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Soil Conservation Decision

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Introduction

The goal of soil conservation is to reduce erosion-induced productivity loss. Wischmeier and Smith demonstrated that soil loss of 5 tons per acre per year (11.2 tons per hectare per year) is generally considered the maximum soil-loss tolerance (T-value) to permit a high level of crop productivity to be economically sustained for an indefinite period. The T-value criterion for evaluating on-site and off-site damages has gained support from the scientific conservation community throughout the past two decades (Sharp and Bromley). The traditional T-value criterion may overprotect a number of soils. Such criteria may be realized, but at the expense of current crop production and income for some farmers. As an alternative, the cost criterion with regard to a particular conservation measure may prove to be more useful for both farmers and policy makers and more accurately reflect the farm-level decision process (Burt; Walker; Crosson and Stout).

Walker introduced an erosion-damage function incorporating a crop-yield, soil-depth (Y-D) function. Although Walker's model develops an intertemporal net-benefit differential for alternative conservation practices, his methodology omits weather variables and farmer expectations relative to the probability of occurrence of a particular weather pattern. The model presented in this paper includes these elements within a Y-D framework. The model estimates a crop-yield, soil-depth function, and uses the estimated function to determine the optimal adoption strategy, under alternative scenarios with respect to crop prices, relative yields for
conservation versus conventional tillage and interest rates. Empirical results are based on crop production data on a fragipan soil and climatic conditions in Western Kentucky.

**Stochastic Variables and the Y-D Function**

In a Y-D function, soil depth is a partial proxy for many other variables that also affect crop yields. Assuming that a deep soil is required for rooting space and plant nutrients, then the general relationship between crop yields and soil depth is positively sloping, ceteris paribus (Pierce et al.; Frye, Murdock and Blevins). Unfortunately, there is no exact way to determine the appropriate functional form for a specific data set on crop yields and soil depths. However, economic and agronomic principles suggest specific functional forms of the relationship.

Any function describing the crop-yield soil-depth linkage should exhibit the following agronomic properties: (1) diminishing marginal returns to topsoil, (2) a non-zero intercept (positive yield even when topsoil is depleted), (3) a maximum attainable yield, and (4) nonnegative marginal returns to topsoil (Hoag and Young). There may be complementarity between soil erosion and crop production efficiency, particularly when dealing with the newly opened farmlands (Heady). The Hoag and Young criterion calls for a function that first increases at a very rapid rate, and then reaches a yield plateau.

A Y-D function which asymptotically approaches some maximum level of attainable yield may be adequate. Most farmland proposed for conservation practices has been cultivated for many years. Although soil depth decreases over time, usually there is no point where the marginal product of additional soil depth becomes negative. Model specification begins with the definition of a mechanistic growth model (MGM) representing the
relationship between crop yields and topsoil depth. The MGM function consistent with the Hoag and Young agronomic criteria, but incorporating a stochastic component, was selected for estimation:

$$y = a[1 - \beta \exp(-\gamma x)] + \epsilon$$

where $y$ is yield, $x$ is topsoil depth, $a$, $b$ and $g$ are constants and $\epsilon$ is a stochastic error assumed normally distributed with a mean of zero and a variance of $\sigma^2$.

Precipitation during the growing season is the main characteristic of weather affecting crop yields in a particular growing season. Although rainfall measured throughout a crop season is inherently continuous, Anderson, Dillon, and Hardaker argue that a discrete representation of the variable may prove adequate. The farmer is assumed to be primarily concerned with lower and upper bounds on outcomes (crop yields) as influenced by the random precipitation variable.

Three discrete categories were defined, above normal ($w_1$), normal ($w_2$), and below normal ($w_3$). The three categories were primarily based on the total quantity and distribution of rainfall during a growing season. The simplest approach is to determine probabilities for each pattern under the assumption that an event (pattern) in year $t$ is independent of the event in any other year. In this way, the probability of each pattern occurring within a particular crop year may be defined by $P_1 = NO_1/C$, where $P_1$ is the probability of occurrence for weather pattern 1, $NO_1$ is the number of occurrences of weather pattern 1, and $C$ is the number of crop years. If weather pattern categories ($w_i$) do not accurately describe the weather pattern during the growing season, the effects are incorporated in other parameters of the model. The weather vector can be redefined as:

$$S_n = \{s_{n1}, s_{n2}, s_{n3}, s_{n4}, \ldots, s_{ng}\}$$
where $s_{n1}$ and $s_{n2}$ are components of rainfall and the variability of rainfall not accounted for in the $w_i$, but that remained constant over the growing seasons for which the data were collected and $s_{n3} - s_{ng}$ are other weather components that did not vary over the crop season. In order to represent those precipitation components which did not remain constant over the sample growing seasons, a new vector must now be defined as:

$$S_e = \{s_{e1}, s_{e2}, s_{e3}, s_{e4}, \ldots, s_{eg}\}$$

where $s_{e1}$ and $s_{e2}$ are random stochastic components of rainfall and the variance of rainfall not accounted for by either the $w_i$ measure or in $s_{n1}$ or $s_{n2}$, and $s_{e3} - s_{eg}$ are other random stochastic components of the weather pattern that varied over the growing seasons and were also unaccounted.

Since crop yields are influenced by variables other than weather and soil depth, the vector $Z = \{z_1, \ldots, z_h\}$ is introduced, where the individual $z_i$ represent determinants of crop yields other than weather patterns and soil depth. For example, $z_1$ might be insects, $z_2$ diseases, $z_3$ weeds, and so on. Of course, many of these factors also interact with individual weather variables in the $S$ vector and with the soil depth.

For such elements representing non-weather factors which remained constant over the period of the experiment, the vector $Z_n = \{z_{n1}, \ldots, z_{nh}\}$ is defined. These are the factors that the agronomists conducting the yield experiments were able to hold constant over plots and growing seasons. Conversely, the stochastic non-weather components which were not held constant over the growing season (despite the efforts of the agronomists) are described by the vector $Z_c = \{z_{c1}, \ldots, z_{ch}\}$.

