq (1/q^{*})^{\alpha} \tag{11}$$

Through the use of Eq. 11 it is possible for the model to select a level of t endogenously. Since t is always non-negative, Eq. 10 requires that $t \leq g$. If Eq. 10 is constraining the model will select a level of t that is least constraining but will still satisfy Eq. 8. Enforcing Eq. 10 for all levels of $a > 0$ will not be easy. However, with $a = 1$ the linear Target-MOTAD model can be used to enforce Eq. 11 (Atwood *et al.*, 1988; Qiu *et al.*, 2001). Qiu *et al.* (2001) built on research by Atwood (1985) to develop an upper partial moment (UPM) inequality approach to impose the safety first constraint in a Target-MOTAD framework that will ensure that the target pollution level will be met at a certain specified probability level. Qui *et al.* (2001) imposed the following safety-first constraint in the UPM to ensure the target pollution level is maintained.

$$\textstyle\sum_{r} Pr(\sum_{j} e_{rj} \geq G) \leq 1/L^{*} \tag{12}$$

Where G is the environmental goal set by the environmental regulator. Enforcing Eq. 12 in the environmental Target MOTAD ensures that the probability of achieving an environmental variable in excess of the specified goal ($\sum_{r} Pr(\sum_{j} e_{rj} \geq G)$) is less than a specified acceptable probability level ($1/L^{*}$).

3. Data and Procedures

Estimation of trade-off models requires information regarding the environmental impact of production. The next section will focus on quantifying the environmental variable before discussing the trade-off models.

3.1. Quantifying Environmental Risk

Matthews (2014) used flexible response functions to quantify production and environmental risk associated with fertilizer use. This article uses the response functions estimated by Matthews (2014) to capture empirical production and environmental risk in the trade-off model. The data used to estimate the flexible response functions was simulated with a mechanistic, generic crop growth model originally developed for irrigation scheduling (Annandale *et al*., 1999). The Soil Water Balance (SWB) model was extended by Van der Laan *et al*. (2009) through the addition of nitrogen and phosphorus simulation routines and algorithms to SWB that allows for salt and nutrient simulations. Algorithms incorporated into newly developed SWB_Sci allow the model to simulate above ground nitrogen mass, grain nitrogen mass and soil water content and the fate of nitrogen. Van der Laan (2009) tested and validated SWB_Sci using historical datasets collected in the Netherlands, Kenya and South Africa.

The simulation model was used to simulated crop production and an environmental indicator consisting of nitrate runoff and leached for the production of late monoculture maize (planting date 15 December) under irrigation on two soil types at Glen, South Africa. Maize production was simulated for a sandy clay loam (SCL) or a sandy clay (SC) soil using 19 different production years while assuming an initial soil nitrogen level of 33kg. Nine levels of fertilizer could be applied in either a single or a split application. When using a split application two thirds of the desired nitrogen level was applied on the day of planting while the remaining third was applied seven weeks later. Only applications above 70kg/ha was applied in a split application.

The simulated data was used to estimate production, irrigation water and nitrate loss response function for every production year based on the decision makers' fertilizer use decision (Matthews, 2014). Every production year is referred to as a state of nature. The average crop yield, average irrigation water and average nitrate loss functions showed very little response for fertilizer application. However, significant differences were observed between different states of nature. The estimated standard deviations indicated reduced yield variability, increased water use variability and increased nitrate loss variability with increased fertilizer use. A detailed discussion of the producers and the response functions is available in Matthews (2014).

3.2. Economic-Environmental Trade-Off Models

The production and environmental risk functions fitted by Matthews (2014) are incorporated into a UPM and UFM model to estimate the conservativeness of the UPM. Both models included a generic model to optimize decision-makers' fertilizer decisions and constraints specific to the compliance models. Next the generic model will be discussed followed by the UPM and the UFM models.

