AN ABSTRACT OF THE THESIS OF

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Title: Producer Behavior and the Distribution of Potential Long Run Consequences in the Agricultural Market

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This study is directed toward an investigation of the longer term aggregate consequences that arise from producer behavior in a production environment characterized by risk and uncertainty. In particular, the papers included herein examine circumstances under which individual actions may result in adverse long term consequences in the aggregate market, even though they are based on rational decision-making from the producer's point of view. The research is conducted in two distinct components, resulting in the presentation of two separate manuscripts.

In the first paper a single product market model is developed with producer actions characterized by risk

averse behavior. Individuals are assumed to maximize the expected utility of profits according to a mean-variance specification. Using an analytical framework, it is determined that risk averse actions can increase aggregate risk levels once market adjustment is completed. Aggregate market risk is measured by the change in the expected value and variance of consumers' and producers' surplus. Market effects are found to depend on the relative elasticity of demand and the price expectation formulated by the producer.

The second paper explores the issue of declining soil productivity from a social perspective. Using a simulation model developed for a generalized agricultural market, the potential long term impacts of erosion on crop prices and on resulting measures of social welfare are examined. It is found that in the aggregate producers with erosive land are generally better of without erosion control than with erosion control, at least for the first few generations. In the long run however, these producers are significantly worse off as the effects of erosion outweigh any technology improvements.

Producer Behavior and the Distribution of Potential Long Run Consequences in the Agricultural Market

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CHAPTER 1

INTRODUCTION

Welfare economics is described as "that branch of study which endeavors to formulate propositions by which we may rank, on the scale of better or worse, alternative situations open to society" (Mishan, p.199). The branch of study focuses on normative concerns rather than on positive problems. Normative issues are those that examine the manner in which society ought to allocate scarce resources, positive issues focus on the manner in which allocation actually occurs (Just, Hueth and Schmitz).

The foundations for welfare economics are embedded in the concept of individual welfare. The individual is presumed to be the best judge of his or her own well-being (Eckstein). Alternative economic choices are ranked by the individual on the basis of personal preference. Social welfare is considered to be merely a function of the welfare of the individuals that comprise the group. The consequences of any action that may alter the distribution of resources within society is measured as the aggregation of impacts across all individuals affected by the resource change. Measurement of the potential welfare effects that may arise from alternative policy actions is based on the ability of 'gainers' from the action to compensate 'losers'. It is not necessary that actual compensation occur, only that the potential net gain exist (Eckstein).

Welfare analysis has been applied extensively in the area of agricultural and resource economics to the examination of resource allocation decisions (Castle, Kelso, Stevens, and Stoevener). Areas of application have included agricultural policy analysis (including trade and pricing policy), water resources development, public land management, recreation and agricultural pollution. In many cases, resource allocations have distributional impacts that extend beyond a single period. Development of a water project generally includes a planning horizon that extends several decades into the future. Farm management practices that encourage soil erosion have long-term effects that arise from both the loss of soil productivity and the off-site environmental damage that occurs from the increased sedimentation of waterways. Even producer choice of an optimal crop mix for the current growing season can be characterized by a multi-period decision environment;

resource commitment at the planting stage is made based on uncertain knowledge of market conditions that will prevail at the time of harvest. Resource decisions like those described above introduce "passage of time ...with consequent problems of comparability of values over time, predicting future conditions (and) facing risks that increase with futurity" (Howe, p.151). The consequences of risk and uncertainty on allocation decisions and the circumstances under which stochastic influences may arise in the agricultural environment are topics explored more closely in this thesis.

The Role of Risk and Uncertainty

Analysis of agricultural producer behavior in the face of risk and uncertainty has been conducted by researchers and policy makers over the last several decades. Although risk issues were originally considered secondary to the structural problem of low farm income, recent years have seen a reemergence of research examining risk behavior and risk management strategies (Barry).

The period between 1970 and 1986 has brought several important changes to the economic risk environment of agricultural production. First, the period has seen a dramatic increase in the level of agricultural exports.

In 1983 exports accounted for over forty percent of aggregate net farm crop-related income (USDA, 1985). Although foreign trade provides an important market for the agricultural sector, it increases the sensitivity of producer income to social, political and market induced fluctuations in the world economy. A second important element of change has been the rapid increase in the market rate of interest and in the cost of production inputs. Spurred on by spiraling inflation during the 1970s the cost of debt service has risen dramatically, leading to an increase in the level of financial risk faced by many producers. Finally, the technological transition of agriculture in recent decades has led to a significant reduction in farm labor and an increasing dependence on technology intensive inputs (including specialized machinery and livestock production facilities, improved seed varieties, and fertilizers and herbicides). With this new dependence on technology related inputs comes an enhanced uncertainty regarding potential innovations that may occur just down the road, thereby increasing the risk associated with making long term investment commitments.

These factors, in addition to the more traditionally recognized yield and price related risks, have been the focus of current research on the risk environment of agricultural production (see Barry). Because farmers are generally perceived as being risk averse, most efforts have examined methods by which producer exposure to risk can be controlled. However, concerns have recently been raised that efforts to control risk in the short run may actually lead to an increase in long run risk exposure for both the individual producer and for the aggregate market. In papers examining the risk parameters of irrigation decisions, Boggess and Young (1984a) conclude that although short term risk exposure may be reduced, long term exposure may in fact increase because of the potential for significant increases in future irrigation costs. McCarl and Musser expand the development of a long run risk concept by suggesting that appropriate considerations must include both the individual and aggregate consequences of short term individual risk advoidance behavior. It is the latter concern (the aggregate consequences of individual actions) to which the efforts in this thesis have been directed.