The effects of weather and non-weather related variables that were truly constant are adequately measured by the weather pattern.
categorization (the $w_i$) effect upon the parameters $\alpha$, $\beta$ and $\gamma$, incorporated in the $Y-D$ function. That is:

\[
\alpha = \alpha(x, w_1, w_2, w_3 | s_{n1}, \ldots, s_{ng}; z_{n1}, \ldots, z_{nh})
\]

\[
\beta = \beta(x, w_1, w_2, w_3 | s_{n1}, \ldots, s_{ng}; z_{n1}, \ldots, z_{nh})
\]

\[
\gamma = \gamma(x, w_1, w_2, w_3 | s_{n1}, \ldots, s_{ng}; z_{n1}, \ldots, z_{nh})
\]

where $x$ is the depth of the soil and other variables are as previously defined. The effects of uncontrolled random weather and non-weather variables are included in the stochastic error term.

**Linkages Between Yield and Soil Depth**

Essential to the development of a farm-level decision model is the formulation of expected production and corresponding expected profit functions. These functions, in turn, depend upon the observed weather patterns. Using the probability of occurrence for each weather pattern, it is possible to form an expected yield function from data for three weather patterns by $E(y_{ij}) = \Sigma P_i y_i$, where $E(y_{ij})$ is the expected value of yield associated with weather pattern $i$ and soil depth (observation) $j$, $P_i$ is the probability of occurrence of weather pattern, and $y_i$ is expected yield.

In addition, an expected intertemporal profit function is:

\[
E(\Pi_1) = \Sigma P_i \{p_t y_{it} - C_{it}\},
\]

where $E(\Pi_1)$ is the expected value of intertemporal profit, $P_i$ is the probability of weather pattern $i$, $y_{it}$ is the crop yield associated with weather pattern $i$ in period $t$, $p_t$ is the crop price in period $t$, $C_{it}$ is the production cost associated with weather pattern $i$ in period $t$, $i = (1, 2, 3)$, and $t = (1, \ldots, T)$. However, with constant output prices ($p$), and assuming that operational costs are not affected by the weather pattern, then the intertemporal profit function with discount factor $r$ is equivalent to:

\[
E(\Pi_1) = \Sigma_t [p (\Sigma_{i} P_i y_{it}) - C_t)] (1+r)^{-t}
\]
The soil depth loss for a single crop year under erosive practices is
\[ \Delta x = (0.019)S, \]
where \( \Delta x \) is the soil depth loss (cm) and \( S \) is the soil loss in tons per acre, assumed constant over time. The number 0.019 is the assumed depth of one ton of soil spread over one acre, (see Larson, Pierce, and Dowdy). The soil depth at time \( t+1 \) can be calculated as
\[ x_{t+1} = x_t - n \Delta x = x_t - n (0.019)S, \]
where \( x_{t+1} \) is the soil depth in period \( t+1 \) (cm), and \( n = i = 1, 2, \ldots, T - 1 \).

Yields can be determined from the Y-D function for different soil depths, assuming that technology was constant over the four years contained in the Y-D data set. Yields at a particular soil depth, say \( x_t \) or \( x_{t+1} \), according to the estimated Y-D function are expressed as:
\[
y(t|x_t) = a \left[ 1 - \exp(-\gamma x_t) \right]
\]
\[
y(t|x_{t+1}) = a \left[ 1 - \exp(-\gamma (x_t - 0.019S)) \right]
\]
\[ = a \left[ 1 - \exp(-\gamma x_{t+1}) \right] \]
where \( y(t|x_t) \) is the yield at time \( t \) (technology \( t \), according to the estimated Y-D function) and soil depth \( x_t \). Technological change will shift the estimated Y-D curve upward, indicating a general increase in productivity. Conversely, erosion will reduce productivity.

**Estimation of the Y-D Function**

A single data set was used to estimate the parameters of equation (1), using the weather-adjusted dataset from experimental trials for corn under conventional versus conservation tillage at Princeton, Kentucky. This estimated function was:

\[
y = 128.285 \left[ 1 - 10.289 \exp(-0.098x) \right]
\]
\[
(3.803) \quad (6.391) \quad (0.019) \quad R^2 = .984
\]
The coefficient of determination suggests that once the data were adjusted for weather, nearly all the yield variation could be attributed to soil depth and that procedures used to adjust for differences in weather patterns by classifying the weather into three distinct categories were probably adequate. The contention of Anderson, Dillon and Hardaker that the weather variable may be adequately measured with discrete categories thus has empirical support. The high coefficient of determination also indicates that agronomists responsible for generating the yield data adequately controlled for factors that influence crop yields other than weather and soil depth. Equation (2) has the properties of the crop-yield, soil-depth relationship suggested by Hoag and Young, except for a negative intercept. The maximum attainable yield, as \( x \) approaches infinity, is 128.285 bushels per acre. Decreasing but non-negative marginal returns or productivity to soil depth occur. The intercept is -1191.64, which implies that at a soil depth of 23.787 cm, the expected yield is zero. This result may be not surprising, in that some data came from fields with virtually no topsoil (A horizon). In the Purchase area where the experiments were conducted, some fields have a fragipan covered by almost no topsoil (Grosman and Carlisle). On such soils, a corn yield of zero could occur, particularly in a year with below normal weather. However, since the Y-D function was estimated using small number of observations (19 for each year), interpretation outside the soil-depth domain must be carried out with caution (Cassidy, p 150; Wonnacott and Wonnacott, p. 65). Cassidy argues that little emphasis should be placed on the sign, significance, or interpretation of the intercept terms.
Yield Differentials and the Technological Change Model

Young, Taylor and Papendick reported an interaction between technological progress and soil depth for wheat cropland in the Palouse area. They did not address the possible interaction between a weather pattern and the soil depth. Conclusions were based on two Y-D functions estimated using data sets on soil depth and yield that were collected from two different periods, 1952-1953 and 1970-1974 (Taylor).

