Information Value and Risk Premium in Agricultural Production under Risk: The Case of Split Nitrogen Application for Corn

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Abstract.

This paper considers an agricultural production model of sequential nitrogen application under risk. Because of random shocks between successive production stages, optimal fertilization decisions depend on the magnitude of farmers' risk aversion (risk premium), and the possibility for farmers to process information (value of information).

We propose a joint estimation procedure of technology and risk aversion parameters, using a structural, simulation-based econometric technique. Parameter estimates for the representative farmer's utility function allow to compute both the value of information and the risk premium for farmers. Those account together for about 30 percent of fertilizer cost for Midwest corn producers.

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1 Introduction

Much empirical evidence has emerged recently to support the fact that non point source pollution (NPSP) can be reduced by directly targeting agricultural production practices. Analyzing determinants of fertilizer and pesticide overuse by farmers has become a major issue, and in particular farmers' risk attitudes. The way farmers make decisions under risk conditions needs to be analyzed accounting for random shocks affecting crop yield such as climatic variations, soil and moisture conditions, and cropping practices. In this paper, we address the issue of split nitrogen application by modeling agricultural crop production as a multiple-stage process. At each stage of that process, information on crop condition becomes available to the farmer. Because of the cost of information processing, the farmer may decide not to use all the information available at every stage in the production process. It is then possible to compute the value of information corresponding to the farmer's ability to use such information, a concept different from the risk premium associated with production risk. Evaluating average farmers' risk attitudes, value of information and risk premium as implied by random shocks on different stages of production is an important empirical issue. It requires in particular accurate data on fertilizer applications and other cropping practices. Such line of empirical research therefore departs from previous studies concentrating on farm-level decisions under risk. The outline of the paper is the following. In Section 2 we present the basic model of sequential decisions applied to split nitrogen application under risk. Section 3 presents econometric considerations. Data used and estimation results are in Section 4. Section 5 concludes.

2 The basic model

We present here the problem of optimal nitrogen fertilizer application in the framework of a simple dynamic, stochastic model of sequential choice under uncertainty. There are three stages ($t = 0, 1, 2$) in the production process. The first stage ($t = 0$) corresponds to initial nitrogen application x_0 (late winter or early spring, before or at planting). The second stage ($t = 1$) occurs during the growing season, when the influence of the first nitrogen application is already assessed. Between stage 0 and stage 1, nitrogen runoff or leaching may have occurred, resulting in a possible nitrogen deficit for the plant. Decision variable x_1 consists in the complementary nitrogen application (sidedressing). The final stage ($t = 2$) corresponds to harvesting. We assume that at this stage, there remains uncertainty on crop condition because of exogenous factors not related to nitrogen runoff[2]. Variable u_0 represents a random shock on observed initial nitrogen stock in soil before the new crop is considered (nitrogen carry-over from previous crops).

Random variable u_1 occurs after the first nitrogen application (x_0). It is interpreted here as a shock (possibly of climatic origin) affecting the degree of nitrogen runoff or leaching between period of first application (fall, early spring) and growing season. The soil potential for nitrogen leaching may be known to the farmer as a typical private information, but climatic variables also have a major impact on nitrogen runoff or leaching. Viewing the problem in terms of sequential decisions under risk conditions allows to model nitrogen availability to the plant as follows. Let N_t denote total nitrogen available at time t, N_0 initial nitrogen stock before planting, and R is crop yield. Nitrogen uptake by the plant is assumed to be a fraction γ of nitrogen available. The nitrogen run-off parameter is denoted β, i.e. $\alpha = 1 - \beta$ is the fraction of nitrogen not subject to run-off, and available to the crop[3]. $\tilde{x}_0$ and $\tilde{x}_1$ represent nitrogen take-up by the plant, i.e. the useful input level to grow crop.

With parameters introduced above, we have: $\tilde{x}_0 = \gamma\alpha(N_0+x_0)$ and $\tilde{x}_1 =$

[2]An example for this is temperature at the end of growing season, whose variation may affect crop for a given, fixed nitrogen level available to the plant.

[3]We use here the same notation as Feinerman and al. [1990].

$\gamma(N_1 + x_1)$ where $N_1 = (1-\gamma)\alpha(N_0 + x_0)$. Successive nitrogen levels in the soil are: $N_0 = A_0; N_1 = (1-\gamma)\alpha(A_0 + x_0)$; $N_2 = (1-\gamma)(N_1 + x_1)$. Finally, at time $t = 2$ crop yield R is determined as a function of past nitrogen stocks and successive nitrogen applications:

$$R = F(\tilde{x}_0, \tilde{x}_1, u_2) = F\left[\gamma\alpha(A_0 + x_0), \gamma(N_1 + x_1), u_2\right]$$

with a random term u_2 reflecting uncertainty not related to nitrogen runoff.