Thesis Outline

The research included herein has been conducted in two parts, resulting in the presentation of two distinct manuscripts. The first paper explores the fallacy of composition argument as it relates to agricultural production under conditions of risk. The paper is conceptual in construct, defining conditions under which an increase in individual risk avoidance behavior may, after market adjustments have occured, lead to an increase in the level of risk in the aggregate market. Risk in the aggregate market is measured in terms of changes in the mean and variance expressions for the social welfare measures. The second paper explores issues surrounding the long term uncertainties concerning soil erosion, technological advances and the future price and availabilities of agricultural supplies. A scenario analysis is used to examine the long term consequences (again in terms of relative changes in the social welfare measures) of producer decisions to maintain or forego soil conservation activities. The producer decision appears as an exogenous parameter in the scenario analysis. Each paper explicitly recognizes that producer actions have important consequences for aggregate well-being.

The thesis is presented in five chapters. Chapter 2 presents a short literature review on the manner in which considerations of risk have been incorporated into agricultural production analysis. The fallacy of composition paper is presented in Chapter 3 while the topic of the long term consequences of soil erosion is presented in Chapter 4. A review of the literature more specific to the topics addressed in the individual papers is included in the appropriate chapter. The final chapter includes a brief discussion of the general conclusions from each paper and their relevevance to considerations of long run risk.

CHAPTER 2

DECISION-MAKING IN AN UNCERTAIN ENVIRONMENT

The manuscripts included in this thesis revolve around a central theme, namely the potential long run consequences of agricultural producer behavior in alternative decision-making environments characterized by risk or uncertainty. Long run consequences, as they are described in the current research, are assumed to be any impacts that cannot be completely ascribed to the period during which the resource decision is made. In Chapter 3 the long run refers to the period after which all market adjustments have occured while the long run in Chapter 4 refers to a period of several generations. However, in each scenario, producer behavior in the initial time period directly affects the distribution of welfare changes over the time period of analysis.

A review of the literature specific to the subject of Chapters 3 and 4 is included therein. The issues examined in the current chapter are more general in nature, describing the manner in which the role of risk and uncertainty is perceieved to enter into the decision-making process of the agricultural producer. A brief review of the development of welfare economics as a means of evaluating the consequences of resource changes is also included.

A REVIEW OF WELFARE ECONOMICS

The development of welfare economics can be separated into two distinct eras: (1) the 'old' welfare economics predominated by the Marshallian theory of consumer surplus and (2) the 'new' welfare economics ushered in by Hicks and Kaldor in 1939. Just, Hueth and Schmitz denote the distinctions between the 'old' and the 'new' welfare economics as follows:

> a) The old welfare economics accepted the principle that social gains are maximized by competitive markets, and therefore, where noncompetitive interferences exist, the economist was justified in recommending policy actions that eliminate those distortions;
>
> b) The old welfare economics considered only partial equilibrium analysis in developing policy recommendations; and
>
> c) From an empirical standpoint, the old welfare economics held that the area to the left of the demand curve and above the price line could be considered a serviceable money measure of consumer utility while the area to the left of the supply curve and below the price line was a similar measure for producer welfare (pp. 5-6).

The old welfare economics deemed the necessary aim of economic policy to be maximization of the real value of social income, where real value was considered to be reflected in market prices. Social welfare was assumed to be direclty correlated with economic welfare. Increments of economic welfare were assumed to be valued equally by all individuals. The goal of economic policy was to maximize the "sum of the consumers' surpluses derived from the various commodities in the social dividend" (Hicks, p. 697). To facilitate measurement, economic welfare was measured using commodity values as reflected in the market.

The New Welfare Economics

From its beginnings in the late 1930s, proponents of the new welfare economics sought to refute many of the tenants of classical welfare theory. The most significant of these disputes centered on the concept of individual welfare or satisfaction. The classical theorists argued that the marginal utility of income could be considered constant for all individuals. Economic welfare was considered to be improved so long as project benefits outweighed project costs regardles of to whom they accrued.

With the advent of the new welfare theory however, seriuos doubt was cast on the appropriateness of interpersonal utility comparisons. Chipman and Moore noted that the problem of interpersonal comparisons of utility was first addressed by Pareto in 1894 and 1895 and later by Barone in 1908, though the developments went unnoticed by English-speaking economists until the mid-

1930s. Pareto concluded that because of the problems inherent in making individual utility comparisons, a change in social welfare was desirable only if at least one person considered himself better off after the change and no one considered themselves worse off. This later became known as the test for Pareto efficiency and has become a basic tenant of the new welfare theory.

Because the Pareto criterion failed to cover a wide range of policy issues whereby some individuals were inevitably made worse off, economists sought to "...develop a normative welfare criterion with more general applicability to actual economic decisions which inevitably help some people and harm others" (Haveman and Weisbrod, p. 138). Beginning in the late 1930s, a methodology was devloped whereby differences in the marginal utilities of income across individuals could be considered in making objective policy prescriptions. This period marked the beginning of the new welfare economics.

A key theoretical development was the derivation by Kaldor and Hicks of the principle of hypothetical compensation. The Kaldor Hicks test for efficiency did not require that no one be made worse off in a reallocation of resources. Rather, it required only that the potential gainers of the investment or allocation decision be able to compensate the potential losers. It was not necessary that the compensation actually be carried out.

A Critique of the New Welfare Economics

The introduction of the compensation test served as an effective wedge between the efficiency and distributive dimensions of public investment and resource allocation decisions. Indeed, Hicks noted that "...if measures for efficiency are to have a fair chance, it is extremely desirable that they should be freed from the distributive complications as much as possible" (p. 712). The most critical opposition to the separation of efficiency and distributive issues came from I.M.D. Little in 1950. He argued that value judgements are inherent in welfare economics, particularly with regard to distributional issues. Little offered two criteria for judging the desirability of a change in resource allocation. The first was similar to the Kaldor-Hicks compensation criteria while the second required that the resulting redistribution of income 'be good'. The question of what constitutes a 'good' redistribution of income was not resolved.