In this study, interactions between technological change and soil depth and interactions between weather patterns and soil depth were considered. Within such a framework, if there is an improvement in technology in period \( t+1 \) relative to period \( t \) upon which the function was based, then the yield at a given soil depth (according to the Y-D function) must be adjusted upward by the amount of the productivity change.

At soil depth, \( x_t \), the crop yield (per acre) from the Y-D function is \( y(t|x_t) \). In time \( t+1 \), with improved technology but with a soil depth \( x_{t+1} \) (where \( x_{t+1} < x_t \)) the yield is \( y(t+1|x_{t+1}) \) which may not always be less than \( y(t|x_t) \) even if \( x_{t+1} < x_t \). This is expressed as:

\[
y(t+1,x_{t+1}) = y(t|x_t) - \Delta y(t|x_t) + \Delta q_{t+1}
\]

which is equivalent to:

\[
y(t+1,x_{t+1}) = y(t|x_{t+1} - \Delta y) + \Delta q_{t+1}
\]

\[
= y(t|x_{t+1}) + \Delta q_{t+1}
\]

where \( y(t+1,x_{t+1}) \) is the adjusted yield level at time (technology) \( t+1 \) and soil depth \( x_{t+1} \), \( y(t|x_{t+1}) \) is the yield level at time \( t \) (technology \( t \), or according to the estimated Y-D function), and at soil depth \( x_{t+1} \), \( \Delta y \) is the loss in yield and \( \Delta q_{t+1} \) is the amount of yield improvement (adjustment) due to technological change in the period \( t+1 \).
To measure $\Delta q_{t+1}$, a productivity-trend (P-T) function relevant to conventional and conservation practices is needed. The P-T function is defined as:

$$\ln q_t = g(t) = \alpha + \beta \ln t + \gamma t + \epsilon$$

where $q_t$ is the (average) productivity for period $t$ (bushels per acre), $g$ is a function describing the relationship between $t$ and $q_t$. $\frac{\partial g}{\partial t} > 0$ and $\frac{\partial^2 g}{\partial t^2} < 0$, indicating that efficiency improved at a decreasing rate over time, $t$ is an annual time trend representing technical change, $\alpha$, $\beta$ and $\gamma$ are the parameters and $\epsilon$ is a random error term. From equation (5), a discrete productivity change from a period (say period $t$ to period $t+1$) which is compatible with the base period of the Y-D function is given by $\Delta q_{t+1} = q_{t+1} - q_t$. An indicator of yield improvement between the two periods can be defined as $m_{t+1} = (\Delta q_{t+1}/q_t) \cdot 100$. The statistic $m$ is a multiplicative shift factor (uniform throughout the soil-depth levels) for the Y-D function. Such an assumption is consistent with agronomic principles (Young, Taylor, and Papendick), although in the real world the multiplicative shift factor is not always uniform. The uniform multiplicative shift factor indicates that in period $t+1$, each yield generated by the Y-D function will be shifted upward by the same constant proportion $m$. However, $m$ will certainly change over time, but lie between zero and one.

Technological progress in time $t+1$ ($\Delta q_{t+1}$) is indicated by the P-T function and can be approximated as follows:

$$\Delta y_{t+1} = m_{t+1} y(t|x_{t+1})$$

Therefore:

$$y(t+1,x_{t+1}) = (1+m_{t+1}) y(t|x_{t+1})$$
The adjusted yield level for each successive soil depth \((x_{t+i}, i>1)\) from one production period to the next, namely \(t, t+1, t+2, \ldots, t+i\) is:

\[
\hat{y}(t+2, x_{t+2}) = (1+m_{t+2}) \hat{y}(t+1, x_{t+2}) \\
= (1+m_{t+2})(1+m_{t+1}) y(t|x_{t+2}) \\
\vdots \\
= (1+m_{t+1}) \ldots (1+m_{t+1}) y(t|x_{t+1}) \\
\hat{y}(t+i, x_{t+i}) = (1+m_{t+1}) \ldots (1+m_{t+1}) y(t|x_{t+1})
\]

where \(\hat{y}(t+2, x_{t+2})\) = the adjusted yield level with technology \(t+2\) and soil depth \(x_{t+2}\), where \(x_{t+2} < x_{t+1}\) due to erosion.

\(\hat{y}(t+1, x_{t+1})\) = the adjusted yield level (at soil depth \(x_{t+1}\)) for the period \(t+1\) and again adjusted to capture the impact of technology \(t+2\).

\(\hat{y}(t+i, x_{t+i})\) = the adjusted yield level at soil depth \(x_{t+i}\) and technology \(t+i\).

\(y(t|x_{t+i})\) = yield level at technology \(t\) and calculated soil depth \(x_{t+i}\)

\(m_{t+1}\) = the multiplicative shift factor for period \(t+i\).

**Development of the Intertemporal Profit Function**

Suppose an individual farmer in period \(t-1\) employed a particular conventional (erosive) production practice with a technology \(t-1\). The farm is endowed with a soil depth, \(x_{t-1}\), at the beginning of the production period. The minimum (variable) cost incurred was \(c(t-1, x_{t-1})\), and return was \(py(t-1, x_{t-1})\). For production in the current period \(t\), the farmer is assumed to apply particular production practices, conventional or conservation. The farmer might again use conventional practices for at least one more year in order to maximize the difference between expected
returns and the production cost. This choice (call it option A), is
expressed by an intertemporal profit function:

\[
\Pi_1 = py(t, x_t) - c(t, x_t) + \sum_{i=1}^{n-1} \left[ py(t+1, x_{t+1}) - c(t+1, x_{t+1}) \right] (1+r)^{-1} + \sum_{m=0}^{T-n} [py(t+n+m, x_{t+n})^C - c(t+n+m, x_{t+n})^C](1+r)^{-(n+m)}
\]

where:

\( \Pi_1 \) = the present value of intertemporal net revenue for
option A at a discount rate \( r \).