3.2.1. Generic model

The generic model was used to determine production decisions for risk neutral decision makers when no environmental constraint is enforced. The following equations were used to optimize fertilizer usage:

$$Maximise\ GM_s = (Y_s(N)P_Y - NP_N - W_s(N)P_W - C_a - C_YY_s(N)) * HA \tag{13}$$

s.t.

$$Y_s(N) = \sum_{s=1}^{S} p_s(\beta_{1s} + \beta_{2s}N + \beta_{3s}N^2 + \varepsilon_s) \tag{14}$$

$$W_s(N) = \sum_{s=1}^{S} p_s(\omega_{1s} + \omega_{2s}N + \omega_{3s}N^2 + \mu_s) \tag{15}$$

$$E_s(N) = e_{1s} + e_{2s}N + e_{3s}N^2 + \tau_s \tag{16}$$

$$N \leq 220 \tag{17}$$

$$HA \leq 1 \tag{18}$$

Where:

p_s	is the probability that state of nature s will occur
GM_s	Gross Margin for –state of nature s (R/ha)
$Y(N)$	is the average crop yield produced as a function of nitrogen applications (ton/ha)
P_Y	price for maize (R/ton)
N	level of nitrogen fertiliser applied (kg/ha)
P_N	price for nitrogen fertiliser (R/kg)
$W(N)$	is the average irrigation water applied as a function of nitrogen applications (mm)
P_W	cost of applying irrigation water (R/mm)
B_A	area dependent cultivation cost (R/ha)
B_Y	yield dependent harvesting cost (R/ton)
β_{is}	represents the i^{th} estimated coefficient for the yield response function in state of nature s
ε_s	is the estimated output residuals for every state of nature, s
ω_{is}	represents the i^{th} estimated coefficient for the irrigation water response function in state of nature s
μ_s	is the estimated irrigation water residual for every state of nature, s
$E_s(N)$	is the level of nitrate that is lost in state s as a function of application rates (kg/ha)
e_{is}	represents the i^{th} estimated coefficient for the nitrate loss function
τ_s	is the estimated emission residual for every state of nature, s
HA	Area cultivated (ha)

The generic model maximizes the gross margin associated with alternative fertilizer application rates for a risk neutral decision maker. Since the trade-off model is solved for a risk neutral decision maker the average crop yield and irrigation response is used in the trade-off model. To determine the average crop yield and irrigation response functions it is assumed that every production year have an equal probability to occur as indicated by p_s. Fertilizer applications are limited to a maximum of 220kg/ha while the area planted are constrained to be no more than one hectare. Thus, the results could be interpreted as percentage changes.

Eq. 16 is included in the generic model to quantify the impact of the optimized production decisions on nitrate losses. Equation 16 represents nitrate losses as an empirical distribution which is continuously related to the amount of fertilizer applied. Equation 16 therefore, plays an important role in enforcing compliance with the environment goal of 28kg/ha since the equation determines the distribution of the environmental variable.

The following two sections describe how to enforce compliance with the UPM and UFM methods.

3.2.2. Environmental compliance with the Upper Partial Moment (UPM)

The compliance model requires additional equations to model compliance with the user-specified environmental goal of 28kg/ha. The additional equations allow the optimization model to determine the economic-environmental trade-offs. The equations that were added to the generic model to complete the UPM model are given below:

$$t = \big(E_s(N)\big)HA + d_s \tag{19}$$

$$\textstyle\sum_s p_s d_s - \theta(t) = 0 \tag{20}$$

$$t + L * \theta(t) \leq G \tag{21}$$

Where:	t	endogenously determined reference level for the environmental variable
	d_s	deviation of pollution emissions above the pollution target in state of nature s
	p_s	probability that state of nature s will occur
	G	is the environmental target set by the environmental regulator
	$\theta(t)$	$\theta(t) = \theta(1, t) = \rho(1, t)$, endogenously determined environmental risk level or the expected deviation above the reference level t
	L^*	the inverse of the acceptable probability (φ) of the environmental pollution being greater than the environmental goal G.