Scitovsky also criticized the practical use of the compensation criteria, introducing in 1941 what has become known as the reversal pradox. He argued that not only must the gainers be able to compensate the losers but that the losers, after compensation has occured, cannot bribe the gainers into returning to the original resource position. The argument is based on the premise that in some cases the economic change resulting from resource reallocation may cause prices to differ before and after project implementation. Samuelson furthered Scitovsky's argument by suggesting that even if the reversal argument can be met, the relative gains from all potential resource allocations must be examined before a decision can be made regarding the desirable of the economic change. Just, Hueth and Schmitz note that although theoretically correct, the Samuelson argument has little practical application since the "approach leads to few cases in which the beneficial empirical evidence can be developed for poicy-makers" (p. 42).

Measuring Welfare Changes

The effects of an economic change on society's well-being are calculated using the welfare measures of producer and consumer surplus. These measures provide monetary valuations of changes in the economic welfare of producers and consumers affected by resource reallocations. Producers' surplus is defined as the area above the supply curve and below some specified price line. A unique measure of producer welfare is provided by quasi-rent, defined as total revenue minus total variable costs. It can be shown that the measure of producer surplus corresponds exactly to the measure of quasi-rents and, therefore, provides a unique money measure of welfare change for the producer.

Unlike the case for producers, defining a unique money measure of economic welfare change for consumers is less straightforward. In economic theory the well-being of the consumer is defined in terms of the satisfaction, or utility, derived from the consumption of goods and services. Unlike quasi-rents, utility is an unobserved phenomenon. The consumer welfare measures, in order to approximate the valuation of utility, are defined in terms of the individual's willingness-to-pay for one economic scenario relative to another. Willingness-to-pay is used as a proxy for the intensity of an individual's preference for alternative states of the world.

A consumers's willingness-to-pay is defined as the amount of money necessary to keep an individual at the same level of satisfaction both before and after some economic change. While intuitively appealing, consumer measures of willingness-to-pay are difficult to determine as they depend on the assumption of constant utility. An alternative measure of consumer welfare is given by the ordinary consumer surplus, defined as the area below the ordinary demand curve and above some specified price line. While consumer surplus is not bound by the assumption of constant utility, it will provide a unique money measure of consumer welfare only under very restrictive assumptions. It has been shown, however, that this measure can be assumed to approximate, within a reasonable set of error bounds, the more appropriate measures of willingness-to-pay (Willig).

Given the caveat above, the measures of producer and consumer surplus provide unique money measures of the change in well-being associated with a shift in the distribution of resources. The measures are appropriate in scenarios that include stochastic as well as non-stochastic events and therefore, provide the basis for measuring welfare change in the material presented in Chapters 3 and 4.

CONSIDERATIONS OF RISK AND UNCERTAINTY IN AGRICULTURAL PRODUCTION

Economic decision-making occurs in a number of alternative market structures. To distinguish among competitive environments and therefore, among those factors influencing supply decisions, markets are generally classified according to the number of firms engaged in production. The most well studied of these categories is perfect competition, defined as a market where a large number of independent firms engage in the production of a homogeneous product. The assumption of a large number of sellers ensures that individual actions will not influence market price, though it is recognized that the combined actions of all producers can affect the market equilibrium. Additionally, the perfectly competitive environment is assumed to be characterized by complete mobility of factors of production and the availability of perfect information on the part of all market participants.

The Competitive Environment

It is generally considered that no market can be described as perfectly competitive, at least according to a literal definition. However, theories of resource allocation under conditions of perfect competition are considered to provide an accurate description of the manner in which production and consumption decisions are made (Mansfield). The competitive structure is seen as particularly appropriate for analysis of the agricultural market where the first two assumptions of perfect competition are felt to be satisfied. Assumptions regarding the complete mobility of production inputs and the availability of perfect information are generally violated, as they are in many markets.

Though not considered here in any detail, several factors highlight the inappropriateness of the third competitive assumption for the agricultural sector. Farm labor has been shown to have a relatively low reservation wage relative to nonfarm occupations, implying some rigidity in the labor force committed to agricultural production (Eisgruber). When a decision is made to cease production, land and machinery inputs are generally transferred across farming operations rather than converted to nonfarm resources. The fixed commitment of agricultural inputs is seen as one of the primary reasons that average farm income remains low relative to average nonfarm income.

Conditions under which the assumption of perfect information is violated are particularly important in understanding the agricultural production environment.

Crop mix and acreage decisions are made several months prior to the time of marketing. Investment decisions are made with planning horizons that extend many years into the future. Consequent with each of these decisions is the need to predict the level of commodity output and market price in an environment characterized by random events and imperfect information. The manner in which the production decison is affected by the presence of these uncertainties is the central topic of this thesis and is the focus of discussion in the sections that follow.

Risk and Uncertainty

In his 1921 seminal work on the role of risk and uncertainty in the competitve environment, Knight asserted that the "assumption of practical omniscience on the part of every member of the competitve system" is one of the primary simplications of the real world required for the development of the theory of perfect competition (p. 197). He argued that it is imperfect knowledge of the future that gives rise to profits. Recognizing that changes in economic conditions create a divergence between commodity price and marginal production costs, Knight pointed out that individuals who are first to respond to the change accrue the profit. Because unanticipated change implies the existence of uncertainty and because unanticipated economic change gives rise to profits, Knight argued that uncertainty is an inherent part of the economic environment.

In many instances the terms uncertainty and risk are used interchangably in discussions of random events. Earlier, Knight had made a subtle distinction between the terms, defining risky outcomes as those where the likelihood of occurence could be foreseen and uncertain outcomes as those for which the likelihood of occurence is unforeseen. Risk was thought to encompass objective probabilities while uncertainty reflected subjective probabilities. It was later recognized that from the point of view of the decision-maker, measures of risk also encompassed largely subjective probabilities (Bessler). Consequently, risk has become the more generic term used to describe the presence of random occurences in the decision-making environment.