\( p \) = output (corn) price,

\( y \) = output quantity (bu./acre), and \( y \) is function of
technology and soil depth. For example, \( y(t, x_t) \) implies
that the measured yield is dependent upon the
technology used in the period \( t \) and soil depth that
exists at the beginning of period \( t \); \( y(t, x_t) \) applies to
conventional practices and \( y(t, x_t)^C \) is relevant to the
conservation practices.

\( c \) = optimal cost which depends also on technology and
soil depth; \( c(t, x_t) \) applies to conventional practices,
and \( c(t, x_t)^C \) applies to conservation practices.

\( i = 1, 2, \ldots, n-1; m = 0, 1, 2, \ldots, T-n; n \geq 1 \)

Equation (9) represents a sequence of production activities which
consist of at least one year (or \( n \)-year, for \( n \geq 1 \)) of conventional tillage
followed by the adoption of conservation tillage for the remaining years of
the planning horizon. The adoption of conservation practices is said to be
at least one-year delayed.

Alternatively, the farmer might adopt a conservation practice as
recommended by a conservation specialist (called option C). The
corresponding intertemporal-profit function is:
\[ \Pi_2 = p y(t, x_t)^C - c(t, x_t)^C + \]
\[ \sum_{i=1}^{T} [p y(t+i, x_t)^C - c(t+i, x_t)^C] (1+r)^{-i} \]

where
\[ \Pi_2 \] is the present value of net-revenue stream for option C and at a discount rate r. Other variables are as previously defined.

Equation (10) represents a sequence of conservation practices adopted over the time horizon. Notice that the soil depth in each production period is assumed to remain unchanged over time because the conservation practice was adopted. The decisionmaking process involves more than choosing between options A and C. It also includes choices of whether or not to delay the adoption of conservation practices for one or more periods. The nature of the decision depends upon the magnitude of benefits from employing conventional practices for at least one more period, and benefits measured in terms of erosion-induced productivity loss being saved by adopting the conservation practice immediately. If returns from delaying adoption are larger than the measured erosion-induced productivity loss, then there is incentive for the farmer to postpone the adoption of conservation practices. Hence, a measure of reduction in net returns due to mining the soil with erosive practices for one or more periods is given by the erosion-damage function. The erosion-damage function is the difference between values of the two intertemporal profit functions. Equation (9) represents a strategy consisting of n periods under conventional practices, followed by a sequence of conservation practices starting from time \( t+n+1 \) to time T, where \( n \geq 1 \). However, for equation (10), conservation practices are from period t until the end of the time horizon (T). An erosion-damage function with an n-year delay in the adoption of conservation practices is defined as the difference between equations (10) and (9):
The term $\{p_y(t, x_t) - p_y(t, x_t)C\}$ represents the value of the yield differential between the adopted conventional practice (in option A) and the conservation practice (in option C) in period $t$ and at soil depth $x_t$. Hence, it is the component of conventional-tillage advantage over the conservation tillage. The dollar value can be positive or negative depending upon revenue generated from each practice. The term $\{c(t, x_t) - c(t, x_t)C\}$ is the cost differential associated with the yield differential.

If more than a one-year delay occurs in the adoption of a conservation practice, then the returns and cost differential between conventional and conservation practices will include the terms $\Sigma_i \left[\{p_y(t+i, x_{t+i}) - p_y(t+i, x_{t+i})C\} + \{c(t+i, x_{t+i}) - c(t+i, x_{t+i})C\}(1+r)^{-i}\right]$.

The term $p_y(t+n+m, x_{t+n})C - p_y(t+n+m, x_t)C$ is the value of yield differential for the same conservation practice resulting from a difference in soil depth. The discounted value of these terms is appropriately called the present value of erosion-induced productivity loss (Walker, 1986) over the periods $T-n$. It was then considered as a partial measure of a reduction in value of the cropland due to a loss in soil depth, following an $n$-year ($n \geq 1$) delay of conservation adoption. The remaining of loss in land value, supposed to be part of income damage, was considered negligible.

The yield differential, $y(t+n+m, x_{t+n})$, differs from $y(t+n+m, x_t)$. The soil depth at time $t$ is $x_t$, but at time $t+n$ the depth is $x_{t+n}$. As $n$ becomes
larger, the greater the difference with respect to $x_t$, and the greater the yield differential. The associated cost differential is $c(t+n+m, x_t)^C - c(t+n+m, x_{t+n})^C$. Walker assumed that the cost differential for two different soil depths, $x_t$ and $x_{t+1}$, under conservation practices, was negligible (assumption 1). To evaluate equation (11), $c(t+n+m, x_t)^C$ is assumed equal to $c(t+n+m, x_{t+n})^C$. In each time period, the farmer incurs the same cost regardless of the soil depth. The farmer makes no attempt to offset nutrient losses inherent in the loss of soil by applying fertilizer. In addition, no extra energy is assumed to be required following an erosive tillage practice applied during earlier periods within the time horizon. Since $c(t+n+m, x_t)^C - c(t+n+m, x_{t+n}) = 0$, then $py(t+n+m, x_{t+n}) - py(t+n+m, x_t) < 0$. Consequently, the evaluation framework becomes applicable only for cropland affected by sheet and rill erosion.

When a one-year delay in the adoption of conservation practices is considered, both $[py(t+i, x_{t+1}) - py(t+i, x_t)]$ and $[c(t+i, x_t)^C - c(t+i, x_{t+1})]$ are zero. When $n$ is greater than one, the erosion-damage function (11) can be evaluated, but $c(t+n+m, x_t)^C - c(t+n+m, x_{t+n})^C$ need not be calculated. The erosion-damage function (11) is sensitive to changes in any of its arguments. Certain terms will not appear when only variable costs are of concern, but must appear when specific capital investments are considered. Moreover, the NPV concept discounts the net cash flow. Consequently, varying the debt repayment period will lead to new values for the erosion-damage function. Hence, in calculating the erosion-damage function the time path for debt repayment must be considered.