The UPM uses the user-specified environmental goal (G), an acceptable probability level (L^*) and an endogenous environmental risk level ($\theta(t)$) to estimate the endogenous target, t which will be maintained in the UPM (Eq. 21). The endogenous environmental risk level (($\theta(t)$)) is estimated in Eq. 19 based on the expected deviation ($p_s d_s$) of the decision makers nitrate loss from the endogenous target, t. The deviation of pollution emissions (d_s) is estimated in Eq. 19 as absolute deviation in nitrate loss ($E_s(N)$) from the endogenously determined target (t). While L^* can be interpreted as the inverse of the acceptable probability (φ) of environmental pollution being greater than the environmental goal G (Qiu *et al*., 2001).

The estimation of the endogenously determined target (t) relies heavily on the underlying distribution of the environmental variables (Qui *et al*., 2001) and the level of compliance. Therefore, the results obtained with the use of the UPM are typically conservative.

3.2.3. Environmental compliance with the Upper Frequency Method (UFM)

The UFM of enforcing probabilistic environmental compliance is based on the premises that any compliance probability can be expressed for the discrete case as the frequency by which a target may be exceeded. Restricting the number of states in which the environmental target might be exceeded guarantees compliance. The modeling procedure utilizes the Environmental Target-MOTAD model specification to identify states of nature in which the environmental target is exceeded and uses binary variables to restrict the number of times the target is exceeded. The following equations were used to ensure compliance:

$$G - E_s(N) - d_s \geq 0 \tag{22}$$

$$-IB_s + d_s \leq 0 \tag{23}$$

$$\sum_s B_s \leq uf \tag{24}$$

Where: B_s binary variable indicating whether the environmental target is exceeded in state of nature s

uf upper frequency indicating the number of times a target might be exceeded to enforce compliance

l large number which is used to give permission for a state of nature to exceed the target given B_s has a value of one

Absolute deviations (d_s) are estimated in Eq. 22 as the deviation in nitrate loss ($E_s(N)$) from the environmental goal (G). Equation 22 is the same as for the UPM (Eq. 19) with the exception that the deviations are calculated from G and not t as in the UPM. The UFM therefore overcomes the conservativeness of the UPM in maintaining the true environmental goal and not an endogenously determined target that is dependent on the distribution of the environmental variable. Equation 23 uses a binary variable to identify whether a specific state of nature exceeds the environmental goal. Every time $E_s(N)$ exceeds G, B_s takes a value of one. The B_s's are counted to determine the frequency by which the environmental goal is exceeded. The probabilistic constraint is enforced by Eq. 24 which restricts the number of times the environmental goal is exceeded to uf. The value of uf is calculated as $(1 - \varphi)S$ where φ specifies the compliance probability and S the total number of states of nature. The choice of uf is an integer value that corresponds with a value closest to the estimated discrete compliance probability without exceeding the compliance probability. The UFM can, therefore, also be conservative in the estimation of the trade-offs although the UFM will never be as conservative as the UPM.

3.3. Estimation of UPM Compliance Conservativeness

The conservativeness of the UPM was estimated with exogenously calculated actual compliance probabilities and the compliance probabilities that were achieved with the UFM. The exogenous conservativeness is captured through the use of exogenously constrained methods. First the UPM was solved for a user-specified environmental goal, G, and a user-specified compliance level. However, the UPM maintains the environmental goal, G, at a compliance level greater than that specified. The expectation was that the exogenously estimated compliance level will be greater than that specified because the UPM determines an endogenous target, t, which is maintained at the specified compliance level. To estimate the conservativeness of the UPM a second UPM model was solved to achieve an actual compliance equal to the specified compliance in the first UPM through an iterative procedure. The exogenous conservativeness of the UPM was estimated as the difference in the gross margins determined with the first and second UPM.

The endogenous conservativeness of the UPM was estimated as the difference between the gross margin for the first UPM and UFM. The specified compliance of the first UPM was converted into integer values that indicate the number of times the environmental goal should be maintained (uf) in the UFM. The estimated uf was then used to determine the economic-environmental trade-offs with the UFM model.

4. Results

The results in Table 1 are divided into three sets of results. The first set of results (Upper Partial Moment Model 1) shows the optimization results for the user specified compliance level. To determine the exogenous conservativeness of the UPM a second UPM (Upper Partial Moment Model 2) was solved to ensure an exogenously estimated actual compliance equal to the specified compliance in UPM model 1. The results for the second UPM optimization are shown in the second set of Table 1 (Upper Partial Moment Model 2). The third set of results is the UFM results (Upper Frequency Method). The specified compliance of the UPM Model 1 was incorporated into the UFM to estimate the trade-offs with the UFM.