Measures of Risk

Although a precise definition does not exist, risk is intuitively understood to refer to the likelihood of suffering an adverse outcome from a random event. In economic research empirical and conceptual measures of risk have alternatively been defined as i) the size of the largest potential loss resulting from the risky prospect, ii) the probability that the decision variable will not exceed a minimum desired level, and iii) measures of the dispersion of outcomes about some expected value (Young, 1984).

The first definition is associated with minimax decision rules that choose among random events by selecting the path that minimizes the maximum potential loss from an adverse outcome. A related decision rule, the maximin rule, selects among risky prospects by choosing the path that maximizes the minimum likely outcome of the random event. In each case the likelihood that a particular event will occur is not considered.

Decision models incorporating a safety first criteria include a measure of risk according to the second definition. Actions are taken to ensure that a minimum level of the decision variable is maintained. A producer is assumed to maximize expected profit such that the probability of returns falling below a minimum value does not exceed a predetermined level (Robison et al).

The measure of risk included in the third definition appears most often in the context of expected utility maximization. Von Neumann and Morgenstern were able to show that when a decision-maker's preference ranking for risky alternatives follows a set of reasonable axioms, a single attribute utility function describing the preference orderings can be assumed to exist (Young et al). Selection among the risky prospects was shown to be equivalent to the maximization of the expected utility associated with the alternative outcomes.

The expected utility function can be defined as a function of the mean and higher order moments of the probability distribution of the decision variable (Anderson, Dillon and Hardaker). In many cases, the expected utility function is expressed only in terms of the mean and variance of the argument. A trade-off can be shown to exist between these two moments such that higher levels of expected return can be achieved only by the acceptance of a higher level of variance in the potential outcomes. Increased variance becomes the °risk' associated with actions designed to increase expected levels of return. This mean-variance trade-off is particularly well-developed in the portfolio selection literature (Barry and Baker).

Risk Attitudes

Individual risk preferences are generally considered to take one of three forms -- risk preferring, risk neutral or risk avoiding. An individual is said to be risk preferring if the certainty equivalent of a risky prospect is greater than the expected value of the uncertain outcome. (The certainty equivalent is defined as that amount of money which leaves an individual indifferent between accepting a risky prospect and receiving the °sure' amount of income.) If the certainty equivalent is less than the expected value of the outcome the individual is considered to be risk avoiding. The individual is risk neutral if the values are equivalent.

The measurement of risk attitudes has taken many forms including direct elicitation of utility functions, inferences based on the difference between actual and predicted producer behavior, experimental game techniques and interval estimation measures (Robison et al). Empirical studies have identified a wide diversity in risk attitudes among producers, although they have generally indicated a tendency towards risk aversion (Robison et al; Young et al). An understanding of risk preferences at the individual level is an important factor in evaluating producer actions in an uncertain environment.

Risk in the Production Environment

The incorporation of risk into the agricultural decision-making environment is a result of the essential nature of the production process. Agriculture provides a striking example of Knight's 'forward looking economic process'.

> At the bottom of the uncertainty problem in economics is the forward looking nature of the economic process itself. Goods are produced to satisfy wants; the production of goods requires time, and two elements of uncertainty are introduced, corresponding to two different kinds of foresight which must be excercised. First, the end of productive operations must be estimated from the beginning. It is notoriously impossible to tell accurately when entering upon a productive activity what will be its result in physical terms, what (a) quantities and (b) qualities of goods will result from the expenditure of given resources. Second, the wants which the goods are to satisfy are also, of course, in the future to the same extent, and their prediction involves uncertainty in the same way. (Knight, p.237)

Acreage, crop mix and input use decisions must be made several periods prior to the time of final harvest. At the time that production decisions are made, the precise level of final output is unknown to the producer. During the interval between input commitment and harvest stochastic parameters can play an important role in determining final output and the net returns that accrue to the farming operation. In particular, weather and pest related factors interact with other production inputs to determine crop yield so that actual yield is unknown to the producer until the time of harvest (Knight's first type of economic uncertainty). The crop price to be received at the time of marketing is also unknown at the time of resource commitment. The stochastic nature of aggregate supply and potential changes in consumer demand cause market price to appear as a stochastic parameter in the production decision (Knight's second type of economic uncertainty). Net farm income will also be subject to variability in potential outcomes because of the randomness associated with price and yield.

Risk Considerations in the Short Run

Efforts to model risk behavior in the short term are usually static in nature, reflecting single period decision models (Antle). Short-run risk in agricultural production is generally associated with variability in the profit that may accrue over the production season. Decision rules used in modeling efforts have included expected profit maximization, mean-variance and semi-variance analysis and mean and total absolute deviation models (Selley). The behavioral assumptions included in the models presuppose a preference on the part of producers to control exposure to risk. These assumptions are generally supported by manager actions at the farm level (Jolly; Sonka and Patrick). Risk averse behavior is included in many of these models though Antle has argued that the assumption is not necessary. He argues that risk considerations are important to producers because of the effect of uncertainty on expected income, regardless of risk preferences.

Risk Considerations in the Long Run

Although many efforts to model risk behavior have considered only single period decisions, it is recognized that decisions made today have implications for outcomes in the future. Whether actions in the short run accrue sequentially over time as in a decision tree analysis or result in irreversible path selections, decisions made in the near term give rise to potential outomes in the longer term.

In an effort to define issues that might be relevant in modeling the role of long run risk in agricultural production, McCarl and Musser have suggested that the Knightian concepts of foreseen and unforeseen stochastic events must be distinguished in long run analysis. When future risk is characterized by a continuation of previously observed random proceses, appropriate modeling efforts are likely to include dynamic considerations of long run production and investment decisions. A scenario analysis is considered to be most appropriate when evaluating the long term consequences of unforeseen risk. Since the likelihood of the random events is unknown in this case, a best case-worst case scenario format can be defined to determine a potential range for the uncertain outcomes resulting from the random events.

In concluding their review, McCarl and Musser suggested that, prior to extensive efforts to model long run risk, research plans should be directed toward an expanded understanding of long run risk behavior. In particular, i) what are the appropriate long run risk considerations and ii) how do actions taken in the short term affect the exposure of the decision maker to long run risk.