The Y-D function was a proxy for yields under conventional practices with a particular technology. At time $t$, an assumption is made with regard to yields under conventional versus conservation practices. Therefore, the
Y-D function can also be used to approximate yield differentials occurring on cropland with two different soil depths cultivated under the conservation practices using a specific technology. The conservation practice used to illustrate was the no-till system (Phillips et al.; and Maglaby et al.).

Estimation of The Production Return and The Cost-Adjustment Path

Intertemporal profit functions require knowledge of output prices, yields, costs, and interest rates. Since output prices and production costs have not been specifically addressed, the measurement of the productivity change over time will focus on a productivity-trend (P-T) function. Two types of productivity data may be used to estimate a P-T function: the total productivity index (TPI) or the average yield per acre (AYPA) method. Growth in output due to technical change can be partitioned into a neutral part (pure productivity efficiency improvement) and a non-neutral part, (which may come from an increase in the quantity or a change in the quality of inputs), or structural change in the industry (Solow; Griliches; Lingard and Rayner; Walker and Young).

The total productivity index (TPI) is defined as the ratio of real product to real factor input or, equivalently, the ratio of the price of factor input to the product price (Christensen and Jorgenson). It is essentially a measure of productivity previously used. The TPI can be measured from factor shares (assuming competitive equilibrium) based on formula derived from a specific transformation function (e.g. Ball). The TPI measures the impact of pure efficiency improvement.

The AYPA data measures both neutral and non-neutral technical change, and AYPA productivity data is readily available at local, regional, or national levels. The AYPA data pose different implications with respect to the treatment of future output prices and costs for each type of production.
practice in comparison with the implications posed by the TPI data. Future
trends in output prices and costs are difficult to determine.

If the assumption of constant output price and cost is adopted, yield
improvement over time can only be measured from TPI productivity data.
This is because the TPI data can only explain pure efficiency improvements
over time and every efficiency improvement is assumed to affect both output
prices and unit costs in exactly the same fashion. This assumption will
not hold if AYPA data are used, in which case the non-neutral part of
technical change could directly affect the per acre operating cost.

The TPI data series for U.S. agriculture (Ball) were used to estimate
the P-T function. The productivity trend for corn production under
conventional and conservation practices was then assumed to follow the
same path as described by the estimated P-T function. The P-T function,
which represents the productivity trend for the U.S. agriculture, with
standard errors in parentheses, is:

\[ \ln q_t = -0.586187 + 0.016315 t + 0.028463 \ln t \]

\[ (0.02) \quad (0.001) \quad (0.015) \]

\[ R^2 = 0.977 \]

where \( \ln q_t \) = the log of productivity index for the period \( t \).

A series of multiplicative shift factors (or \( m \) which for each specific
time \( t \) is uniform throughout the soil-depth levels) was measured. The year
1979 was the base period upon which the C-S function was estimated. The
productivity change over time (1979-2008) decreases at a decreasing rate.
For example, in 1979 the productivity improvement was 1.73678 percent, and
this improvement would be 1.71462 percent and 1.70108 in 1989 and 1999
respectively.
Equation (12) is assumed to represent both conventional and conservation practices. Output price and costs were assumed constant over time. Cost differentials between conventional and conservation practices were specified. The discount rate was assumed constant throughout the 30-year time horizon. A real discount rate of 4 percent was used.

Research in Kentucky, Maryland and Virginia found that conventional tillage produces more corn than no-till at low nitrogen application rates, but no-till usually produces more than conventional tillage at high rates of nitrogen application (Frye and Phillips). With 150 lbs. of fertilizer nitrogen per acre, conventional till yields 15.9 percent less than no-till on Crider silt loam, about two percent lower on Maury silt loam and Allegheny loam (Hudson), but yields approximately the same on Tilsit silt loam (Phillips et al.). On the average, for corn in Kentucky, no-till with 150 lbs. nitrogen fertilizer produces higher yields than conventional cultivation practices. Moreover, conservation practices can save liquid-fuels energy as well as keep the soil from eroding (King). Absolute productivity growth over time under conservation-tillage practices may be greater than under conventional-tillage practices. However, corn yields are assumed to grow at the same rate due to technical change over time under both conventional and conservation practices. The growth path of corn productivity follows equation (12), and a constant corn price of $2.75 per bushel was assumed.

Mueller, Klemme and Dariel reported that in the long run, production costs for corn under no-till were about one percent lower than under conventional-tillage. Epplin, Tice and Lee found that the operating costs for conservation tillage practices were approximately four percent higher than for conventional-tillage. In 1985, the expected variable cost for
corn production using conventional-tillage practices in Kentucky was $174.99, and $192.37 (about 9.9 percent higher) when using no-till. The Kentucky Special Resource Study (USDA, 1985) also reported that total costs per acre for no-till were 9.3 percent higher than for conventional tillage.

This study assumed higher costs under the conservation practices. No-till requires a specialized or modified planter (USDA 1985b pp. 3-4). The adoption of no-till system by a farmer may involve some additional capital investment. Such an investment must be specifically reflected in the cost components of the erosion-damage function, assuming the decisionmaker does not rent (custom work) the corn planter.

The erosion damage function was based on the principle of discounted cash flow (DCF), rather than internal rate-of-return rules, for example using \( p, r \) comparison rules. The erosion-damage function deals with two possible production strategies. One possibility is a sequence of production activities involving conventional practices in the first or first several years followed by the adoption of conservation practices to be used thenceforth (option A). Another possibility is conservation practices in each season throughout the time horizon of concern (option C). The two options are mutually exclusive. The principle of discounted cash flow (DCF) is then relevant.

**Alternative Empirical Scenarios**

In Table 1, values for the erosion-damage function were calculated for corn land with a soil depth to the fragipan of 60, 57.5, 55, 52.5, 50, 45, and 35 cm. An average soil loss of 15.28 tons per acre, a (real) discount rate of 4 percent and a no-till/conventional yield ratio \( (y_c/y_a) \) of 1.03 was assumed (i.e. no-till has 3 percent higher yields than conventional tillage). Under this set of assumptions, only on cropland with a 60 cm
soil depth to the fragipan is it advantageous to delay adoption of the conservation practices for one more year. No-till should be adopted from the start of the planning horizon when the cropland has 57.5 cm or less soil depth to the fragipan. For a soil depth of 60 cm and above, at least a 5-year delay in the start of conservation practices is suggested by the results.