INSERT TABLE 1

The first column in Table 1 shows the compliance probability (φ) specified by the researcher. The second column (GM) indicates the gross margin estimated with the trade-offs model under the environmental constraint and specified compliance. The third column (t) indicates the endogenous environmental target that is maintained in the UPM. The UPM maintains the environmental goal (G) by maintaining the endogenous environmental target (t). Since the environmental target (t) is much stricter than the environmental goal (G) the actual compliance level to the environmental goal is estimated exogenously using the optimized distribution of the environmental variable. The exogenously determined actual compliance level indicates the actual compliance to the user specified environmental goal (G) of 28kg.

Next the exogenous and endogenous conservativeness of the UPM will be discussed based on the results shown in Table 1.

4.1. Exogenous conservativeness

The exogenous conservativeness of the UPM is determined as the difference between the gross margin estimated in UPM model 1 and UPM model 2 as shown in Table 1.

The exogenous conservativeness of the UPM shows that even though a compliance level of 0.596 was specified, an actual compliance of 0.895 is maintained while a gross margin of R9 348 is realized for production on a SCL soil using a single fertilizer application. The actual compliance is greater than that specified because the UPM determines an endogenous target of 13.9kg that is maintained at the specified compliance level. The UPM chooses an endogenous environmental target (t) based on the distribution of the environmental variable. The endogenous environmental target is maintained at the specified compliance while the user-specified environmental goal is achieved at the actual compliance. Similarly, for a specified compliance level of 0.848 the environmental goal is achieved with an actual compliance of 0.947 while realizing a gross margin of R6 209. However, the UPM solved the optimization problem for an endogenous target of 15.9kg therefore G was maintained at an exogenous compliance level of 0.847. The cost of conservativeness is estimated by comparing the estimated GM of R6 209 to the GM when the exogenously determined actual compliance in UPM model 2 is 0.848. Solving the UPM for the specified compliance level of 0.596 and 0.848, results in a gross margin of R17 551 and R10 883 respectively. The exogenous conservativeness of the UPM is therefore, R8 203 (R17 551 - R9 348) for a specified compliance of 0.596 and R4 674 (R10 883 - R6 209) for a specified compliance level of 0.848. With increased compliance to the environmental constraint the exogenous conservativeness decreases. The same is true for production on a SCL soil using a split fertilizer application.

For production on a SC soil when using a single fertilizer application the gross margin for a specified compliance level of 0.649 is R6 868 while the actual level of compliance to G is 0.930. Optimising for the exogenously determined compliance of 0.649, results in a gross margin of R13 568. The exogenous conservativeness of the UPM at a compliance level of 0.649 is therefore R6 700 (R13 568 - R6 868) while the gross margin for a specified compliance level of 0.895 is R3 737 with an exogenously estimated actual compliance of 0.953. Optimizing for an exogenously estimated actual compliance of 0.895, results in a gross margin of R7 428. The exogenous conservativeness faced by the decision maker amounts to R3 691 (R7 428 - R3 737). Similar to the results for production with a single fertilizer application the exogenous conservativeness will decrease with an increase in compliance probability. Although the exogenous conservativeness associated with production on a SCL soil and SC soil follow a similar trend the exogenous cost of conservativeness is greater for production on a SC soil compared to production on a SCL soil. It should also be noted that at relatively low levels of specified compliance the exogenous cost of compliance, although high for production on a SCL and SC soil is within the same ranges. When the specified compliance is very high (0.900) the exogenous cost of compliance is substantially greater on a SC soil than on a SCL soil.