CHAPTER 3

THE AGGREGATE CONSEQUENCES OF AN INCREASE IN RISK AVERSION

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Contribution of Authors: Dr. McCarl provided assistance in developing the conceptual framework for analysis and in suggesting revisions to earlier drafts. Development of the analysis and all report writing was conducted by the primary author.

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CHAPTER 3

THE AGGREGATE CONSEQUENCES OF AN INCREASE IN RISK AVERSION

INTRODUCTION

Risk is a pervasive phenomenon influencing agricultural production. There is a long history of agricultural economics research designed to show farmers how to "manage" risk (Barry). A number of risk management strategies and instruments are made available. These generally include mechanisms for risk-sharing such as price supports and crop insurance or activities designed to reduce risk as in the case of crop diversification (Newbery and Stiglitz). However, there can be questions raised about whether such strategies have been or are effective, particularly given that instability remains in the agricultural sector. Increasing individual risk avoidance behavior may not necessarily lead to risk reduction at the aggregate level but rather, in some cases, to an increase in risk. Such an occurence would seem to introduce a "fallacy of composition" argument in terms of risk and risk aversion.

Agricultural economists have long been involved in fallacy of composition arguments (Shepherd). Actions that appear to be profitable to an individual may prove to be unprofitable to the aggregate sector after market adjustments have been made. Profitability to producers has been shown to depend on the relative elasticities of supply and demand (Henderson and Quandt).[1] Similar arguments may hold in terms of the response of aggregate risk to individual risk averse actions. Whether risk averse actions by individuals result in a riskier situation after market price adjustments are taken into account may also depend on the level of the demand elasticity. The purpose of this portion of the research is to investigate the aggregate consequences of risk averse behavior, developing conditions under which changes in individual risk avoidance behavior lead to "riskier" aggregate markets.

Risk averse actions taken by an individual producer will depend in part on the crop price anticipated to be received at harvest. The manner in which the farmer formulates the price expectation will have an important effect in determining market equilibrium. The formulation of price expectations by a producer have generally been treated as adaptive, calculated as a weighted average of past prices (Fisher). However, an important alternative to this method is provided by the rational expectations hypothesis. In this case, expectations are formulated with all relevant market information so that anticipated price is coincident with actual price. Because the form of the price expectation is important in determining production behavior, it is expected that it will also hold important consequences for the impact of individual risk averse actions on aggregate risk.

The manner in which individual risk avoidance actions may affect aggregate risk is pursued analytically. A simple one product, one producer model is developed, constructed under two alternative expected price formulations. A rational expectations model is developed as is a model assuming an adaptive expectations framework; the models are similar in all other respects. Producers are assumed to maximize profits according to a mean-variance specification of the expected utility hypothesis. Included in the formulation is a risk aversion parameter characterizing the risk behavior of the individual producer. Once specified, the individual model is aggregated into a market model. The market is assumed to be made up of a large number of identical perfectly competitive producers collectively facing a downward sloping demand curve. Sensitivity of the aggregate model to changes in the risk aversion parameter is examined to determine the effects of individual risk avoiding actions on market performance. Results are examined according to the expectations model used at the individual level.

A REVIEW OF PRICE EXPECTATIONS

Many types of economic decisions require actions that must be based on expectations of uncertain future outcomes. A capital investment decision by a firm or household must be made with a forecast of market prices that will occur several periods into the future. Decisions by a firm on how much to produce in the current period are based on prices that are expected to prevail at the time the product is brought to market.

The formulation of price expectations is a particularly important consideration in developing models of agricultural supply response. Because of the nature of the production cycle, a farmer's acreage and crop mix decisions must be made several months prior to the harvest period, requiring a forecast of market and weather related phenomena expected to affect the prevailing price and total supply available at the time of marketing. Although the role of expectations in the agricultural supply decision is recognized as being fundamental, the manner in which the forecasts are formulated is not universally agreed upon.

Developing a price forecast to be used in decision-making is a subjective phenomenon; individuals base their expectations on past experience and on information currently available to them. Because experience and information is not homogeneous across individuals, developing an aggregate rule for price forecasts is not straightforward. There are however, several general formulations that have been used extensively throughout the literature. These include naive expectations, adaptive expectations and the rational expectations hypothesis. Because the latter two formulations will be used extensively in the current analysis, they will be reviewed in some detail. Naive expectations will be introduced only briefly.

Naive Expectations

Naive expectations, also referred to as static expectations, hypothesize that the expected future value of a variable is equivalent to its value in the current period. That is, current conditions are expected to prevail into the future, implying that the economy has achieved a steady-state equilibrium which can be maintained indefinitely (Shaw). Perhaps the most famous example of the naive expectations framework is the cobweb model developed by Ezekial to explain cycles in agricultural supply (Sheffrin). The model is used to describe the presence of potential market instability when a delay exists between the production decision and the availability of final output. It is therefore, most often applied to the agricultural market.

The basic hypothesis of the model is that the producer's price forecast for the next period is just equal to the actual price in the current period, or $P^*_t = P^*_{t-1}$ where P^*_t is the expected price for time t (formulated in time t-1) and P^*_{t-1} is the actual price in time t-1. The price formulation causes periods of low supply and high price to be followed by periods of excess supply and low price. The model converges to a stable equilibrium only if the slope of the supply curve is steeper than that of the demand curve. Carter and Maddock note that since its initial presentation the cobweb model has received little empirical support. The lack of acceptance generally results because the model does not allow for learning behavior on the part of the decision-maker.