The dynamics of capital investment were then introduced. The investment was assumed to be on a 6-row no-till corn planter at a price of $20,000, a 7-year expected life, and a 10 percent interest rate for a 42-month mortgage. All other assumptions remained the same. At a 4 percent real discount rate, the adoption of no-till at the start of the planning horizon is not suggested for cropland with a soil depth of 57.5 cm or above. With the given assumptions, no-till should be adopted for cropland with soil depth of 55 cm or below. Hence, Table 1 suggests that the need to buy a new no-till corn planter tends to postpone the adoption of conservation tillage (no-till) by a farmer.

**Sensitivity Analysis**

The sensitivity analysis varied $y_c/y_a$ ratios, interest rates, and output prices. In Table 2, the discount rate and the ratio of $y_c/y_a$ are varied. At a specific interest rate, as little as a one percent shift in $y_c/y_a$ could result in a substantial change in the calculated value for the erosion-damage function. At a $y_c/y_a$ of 1.03 or below and a discount rate of 4 percent, the adoption of no-till for decision period $t$ is not suggested by the net-present-value rule. If $y_c/y_a$ is increased to 1.035, at a discount rate of 4 percent the conservation tillage should be adopted, but not at a discount rate of 6 percent. If $y_c/y_a$ is 1.04 or above, the erosion-damage function values are negative, indicating that the switchover point from conventional to conservation tillage practices has passed and
the conservation adoption is necessary. When the investment cost for a no-
till corn planter was taken into account, no-till was adopted even at a 10
percent discount rate, assuming that, in decision period t, no-till had at
least 5 percent greater yields than conventional tillage.

Sensitivity analyses with respect to the discount rate are presented
in Table 2. As the discount rate increases, adoption of the conservation
tillage is postponed. Table 1 also presents a sensitivity analysis with
respect to the output price. The higher the output price, the more
desirable is no-till. An increase in the output price accompanied by a
value of $y_c / y_a$ of greater than one increases the present value of net-
benefit differentials for the two sequences of activities (where soil depth
decreases for the conventional practice) in favor of conservation. Table 13
implies that if corn price is high, more effort will be devoted by farmers
to soil conservation. Conversely, during times of persistently low corn
prices, farmers (such as those in the Purchase area with fragipan soils)
will be less likely to adopt specific soil-conservation practices.

Sensitivity analysis indicates that a high ratio of conservation to
conventional yields accompanied by low discount rates and high corn prices
could lead farmers to be more responsive to soil conservation program. The
calculation of the erosion-damage function will be meaningful to a
decisionmaker if the supplemental assumptions are correctly anticipated and
determined.

The evaluation of erosion-damage functions relies on the expected
yield calculated from the estimated Y-D function. Yields represent
weighted averages based on the probability of occurrence of above-normal,
normal, and below-normal weather patterns. An erosion-damage function is
not sensitive to the potential for farm bankruptcy. A net loss might occur
on a farm with a soil depth insufficient to produce profitable corn yields when weather is bad. (Of course, farmers may go bankrupt for many reasons other than loss of soil to erosion. However, a farm may theoretically be in jeopardy if, because of soil erosion, the dollar value of harvested output cannot cover total costs.)

The adoption of conservation practices to maintain soil depth can be viewed as an insurance policy. The estimated C-S function for the below-normal weather pattern was \[ y = 96.529 - 4.118 \exp(-0.050x) \]. In the case of bad weather, and at an output price of $2.75 per bushel, production (variable) costs of $92.39 per acre under conventional tillage can be covered only when the output level exceeds 33.60 bushels per acre. This yield is achievable at a soil depth of 36.8 cm. With variable costs of $122.74 per acre under no-till, the break-even level is 40.71 cm. or 44.63 bushels of corn per acre (assuming conventional-tillage to no-till yield ratio is one). The use of no-till at a soil depth of less than 41 cm could mean a substantial loss to the farm business in bad weather. Since the actual data are subject to both stochastic and measurement errors, a soil depth 41 cm. is then the break-even point for corn production with no-till.

Table 3 presents the values for the erosion-damage function under Walker's framework, and the values calculated using the alternative function proposed in this study. The adoption of no-till becomes profitable in year five with Walker's framework, or one year earlier than suggested by the function developed in this study. Given specific cost information on conservation versus conventional practices, then the value of the erosion-damage function under Walker's conceptual framework overestimates the economic attractiveness of conservation practices.
regardless of output prices, interest rates, or values for $y_c/y_a$. The postponement of conservation practices is a consequence of defining a realistic erosion-damage function.

**Policy Recommendations**

Results from the erosion-damage function assumed that the ratio of yields for no-till versus conventional tillage was greater than one $[(y_c/y_a)>1]$. At least for corn in Kentucky, production and cost data used in the evaluation reveal that high yielding no-till production systems may be more costly in terms of variable and total operating costs than are conventional practices. The investment aspect of soil conservation may become irrelevant to the farmer if production costs associated with the no-till system are similar to conventional tillage, and a value for $y_c/y_a$ of greater than one occurs. With more research on the technical aspects of no-till systems, the agronomic and economic competitiveness of conservation over conventional tillage practices may be enhanced over time.