Results showed that exogenous conservativeness decrease with increased compliance to the environmental goal, G. The decision makers fixed resources also influences the size of the conservativeness with a higher conservativeness cost on the SC soil. The implication is that enforcing the environmental constraint in an incorrect manner will result in a significant conservativeness. Such conservativeness will put strain on the agricultural decision maker and agricultural production. The conclusion is that the choice of specified compliance should be carefully researched before policy makers take any decisions regarding the preferred compliance level. Furthermore, the decision makers' fixed resource can contribute to the size of the conservativeness of the UPM, therefore, the decision makers' fixed resources should be considered when evaluating alternative compliance levels. In essence, soil specific information is necessary before any decisions can be made.

4.2. Endogenous conservativeness of the Upper Partial Moment

The endogenous conservativeness of the UPM is determined by comparing the results for the UPM model 1 with that of the UFM for the specified compliance. The results for compliance to an environmental constraint estimated with the UPM and the UFM for risk neutral decision makers are shown in Table 1.

Assuming a specified compliance of 0.596 on a SCL soil for a single fertilizer application, the GM for the UPM is R9 348 compared to the R17 556 realized with the UFM. The endogenous cost of conservativeness of the UPM is therefore R8 208. However, with increased compliance (0.895) the difference in the gross margin estimated with the UPM and UFM decreases to R4 227 (R5 274 for the UPM and R9 501 for the UFM). Similarly to the exogenous conservativeness the estimated endogenous conservativeness decreases with increased compliance. The same is true for production using a split application where the estimated endogenous conservativeness will also decrease with increased compliance. The estimated conservativeness cost will, however, be higher when applying fertilizer in a split application compared to a single application.

Decision makers, who produce on a SC soil with a single fertilizer application with a specific compliance of 0.649, will realize a gross margin of R6 868 using the UPM model compared to the R14 464 from the UFM optimization. The endogenous conservativeness of the UPM is therefore R7 596 (R14 464 - R6 868) and will decrease to an endogenous conservativeness of R4 158 (R6 737 - R2 516) with an increase in compliance to 0.947. Decision makers who use a split fertilizer application on a SC soil will show a decrease in endogenous conservativeness due to increased actual compliance. An actual compliance probability of 0.649 will result in an endogenous conservativeness of R7 330 (R13 965 - R6 635). With increased compliance (0.947) the endogenous conservativeness will decrease to R4 051 (R6 567 - R2 579).

Results show that the soil type used can influence the endogenous conservativeness of the UPM. For all compliance scenarios and fertilizer application techniques, production on SC soil resulted in a higher endogenous conservativeness compared to the SCL soil. The response to fertilizer application technique depends on the soil type used and the compliance level specified. The conclusion is therefore that the decision makers' fixed resources and production decisions should be carefully considered when evaluating environmental constraints with the use of the UPM.

4.3. Comparison of exogenous and endogenous conservativeness

Results showed that the conservativeness cost estimated with the endogenous and exogenous procedures both show a decline in conservativeness with increased compliance irrespective of soil choice or fertilizer application method.

The estimated exogenous conservativeness cost range from a maximum of R8 203 to a low of R350, showing a significant decrease of R7 853 on a SCL soil when using a single fertilizer application. While the exogenous conservativeness cost for production with a split application decrease with R7 766 from R7 835. The endogenous conservativeness costs estimated for a single fertilizer application is R8 208 and decrease to a low R2 968 (reduction of R5 240) while the use of a split application result in a R4 120 reduction from R7885. The use of a SC soil will result in a maximum exogenous conservativeness cost of R6 700 when using a single fertilizer application and R6 062 for a split application with a respective reduction in conservativeness costs of R3 733 and R3 171. The endogenous conservativeness for a single application decrease from R7 596 to R4 158 (reduction of R3 438) while, the endogenous conservativeness for a split application decrease from R7 330 to R4 051 (reduction of R3 279). Although the estimated endogenous conservativeness costs are higher than the exogenous conservativeness, the reduction in conservativeness costs is significantly greater for the exogenous conservativeness estimation procedure.