Adaptive Expectations

Recognizing the limitations of the naive expectations hypothesis in not allowing for learning behavior, the simple hypothesis was modified to permit decision-makers to revise expectations made in the current period according to the degree of error between forecasts made in the last period and actual values in the current period.[2] Formally, the adaptive expectations hypothesis can be written as

$$P_t^* = P_{t-1}^* + \lambda(P_{t-1} - P_{t-1}^*)$$
$$= \lambda P_{t-1} + (1-\lambda) P_{t-1}^* \qquad (1)$$

where λ is the coefficient of adaptation, describing the degree to which expectation errors in the last period are incorporated into the forecast made in the current period (Carter and Maddock). If the expected price for period t-1 (forecast made in period t-2) is less than the actual price in that period then the forecast is adjusted upward for the next period. Similarly, if the expected price is greater than the actual price then the forecast for the next period is adjusted downward. The coefficient of adaptation varies between zero and one; as the value approaches one the adaptive hypothesis approximates the naive expectations rule.

Continuous expansion of the lagged expectation term in equation (1) results in the price expectation in the current period defined as a weighted average of an infinite series of past prices. Because λ takes on a value less than one, prices in more distant periods are weighted less than those in more current periods. The structure of the distributed lag is in the form of a geometric series with declining weights. There is no theoretical justification for such weights however, implying a rather ad-hoc mechanism for determining the relative importance of past prices.

The adaptive expectations hypothesis, though the most widely used formulation in empirical analysis of the agricultural supply response decision, has been criticized on several points (Sheffrin; Begg; Shaw; Carter and Maddock; and Fisher). First, the price expectation depends only on the value of past prices; contemporaneous information and the lagged observations of other variables are not considered. Second, as indicated above, the hypothesis can be formally expressed as a distributed lag series with geometricallly declining weights. Use of these weights, in many circumstances, is without theoretical justification. Finally, it assumed that the decision- maker systematically forecasts the expected price value in error. Although the specification relies on past decisions, there is no 'successful' learning behavior in the model; forecasts are always made with some degree of error.

Rational Expectations

Although the expectations hypotheses discussed immediately above can be readily applied to empirical analysis, they are somewhat arbitrary in their formulations. Naive expectations assumes a steady-state equilibrium, an inference that may or may not be characteristic of the the system being analyzed. Adaptive expectations assumes more fluidity in the equilibrium process but is somewhat myopic with regard to events that are assumed to influence the dynamic adjustment process. Neither hypothesis assumes behavior based on economic theory.

The rational expectations hypothesis, put forth by Muth in 1961, argues that expectations are based on the same circumstances that actually determine the outcome of economic events (Sheffrin). According to the rational expectations hypothesis individual decision-makers formulate expectations based on all currently available information describing factors that will influence the outcome of the uncertain event. Therefore, the decision-maker's subjective expectation of the uncertain event is just equal to the objective probability of the event occuring (Sheffrin). The bases on which the expectation is formulated are the same factors that actually determine fluctuations within the economic system. Unlike the adaptive expectations hypothesis, decision-makers cannot be systematically fooled by non-random fluctuations in market parameters.

Using an example from Sheffrin, an agricultural producer with rational expectations will take into consideration the forecast decisions of all other producers in the market when determining the expected price to be received for a commodity. Each individual will anticipate the supply decisions of all other producers and will determine the expected impact on market price. The expectations formulated by the producer will, on average, be correct since all available information has been assimilated into the decision process. The quantity supplied by producers (based on an anticipated price) will just equal the quantity demanded at the price that prevails at the time of marketing since anticipated price and average price will, on average, be the same.

The most extensive applications of the rational expectations hypothesis have been in the area of macroeconomics, particularly to discussions of financial and labor markets. Much of the discussion has centered around the policy implications that derive from the hypothesis. Rational expectations implies that, in the long run, systematic monetary and fiscal policy will be neutral with respect to fluctuations in employment and aggregate output. Policy actions lead to neutral results because the each individual's expectation of a proposed policy action will be equal to the objectively expected impacts of the policy action. For example, if the government indicates that money supply will be increased, thereby causing the price level to increase, individuals will anticipate the exact magnitude of the price increase and will adjust their actions accordingly. The net result of the policy will be to increase the price level but leave output and employment levels unchanged.

The important point is that economic actors are expected to adjust fully to proposed actions. As the government announces its intentions, this becomes part of the information base available to the decision-maker. The policy decision is fully incorporated into the formation of the price expectation, enabling the individual to respond 'rationally' to the government's proposed action. If however, the government does not announce its intention to raise money supply (to continue the preceding example), then no information regarding such a move is available for public review. Consequently, the rational expectation will not anticipate actual adjustment as it is made without complete information. Policy actions in this case will likely have at least a temporary effect on output and employment. After a period of time, individuals are expected to fully incorporate the new information into their decision process.

Several criticisms have been leveled against the rational expectations hypothesis (Sheffrin; Begg; Shaw; Carter and Maddock; Fisher). First it, is argued that it is unreasonable to assume that individuals have available all information regarding circumstances within the market place. Second, individuals may not process information as accurately as the hypothesis suggests. That is, individuals cannot be expected to completely understand the processes that affect the determination of market values. A third and related objection to the rational expectations hypothesis is that in addition to not understanding the determination of stochastic events within the economy, individuals in most circumstances cannot be expected to understand the manner in which exogenous parameters within the system are determined. A final criticism relates not to the assumptions of the hypothesis but to its ability to reflect reality. The presence of commodity cycles and persistent unemployment is argued to be inconsistent with the tenets of the hypothesis.

The general criticisms are countered by phrasing the rational expectations hypothesis in somewhat weaker terms than its initial presentation. It is argued that it is not necessary that all individuals have all information available in order to formulate an expectation in the same way that it is not necessary that all individuals engage in arbitrage to attain a market equilibrium. Individuals will acquire and process information as long as the marginal benefits from the information gain exceed the marginal cost of acquisition. With the speed and sophistication of current information delivery, proponents of the hypothesis argue that it is reasonable to assume that individuals act in the manner suggested even though complex analysis may be conducted by only a few participants. High transactions costs and time lags involved in processing information are identified as reasons for the persistence of commodity cycles in the presence of rational expectations.