Faced with a price system for output supply and nitrogen input, the farmer solves the following problem:

$$\max_{x_0, x_1} EU(\Pi) \quad \text{where } \Pi = pF(\tilde{x}_0, \tilde{x}_1, u_2) - w(x_0 + x_1) \tag{1}$$

If the producer were to decide to compute all decision functions x, before observing random variables $u's$, we would have truly *ex ante* decision functions. Since information is never strictly worthless, the producer should prefer *ex post* to *ex ante* decisions as long as information cost does not overweigh the gross value of information (Chavas [1991], LaValle [1978]).

3 Econometric considerations

To complete the model specification, random variables appearing at different places in the equations above are considered now. Initial nitrogen stock in soil per acre, A_0, is specified as $A_0 = \exp(\varepsilon_0)$, where ε_0 is normal with mean μ_0 and variance σ_0^2. Second, u_1 corresponds to α, $\alpha \in [0,1]$; we specify α as $\alpha = \exp(\varepsilon_1)/1 + \exp(\varepsilon_1)$, where ε_1 is a normal variate, with mean μ_1 and variance σ_1^2. Finally, the third random variable u_2 (in crop equation), is denoted ε_2.

It is often recognized in the literature (Binswanger [1980]) that farmers exhibit significant aversion to downside risk, i.e. higher moments such as skewness in crop yield modify the optimal decision rules of producers (Pope and Just [1991]). We therefore specify the utility as the following CRRA:

$$U(W) = W^{(1-r)} \times \mathrm{sgn}(1-r)$$

with r the relative risk aversion coefficient. This utility function is consistent with DARA behavior reported by major empirical studies (see e.g. Binswanger [1980])[4]. Another advantage of working with CRRA is the fact that plot-level data may be used in place of farm-level data; and accurate data of nitrogen application is only relevant at the plot level.

The model to be estimated is a system of equations corresponding to the two first-order conditions of profit maximization with respect to x_0 and x_1.

[4]It may also be of interest to test for alternative risk attitudes, i.e. choose a flexible specification for utility which does not limit the researcher to either CARA or CRRA utilities. Chavas and Holt [1996], Saha [1994] propose utility functions that allow for a wide range of possible properties for absolute and relative risk aversion.

First-order conditions of the farmer's program are:

$$\int_{\epsilon_1}\int_{\epsilon_2} \frac{dU}{d\Pi}\left[p\frac{\partial F(x_0, x_1, \varepsilon_0, \varepsilon_1, \varepsilon_2)}{\partial x_0} - w\right] dG_1(\varepsilon_1, \varepsilon_2|\varepsilon_0) = 0 \tag{2}$$

$$\int_{\epsilon_2} \frac{dU}{d\Pi}\left[p\frac{\partial F(x_0, x_1, \varepsilon_0, \varepsilon_1, \varepsilon_2)}{\partial x_1} - w\right] dG_2(\varepsilon_2|\varepsilon_0, \varepsilon_1) = 0 \tag{3}$$

where ϵ_1 and ϵ_2 denote the domain of ε_1 and ε_2 respectively; $G_2(.|.)$ is the conditional distribution function of ε_1, ε_2 given ε_0, and $G_1(.|.)$ is the conditional distribution function of ε_2 given ε_0 and ε_1.

Estimating the first-order conditions jointly with the yield equation helps identifying structural parameters, and does not require numerical rootfinding procedures.

In computing expectations in first-order conditions, a convenient way to proceed is to use importance-sampling simulation (a variant of Monte Carlo simulation). The system of equations is used as the basis for a set of identifying restrictions, for the Simulated Generalized Method of Moments estimation procedure.

4 Empirical application

Data used are collected from various sources at the USDA, for the period 1990-1992. The Cropping Practices Survey (USDA 1992) contains information on yield, nitrogen applications, tillage, pesticides, and other practices at the plot level. We consider in our application a sample of 140 Midwest rain-fed plots, with continuous corn crop. Variable $SNBEF$ is computed as total nitrogen applied to crop before or at planting, and the variable $SNAFT$ as total nitrogen applied after planting, during growing season.

Output supply and nitrogen fertilizer input prices are from USDA state-level data. For climatic variables, we use the state average precipitation from NOAA to compute $RAINBEF$ as the average precipitation during late winter and early spring, and $RAINAFTER$ as the average precipitation for late spring and early summer. Other variables from the Cropping Practices Survey are used as instruments in the Simulated GMM procedure.