The high cost of conservativeness is estimated for relatively low levels of compliance (0.596 and 0.649), since the UPM achieved an actual compliance that far exceeds the specified compliance level. With increased levels of specified compliance (0.947) the actual compliance of the UPM is closer to that specified and therefore the exogenous compliance cost is significantly less. Although the endogenous conservativeness is also less at the higher compliance levels, the UPM is still not able to achieve the specified compliance of 0.947, while the UFM is able to achieve the specified compliance. The conservativeness cost estimated with the endogenous conservativeness procedure is therefore higher than for the exogenous conservativeness estimation procedure. What is also interesting to note is that with increased compliance (from 0.596 to 0.85 the amount with which the exogenous conservativeness exceeds endogenous conservativeness decrease before increasing again. For production on a SCL soil the amount with which the exogenous conservativeness exceeds endogenous conservativeness at a compliance probability of 0.947 is R2 619 and R3 687 for a single and split fertilizer application. The difference in exogenous conservativeness and endogenous conservativeness is therefore significantly large at high compliance probability levels. A reason for this result is that the model can weigh the effect of one production year with exceptionally high nitrate losses very high when estimating the endogenous target and actual compliance resulting in a greater level of conservativeness.

A researcher can estimate the exogenous and endogenous conservativeness to provide an indication of the conservativeness of the UPM. However, the size of the estimated conservativeness is influenced by the technique used to determine conservativeness and the ability of the technique to achieve the user specified compliance. The conclusion is that policy makers should be careful when estimating potential economic-environmental trade-offs and identifying compliance probabilities to regulate agricultural NPS. The conservativeness of the trade-off model is influenced by the ability of the model to achieve the specified compliance probability. Incorrect choice of trade-off model and/or compliance probability could result in the overregulation of agricultural decision-makers.

Results also showed that production decisions' made by the decision maker can influence the size of the exogenous and endogenous conservativeness. When a single fertilizer application is considered, the compliance cost is consistently higher on the SC soil irrespective of the conservativeness measure used. However, the results for the split application show mixed results when comparing the two different soils. Another noticeable result is that the exogenous conservativeness decreases significantly at high compliance probabilities on the SCL for both fertilizer application methods.

On a SCL soil the exogenous compliance cost conservativeness is almost the same for the two fertilizer application methods. When considering the endogenous estimate of conservativeness the split application tends to be higher than the single application method at high compliance probabilities. On a SC soil both application methods conservative measures closely follow each other irrespective of the conservativeness measure used. The exogenous measure tends to give more conservative estimates for the single fertilizer application method at lower compliance probabilities. The conclusion is that it is difficult to clearly determine the impact of fertilizer application method on conservativeness while soils have a more profound impact.

5. Conclusions

The newly developed UFM is easy to use and requires no assumptions regarding the distribution of the environmental variable as the empirical data is used. The UFM behaved well during the optimization process and is much less conservative in the estimation of the trade-offs due to the probability limit which is closer to the actual probability limit displayed by the data. Although the UFM provides a stricter probability bound than the UPM there are some concerns regarding the application of the UFM. The UFM ensures compliance by ensuring that the number of deviations above the goal does not exceed the number of deviations allowed, therefore, a fairly large number of observations is necessary to ensure probability limits close to the actual probability. Since, South Africa faces the same soil water pollution problems as the rest of the world; the model was applied using a South African example. The robustness and the application of the model can only be tested though an evaluation of the model under various climatic conditions and different environmental goals.

Results showed that the conservativeness cost is higher on SCL soil compared to a SC soil, irrespective of conservativeness method. The effect of fertilizer application method used affects conservativeness cost differently between the two soil types and conservativeness measures. Results also showed that the exogenous and endogenous conservativeness estimated with the UPM and UFM is very high. With increased compliance the exogenous and endogenous conservativeness decrease with the greatest reduction in conservativeness realized when estimating exogenous conservativeness on a SCL soil at high compliance probability levels. The estimated endogenous conservativeness is always greater than the exogenous conservativeness and more so when the conservativeness is very high, irrespective of soil type or fertilizer application method. The conclusion is that the conservativeness of the UPM as measured by the exogenous and endogenous conservativeness is very high. However, the size of the conservativeness is very situation-specific and varies due to differences in fixed resources, fertilizer application methods and conservativeness measure.

The conservativeness of the UPM will result in over-regulation since the shadow price for the environmental outcome is derived from conservative responses. Failure to consider the trade-offs generated with the UFM may result in miss-identification of management options to control pollution.