THE PRODUCER MODEL

A model is developed describing a simple one product agricultural market composed of a large number of independent risk averse producers. Each farmer is assumed to provide a homogeneous product and to have no individual influence on the price received for that product. Price (p) and production yield (y) are assumed to be stochastic. Producers face known per acre production costs (c) with the decision variable for the model given by the acreage to be planted (A). A negative correlation between the price and crop yield variables is recognized. However, the covariance between price and yield recognized by the producer is not necesarily the true value of the covariance. With this set of parameters, profits for the ith producer are given by

$$\pi_i = p_i y_i A_i - c_i A_i \ . \quad (2)$$

The optimal level of the decision variable is found by a straightforward application of Bernoulli's principle.[3] Formally, the ith individual is assumed to maximize expected utility where utility is given as a specified function of the individual's profit. We assume maximizing expected utility is equivalent to maximizing the expected value of profit less a risk aversion coefficient times the variance of profit. That is, the producer is assumed to maximize

$$E(\pi_i) - \tfrac{1}{2}\,\phi_i\,\mathrm{Var}(\pi_i) \tag{3}$$

where ϕ_i is a coefficient indicating individual risk preference. Equation (3) has been shown to be equivalent to utility maximization under a number of cases, as discussed below.

The Mean-Variance Specification

The mean-variance specification was originally defined by Freund who showed its relation to expected utility maximization under constant risk aversion and normality. In response to criticisms raised by Borch and Feldstein, Tobin argued that the mean-variance specification was appropriate only in instances where the decision-maker's utility function was quadratic or where the stochastic parameter was normally distributed. Tsiang contended however, that justification for mean-variance analysis extended beyond these two cases. He showed that for various non-polynomial forms of the utility function the Taylor's series expansion converges rapidly beyond the second moment as long as the risk assumed by the individual is a "fairly" small fraction of his total wealth.

Although mean-variance analysis provides only an approximation to expected utility in cases where risk is small relative to total wealth, Tsiang argues the method can provide relatively accurate quantitative or qualitative guidance to the decision maker. Similarly, Newberry and Stiglitz note that mean-variance analysis provides a convenient method for describing behavior when risk attitudes are important as long as the limitations of the analysis are understood. Pope, Chavas, and Just also advance these arguments. For purposes of this analysis, we rely on Tsiang's arguments. No prior assumptions are made about the distributional form of profits; nor do we assume a quadratic utility specification.

Determining Optimal Acreage

The optimal acreage allocation for the individual model can be found by first expanding equation (3). Taking the expectation and variance of profits (equation (2)), the producer is assumed to maximize

$$((E(p_i)Y_i + Cov(p_i,y_i))A_i - c_iA_i) - \phi_i/2\ (A_i^2(E(p_i)^2\sigma_i^2 + Y_i^2\ Var(p_i) + 2E(p_i)Y_i\ Cov(p_i,y_i))) \tag{4}$$

where Y_i is the expected value of the random yield variable, σ_i^2 is the variance of yield, and E(˙) and Cov(˙) are the expected value and covariance operators, respectively. The second paranthetic term is an approximation of the variance of the profit measure in equation (2) when both price and yield are stochastic. The approximation formula is taken from Anderson, Dillon and Hardaker.[4]

Adaptive Expectations

Under the first construction of the individual model the farmer is assumed to forecast average price ($E(p_i)$) at harvest according to a Nerlovian adaptive rule where the current period's price forecast is a weighted average of past prices. Because the farmer perceives no relationship between market price and his own supply, the price expectation is formed independently of the acreage decision. The farmer does however, recognize an inverse relationship between price and yield, perceiving that periods of high yield are generally associated with low price.

Rewriting the price expectation as p_i^* and the covariance between price and yield as $-\zeta$, equation (4) is given by

$$((p_i^* Y_i - \zeta_i)A_i - c_i A_i) - \phi_i/2 \; (A_i^2 \; (p_i^* \sigma_i^2 + Y_i^2 \; \mathrm{Var}(p_i) - 2p_i^* Y_i \zeta_i))$$

Solving the first order conditions for a maximum, the optimal level of acreage for the ith producer is given by

$$A_i = (p_i^* Y_i - \zeta_i - c_i) \; / \; \phi_i \; (p_i^{*2} \sigma_i^2 + Y_i^2 \; \mathrm{Var}(p_i) - 2p_i^* Y_i \zeta_i) \qquad (5)$$

The acreage decision depends on the price expectation, the expected yield per acre, the covariance of price and yield, the variances of price and yield, the risk aversion parameter, and the production cost per acre.

The first order conditions for equation (4) also yield the common EV result that the producer will discount anticipated marginal revenue per acre by a risk factor equaling $\phi_i A_i \; (p_i^{*2} \sigma_i^2 + Y_i^2 \; \mathrm{Var}(p_i) - 2p_i^* Y_i \zeta_i)$. This can be interpreted as an increment to marginal cost reflecting the increased cost of bearing risk.

Rational Price Expectations

The producer model can also be formulated using rational price expectations rather than adaptive expectations. In this case, the producer is assumed to possess complete and accurate information regarding the nature of market demand and the covariance between price and yield. Under the rational expectations formulation the behavioral assumption of the model remains the same. The producer seeks to maximize expected utility according to the relation given in equation (3). Now however, the producer's price expectation will correspond exactly to the true value of expected market price. The producer also will observe the true covariance between market price and crop yield.

Accordingly, the market demand function is assumed to be given by the linear equation $p = a - bQ$ where Q is the total quantity demand at price p. At equilibrium, quantity is defined as the product of the yield per acre, the number of acres cultivated by a producer and the number of farmers engaged in production so that the market demand equation can be re-expressed as $p = a - bynA$. With rational expectations, the price expectation of the individual producer will be equal to the objective expectation of actual market price, or $p_i = a - bYnA$. The variance of price is given by $b^2n^2A^2\sigma^2$ while the covariance between price and yield is recognized by the producer to be $-bnA\sigma^2$.