We estimate our system of equations (10) by Simulated GMM. To investigate the possible effect of rainfall on both nitrogen runoff after the first application and the initial nitrogen stock in soil, we add variables $RAINBEF$ and $RAINAFT$ in the model as follows. The retention parameter is specified as: $\alpha = \frac{\exp(\mu_1 RAINAFT + \varepsilon_1)}{1+\exp(\mu_1 RAINAFT + \varepsilon_1)}$ where μ_0 is a parameter to be estimated. We also incorporate $RAINBEF$ in the expression for initial stock of nitrogen before the first application: $A_0 = \exp(\mu_0 RAINBEF + \varepsilon_0)$. The nitrogen uptake parameter γ is set to 0.6 (see e.g. Meisinger and Randall [1991]). Because of the numerical complexity of the problem, we set the variance of

ε_2 to the variance of the residual from the Least Squares estimation of the yield function, and obtain σ_0^2 through an iterative procedure. The number of drawings is set to 20. Results are presented in Table 1. The Hansen test for over-identification is computed at 1.9690, indicating that the specification of the model is not rejected.

The risk aversion parameter r is rather low and significantly different from 0 at the 10% level only. Parameters μ_0 and μ_1 are of the expected sign, although μ_0 is not significantly different from 0. Rainfall in late spring is significantly decreasing the retention parameter for nitrogen (μ_1 is negative). The Allen Elasticity of Substitution (AES) between initial nitrogen application and sidedressing is computed at 0.3459. Thus, substitution possibilities of nitrogen fertilizer between subsequent stages in crop growth do not appear very important. This stresses the fact that nitrogen loss in early crop condition cannot be fully compensated for by future applications; and for our purpose, nitrogen runoff between late winter and late spring cannot be fully compensated either by sidedressing.

We next compute the value of information and the risk premium implied by our estimates. Since analytical solutions are not possible to obtain, we use a numerical root-finding algorithm. The value of information, denoted

$D(x_0)$, is the solution to

$$\max_{x_1} E_{\varepsilon_1} U[\Pi(x_0, x_1, \varepsilon_1), D(x_0)] = E_{\varepsilon_1} \max_{x_1} U[\Pi(x_0, x_1, \varepsilon_1)]$$

i.e. the amount of money the farmer is willing to receive for not using information on realized random shock ε_1 when making decision about sidedressing x_1. That is, when $D(x_1)$ is added to his profit, he is indifferent between using ex ante solutions for x_0 and x_1 (i.e. before realization of ε_1) or using information on ε_1, when it becomes available, to make decision about x_1. We compute the risk premium, denoted $R(x_0, x_1)$ as:

$$R(x_0, x_1) = E_{\varepsilon_1} \Pi(x_0, x_1, \varepsilon_1) + D - [E_{\varepsilon_1} U(D + \Pi)]^{\frac{1}{1-r}}$$

Descriptive statistics are then computed for the value of information and risk premium on the whole sample. The average value of information is $US\$$ 7.0892 per acre, and the average risk premium is $US\$$ 8.0088 per acre. The mean ratio of information value over profit is 4.5683 %, very close to the average ratio of risk premium over profit, which is computed at 5.1996. Consequently, the aggregate effect of risk aversion and information processing is about 10% of profit per acre. As profit per acre incorporates many additional factors such as machinery, fuel, etc., it is more interesting to compare the value of information and the risk premium to the total fertilizer cost. We find that both D and R account for about 30 percent of this cost, which is rather significant. These values provide some evidence that neglecting information processing by farmers in multi-stage production may lead to conclude that risk aversion behavior is the main determinant in nitrogen application decisions. Our results indicate however that the value of information is as important as the risk premium.

5 Conclusion

In this paper, we estimate a model of sequential nitrogen application under risk conditions. The key issue we address is the random nature of production based on nitrogen fertilization, where nitrogen runoff is likely to occur between successive steps in the production process. The possibility for the farmer to process information becoming available between successive crop condition stages, allows for a distinction between *ex ante* and *ex post* optimal decisions, allowing for computation of the value of information corresponding to the farmer's ability to use such information. This paper proposes joint estimation of technology and risk aversion parameters, using a structural approach and simulation-based econometric inference techniques. Parameter estimates for the representative farmer's utility function allows to evaluate average farmers' risk attitudes, the value of information and the risk premium as implied by random shocks on different stages of production. We

Table 1: Simulated GMM estimates of structural parameters

Variable	Estimate	Standard Error
Constant	106.2217 (**)	1.5350
$\tilde{x}_0$	2.1106 (**)	0.6285
$\tilde{x}_1$	0.6255 (**)	0.0261
$\tilde{x}_0^2$	-0.0220 (**)	0.0054
$\tilde{x}_1^2$	-0.1011 (**)	0.0149
$\tilde{x}_0\tilde{x}_1$	-0.0037 (**)	0.0002
σ_1	0.8944 (**)	0.034
r	0.1061 (*)	0.0625
μ_0	-0.0020	0.0016
μ_1	-0.2839 (**)	0.0022

Notes. ($*$) and ($**$) denote a parameter significantly different from 0 at the 10% and 5% level respectively.

find that risk aversion is present, although not very important in magnitude. The risk premium and the value of information together account for about 10 percent of profit per acre for Midwest corn production, and almost 30 percent of total fertilizer cost.

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