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TABLE 1: **Estimated Compliance to an Environmental Constraint Using an Upper Partial Moment (UPM) and Upper Frequency Moment (UFM) Results for a Sandy Clay Loam (SCL) Soil Using a Single and Split Fertilizer Application (kg/ha)**

	Sandy Clay Loam					Sandy Clay			
	Specified compliance	GM (R)	Target (t)	Actual compliance		Specified compliance	GM (R)	Target (t)	Actual compliance
	Upper Partial Moment (UPM) Model 1					Upper Partial Moment (UPM) Model 1			
Single	0.596	9348	13.9	0.895	Single				
	0.649	8757	16.0	0.895		0.649	6868	14.4	0.930
	0.690	8298	16.7	0.895		0.696	6419	15.0	0.947
	0.749	7642	17.6	0.895		0.749	5883	15.0	0.947
	0.795	7049	16.7	0.901		0.784	5474	14.2	0.953
	0.848	6209	15.9	0.947		0.848	4552	12.8	0.953
	0.895	5274	19.2	0.947		0.895	3737	14.3	0.953
	0.947	4381	25.9	0.971		0.947	2579	13.6	0.982
Split	0.585	9241	13.9	0.895	Split				
	0.632	8697	16.0	0.895		0.649	6635	14.8	0.936
	0.690	8059	17.5	0.895		0.696	6225	16.0	0.947
	0.743	7508	17.3	0.895		0.725	5958	15.6	0.947
	0.795	6856	16.7	0.895		0.789	5268	14.4	0.953
	0.848	6033	15.2	0.947		0.842	4557	13.4	0.953
	0.895	5040	19.7	0.947		0.895	3681	13.6	0.953
	0.947	4315	28.0	0.971		0.947	2516	14.5	0.982
	Upper Partial Moment (UPM) Model 2					Upper Partial Moment (UPM) Model 2			
Single	0.041	17551	0.0	0.596	Single				
	0.181	15402	3.5	0.649		0.205	13568	1.2	0.649
	0.263	14115	5.6	0.690		0.292	12142	1.6	0.696
	0.386	12225	6.3	0.749		0.351	11193	1.6	0.749
	0.404	11954	6.3	0.795		0.363	11003	1.9	0.784
	0.474	10883	7.4	0.848		0.427	10000	3.9	0.848
	0.749	7642	17.5	0.895		0.602	7428	8.3	0.895
	0.930	4731	20.5	0.947		0.778	5546	14.3	0.947
Split	0.041	17076	0.0	0.585	Split				
	0.158	15331	3.2	0.632		0.228	12697	1.1	0.649
	0.316	12954	6.4	0.690		0.345	10879	2.1	0.696
	0.363	12264	6.4	0.743		0.363	10610	2.2	0.725
	0.398	11744	6.6	0.795		0.374	10430	2.2	0.789
	0.427	11309	7.3	0.848		0.439	9481	3.9	0.842
	0.801	6776	16.5	0.895		0.561	7726	5.8	0.895
	0.942	4384	23.0	0.947		0.778	5407	14.6	0.947
	Upper Frequency Method (UFM)					Upper Frequency Method (UFM)			
Single	0.596	17556		0.596	Single				
	0.649	15416		0.649		0.649	14464		0.649
	0.690	14712		0.690		0.696	12387		0.696
	0.749	12577		0.749		0.749	11368		0.749
	0.795	12062		0.795		0.784	11137		0.784
	0.848	11154		0.848		0.848	10134		0.848
	0.895	9501		0.895		0.895	7830		0.895
	0.947	7349		0.947		0.947	6737		0.947
Split	0.585	17126		0.585	Split				
	0.632	16891		0.632		0.649	13965		0.649
	0.690	13727		0.690		0.696	11915		0.696
	0.743	12423		0.743		0.725	11181		0.725
	0.795	12171		0.795		0.789	10624		0.789
	0.848	11335		0.848		0.842	9804		0.842
	0.895	10747		0.895		0.895	8316		0.895
	0.947	8071		0.947		0.947	6567		0.947