In this study, a P-T function was estimated using average (index) data on changes in agricultural productivity at the national level. The approach is more appropriate if the location-, crop-, and tillage-specific productivity data are used. Evaluation of the erosion-damage function was simplified by an assumption of constant production costs under no-till regardless of the soil depth. Such an assumption, consequently, restricts the evaluation framework to be applicable only for the cropland with fragipan horizon that experiences sheet and rill erosion, instead of gully erosion which can cause severe damage. The evaluation framework will be more realistic and its applicability will widen if a specific cost scenario and model are developed to relax the restrictive assumption.
Soil conservation decision factors such as output prices, the yield ratio of conservation (no-till) to conventional-tillage practices, and the discount rate affect the decision in a different intensity and direction. An increase in output price (while $y_c/y_a$ is greater than 1) will encourage corn farmers who operate on cropland with fragipan horizons to more quickly adopt conservation no-till. Conversely, when output prices decrease, farmers will be less inclined to adopt soil conservation practices.

Just as output prices encourage conservation, the yield ratio of conservation to conventional practices is also positively related to motivation of and efforts by farmers to adopt conservation practices. For a given level of production cost in period $t_0$, the beginning of a planning horizon, the higher the yield ratio, the more readily the farmer will adopt conservation-tillage practices. A higher yield ratio affects the conservation decision directly by increasing the immediate benefits from conservation tillage, and indirectly by giving more weight to the value of erosion-induced productivity loss over time.

The higher the discount rate, the slower the conservation adoption. In the analysis, instead of nominal, real discount rates were used. It is a matter of the decisionmaker's perception as to whether real or nominal discount rates should be used. If the cost of purchasing a (new) no-till corn planter is considered, then the adoption of conservation tillage practice is postponed at least one more period.

The decisionmaking procedure proposed in this study can be useful both for individual farmers in making a soil conservation decisions, and for soil conservation agencies in determining soil conservation targets in a
particular area. This is an extension of Walker's framework, which can be useful only to a conservation agency in determining a target site for a conservation program.

In the soil conservation decision analyses presented in this study, appropriate information on the crop-yield, soil-depth (Y-D) function and the productivity-trend (P-T) function was estimated. For crop land with a fragipan horizon, interaction between weather patterns (defined as the amount and distribution of rainfall during the crop season and the critical period of crop growth) affect both the slope and intercept of the Y-D function. This study demonstrated that weather patterns may actually interact with soil depth in determining crop yields. If that is the case, an erosion-damage function that uses a Y-D function from soil-depth and crop-yield data based on a particular weather pattern is not conceptually acceptable.

Using the erosion-damage function, the urgency of the conservation decision on cropland characterized by a very shallow depth to the fragipan horizon was shown. For example, for cropland with soil depth of 40 cm., the corn farmer needs to adopt no-till immediately. However, a short-term analysis that gives attention to the break-even point of the production activity (e.g. using the game-theory approach) may suggest a different conservation strategy. For instance, a strategy to fallow the land and cultivate alternating with no-till over time is more likely to be economically feasible. Otherwise, so long as the use of conservation practices is a partial condition in the lease agreement, cash rental is the risk-free decision.
Table 1. Erosion Damage Function Values, Conservation Adoption, Discount Rate of 4 Percent, Soil Loss of 15.28 ton/acre/year, Varying Prices for Corn, $y_c/y_a$ of 1.03 at the Beginning of Period $t$.

<table>
<thead>
<tr>
<th>Initial soil depth</th>
<th>Corn price ($y_c$)</th>
<th>Years of delay</th>
<th>New planter adoption</th>
<th>Conventional tillage</th>
<th>Net present value</th>
<th>EDF value</th>
</tr>
</thead>
<tbody>
<tr>
<td>60.0 cm $2.75</td>
<td>1</td>
<td>no</td>
<td>$7.0008</td>
<td>$6.3842</td>
<td>$0.6166</td>
<td></td>
</tr>
<tr>
<td>57.5 cm $2.75</td>
<td>1</td>
<td>no</td>
<td>7.0852</td>
<td>8.1471</td>
<td>-1.0619</td>
<td></td>
</tr>
<tr>
<td>55.0 cm $2.75</td>
<td>1</td>
<td>no</td>
<td>7.1932</td>
<td>10.4034</td>
<td>-3.2102</td>
<td></td>
</tr>
<tr>
<td>52.5 cm $2.75</td>
<td>1</td>
<td>no</td>
<td>7.3310</td>
<td>13.3077</td>
<td>-5.9767</td>
<td></td>
</tr>
<tr>
<td>50.0 cm $2.75</td>
<td>1</td>
<td>no</td>
<td>7.5073</td>
<td>17.0161</td>
<td>-9.5088</td>
<td></td>
</tr>
<tr>
<td>45.0 cm $2.75</td>
<td>1</td>
<td>no</td>
<td>8.0202</td>
<td>27.7443</td>
<td>-19.7241</td>
<td></td>
</tr>
<tr>
<td>35.0 cm $2.75</td>
<td>1</td>
<td>no</td>
<td>10.2232</td>
<td>73.8987</td>
<td>-63.6755</td>
<td></td>
</tr>
<tr>
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<td>yes</td>
<td>14.2030</td>
<td>10.6099</td>
<td>3.5931</td>
<td></td>
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<td>57.5 cm $2.75</td>
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<td>yes</td>
<td>14.2874</td>
<td>12.3725</td>
<td>1.9149</td>
<td></td>
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<tr>
<td>55.0 cm $2.75</td>
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<td>yes</td>
<td>14.3954</td>
<td>14.6293</td>
<td>-0.2339</td>
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<tr>
<td>52.5 cm $2.75</td>
<td>1</td>
<td>yes</td>
<td>14.5332</td>
<td>17.5336</td>
<td>-3.0004</td>
<td></td>
</tr>
<tr>
<td>50.0 cm $2.75</td>
<td>1</td>
<td>yes</td>
<td>14.7095</td>
<td>21.2415</td>
<td>-6.5320</td>
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<tr>
<td>45.0 cm $2.75</td>
<td>1</td>
<td>yes</td>
<td>15.2224</td>
<td>31.9701</td>
<td>-16.7477</td>
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<tr>
<td>35.0 cm $2.75</td>
<td>1</td>
<td>yes</td>
<td>17.4254</td>
<td>78.1240</td>
<td>-60.6986</td>
<td></td>
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<tr>
<td>60.0 cm $2.75</td>
<td>2</td>
<td>no</td>
<td>7.0008</td>
<td>6.3842</td>
<td>0.6166</td>
<td></td>
</tr>
<tr>
<td>60.0 cm $2.75</td>
<td>3</td>
<td>no</td>
<td>13.2744</td>
<td>12.3083</td>
<td>0.9658</td>
<td></td>
</tr>
<tr>
<td>60.0 cm $2.75</td>
<td>4</td>
<td>no</td>
<td>18.8476</td>
<td>17.8946</td>
<td>0.9530</td>
<td></td>
</tr>
<tr>
<td>60.0 cm $2.75</td>
<td>5</td>
<td>no</td>
<td>23.7419</td>
<td>23.0032</td>
<td>0.7387</td>
<td></td>
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<tr>
<td>60.0 cm $2.75</td>
<td>6</td>
<td>no</td>
<td>27.9834</td>
<td>27.7001</td>
<td>0.2833</td>
<td></td>
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<tr>
<td>60.0 cm $2.75</td>
<td>7</td>
<td>no</td>
<td>31.5942</td>
<td>32.1268</td>
<td>-0.5326</td>
<td></td>
</tr>
<tr>
<td>60.0 cm $2.75</td>
<td>8</td>
<td>no</td>
<td>34.5885</td>
<td>36.0974</td>
<td>-1.5089</td>
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<tr>
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<td>9</td>
<td>no</td>
<td>36.9883</td>
<td>39.0974</td>
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<td></td>
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<td>60.0 cm $2.25</td>
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<td>no</td>
<td>8.8697</td>
<td>5.2256</td>
<td>3.6441</td>
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<td>60.0 cm $2.50</td>
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<td>no</td>
<td>7.3952</td>
<td>5.8052</td>
<td>2.1300</td>
<td></td>
</tr>
<tr>
<td>60.0 cm $2.75</td>
<td>1</td>
<td>no</td>
<td>7.0008</td>
<td>6.3842</td>
<td>0.6166</td>
<td></td>
</tr>
<tr>
<td>60.0 cm $3.00</td>
<td>1</td>
<td>no</td>
<td>6.0663</td>
<td>6.9668</td>
<td>-0.9005</td>
<td></td>
</tr>
<tr>
<td>60.0 cm $3.25</td>
<td>1</td>
<td>no</td>
<td>5.1318</td>
<td>7.5486</td>
<td>-2.4168</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Erosion-Damage Function Values at Varying Interest Rates, 1-Year Delay in Conservation Adoption, Variable Conservation to Conventional Yield Ratios, Initial Soil Depth of 60 cm, Soil Loss of 15.28 tons/acre/year, Corn Price of $2.75.

<table>
<thead>
<tr>
<th>$Y_c/Y_a$</th>
<th>New Plantera</th>
<th>4 percent</th>
<th>6 percent</th>
<th>10 percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.020</td>
<td>no</td>
<td>$4.1122$</td>
<td>$5.4791$</td>
<td>$7.1381$</td>
</tr>
<tr>
<td>1.030</td>
<td>no</td>
<td>0.6166</td>
<td>1.9984</td>
<td>3.6752</td>
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<tr>
<td>1.035</td>
<td>no</td>
<td>-1.1296</td>
<td>0.2595</td>
<td>1.9451</td>
</tr>
<tr>
<td>1.040</td>
<td>no</td>
<td>-2.8690</td>
<td>-1.4744</td>
<td>0.2180</td>
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<tr>
<td>1.050</td>
<td>no</td>
<td>-6.3578</td>
<td>-4.9496</td>
<td>-3.2406</td>
</tr>
<tr>
<td>1.020</td>
<td>yes</td>
<td>$7.0884$</td>
<td>$7.7585$</td>
<td>$9.0394$</td>
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<tr>
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<td>3.5931</td>
<td>4.2786</td>
<td>5.5767</td>
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<tr>
<td>1.040</td>
<td>yes</td>
<td>0.1077</td>
<td>0.8052</td>
<td>2.1201</td>
</tr>
<tr>
<td>1.050</td>
<td>yes</td>
<td>-3.3813</td>
<td>-2.6698</td>
<td>-1.3387</td>
</tr>
<tr>
<td>1.055</td>
<td>yes</td>
<td>-5.1330</td>
<td>-4.4120</td>
<td>-3.0723</td>
</tr>
</tbody>
</table>

a The new no-till corn planter is a 6-row planter, at a price of $20,000, 7-year expected life, and 10 percent interest rate for a 3.5 year mortgage.
Table 3. Erosion Damage Function Values, Walker's and Proposed Method, Varying Years Delay in Adoption.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Year delay</th>
<th>Conventional induced product-</th>
<th>NPV of erosion product-</th>
<th>EDF value Walker method</th>
<th>EDF value proposed method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>advantage</td>
<td>ivity loss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>$7.0008</td>
<td>$6.3842</td>
<td>$0.6166</td>
<td>$0.6166</td>
</tr>
<tr>
<td>2</td>
<td>7.0096</td>
<td>6.5729</td>
<td>0.4367</td>
<td>0.9658</td>
</tr>
<tr>
<td>3</td>
<td>7.0186</td>
<td>6.7519</td>
<td>0.2667</td>
<td>0.9530</td>
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<tr>
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<td>7.0280</td>
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<td>0.0903</td>
<td>0.7387</td>
</tr>
<tr>
<td>5</td>
<td>7.0377</td>
<td>7.1044</td>
<td>-0.0667</td>
<td>0.2833</td>
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<td>6</td>
<td>7.0472</td>
<td>7.3431</td>
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<td>7</td>
<td>7.0575</td>
<td>7.5089</td>
<td>-0.4514</td>
<td>-1.5089</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Assuming an initial soil depth of 60 cm, a discount rate of 4 percent, a soil loss of 15.28 tons/acre/year, a corn price of $2.75, and a value for $y_c/y_a$ of 1.03.
References


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