With rational expectations the producer is assumed to maximize expected utility according to the expression in equation (3) where[5,6]

$$E(\pi_i) = aYA - bnA^2Y^2 - bnA^2\sigma^2 - cA$$

and

$$\begin{aligned}Var(\pi_i) = {} & a^2A^2\sigma^2 - 2abnA^3\mu_3 - 4abnA^3Y\sigma^2 + b^2n^2A^4\mu_4 \\ & + 4b^2n^2A^4Y\mu_3 + 4b^2n^2A^4Y\sigma^2 - b^2n^2A^4\sigma^4 \ .\end{aligned}$$

It can be seen from the expressions for $E(\pi_i)$ and $Var(\pi_i)$ that the first order conditions for a maximum will result in an equation that is nonlinear in the acreage variable. Optimal acreage must therefore be determined analytically. The effect of increasing risk aversion on the acreage decision can however, be determined by employing the implicit function rule. This discussion is deferred to a later section.

Model Contrasts

The market model used in the subsequent portions of this paper is developed using both rational and adaptive (referred to henceforth as non-rational) price expectations at the individual level. The implications of each of these formulations for the effects of individual risk averse actions on market behavior are examined. Conditions of individual versus aggregate risk arising from each of the model formulations are contrasted.

THE AGGREGATE MARKET MODEL

We now expand the producer model to the aggregate market. The market is assumed to be composed of identical producers supplying a homogeneous product. Each individual faces an identical set of parameters ($\phi_i = \phi$, $p_i^* = p^*$, $Y_i = Y$, $\sigma_i^2 = \sigma^2$, $c_i = c$). Total acreage allocated to production is given by nA where n is the number of individual producers and A is average individual production. Total (post-harvest) output is given by $y'nA$ where y' indicates the realized yield per acre. The optimal acreage rule for both the rational and non-rational expectations formulation results in a constant level of acreage placed in production during each planting period. However, because yield is stochastic, total production is also stochastic. Therefore, the expected value of aggregate production is given by nAY, while the variance is equal to $n^2A^2\sigma^2$.

In order to calculate ex-post (after harvest) aggregate net farm income, it is necessary to incorporate the price-demand relationship into the aggregate profit equation. Using the expression for market price defined in the section above, the linear demand function is given by

$$p = a - by'nA \tag{6}$$

when yield y' occurs. In this analysis, the randomness in market price derives solely from the stochastic nature of crop yield.

Total industry profits, or producers' surplus, are given by the difference between total revenues and total production costs, or

$$\pi = (a - by'nA)\, y'nA - cnA$$
$$= ay'nA - by'^2n^2A^2 - cnA \quad (7)$$

Realized aggregate net farm income is a function of the stochastic yield parameter, the total acreage allocation, and the parameters of the price-demand relationship. The producer's a-priori price expectation affects industry profits only through its influence on the individual acreage decision.

Calculating the Social Welfare Measures

Given the market structure above, mean and variance expressions for producers' and consumers' surplus as well as total social welfare can be constructed. These expressions can then be used to determine the impact of individual risk averse actions on social welfare after market adjustments have taken place.

Calculating Producers' Surplus

Equation (7) describes net farm income under any state of the random yield variable. The mean of producers' surplus is found by taking the expectation of this equation, or

$$E(\pi) = aYnA - bn^2A^2Y^2 - bn^2A^2\sigma^2 - cnA \quad . \tag{8}$$

The variance in producers' surplus is given by

$$\begin{aligned} Var(\pi) = {} & a^2n^2A^2\sigma^2 - 2abn^3A^3\mu_3 - 4abn^3A^3Y\sigma^2 \\ & + b^2n^4A^4\mu_4 + 4b^2n^4A^4Y\mu_3 + 4b^2n^4A^4Y\sigma^2 \\ & - b^2n^4A^4\sigma^4 \quad . \end{aligned} \tag{9}$$

where μ_3 and μ_4 are the third and fourth central moments, respectively, of the stochastic yield variable. The variance measure given in equation (9) is derived in section A3 of Appendix A.

Calculating Consumers' Surplus

Recall that for any state of the random variable y, market demand is given by equation (6), or by its inverse

$$Q(p) = y'nA = (1/b)\ (a - p) \ . \tag{10}$$

To calculate consumers' surplus under a given state of the yield variable, the integral of equation (10) is evaluated over the region from the market price (p) to the vertical price intercept (a), so that

$$CS = b^2 n^2 A^2 y'^2 / 2b \quad . \tag{11}$$

Expected consumers' surplus under all states of the random yield variable is found by taking the expectation of equation (11), or

$$E(CS) = \tfrac{1}{2} bn^2 A^2 (Y^2 + \sigma^2) \quad . \tag{12}$$

The variance of consumers' surplus is given by

$$\begin{aligned} Var(CS) = & \tfrac{1}{4} b^2 n^4 A^4 \mu_3 + b^2 n^4 A^4 Y \mu_3 + b^2 n^4 A^4 Y^2 \sigma^2 \\ & - \tfrac{1}{4} b^2 n^4 A^4 \sigma^4 \end{aligned} \tag{13}$$

where, as before, μ_3 and μ_4 are the third and fourth central moments, respectively, of the random yield variable. The derivation of this equation is given in section A4 of Appendix A.

Calculating Total Social Welfare

Total social welfare is defined as the sum of producers' and consumers' surplus. Adding together equations (7) and (11) total social welfare is given by

$$TSW = ay'nA - \tfrac{1}{2}\, by'^2 n^2 A^2 - cnA \quad . \tag{14}$$

Taking the expectation of equation (14), expected total social welfare is equal to

$$E(TSW) = aYnA - \tfrac{1}{2}\, bn^2A^2\,(Y^2 + \sigma^2) - cnA \tag{15}$$

and the variance of the measure is given by

$$\begin{aligned} Var(TSW) = {} & a^2n^2A^2\sigma^2 - abn^3A^3\mu_3 + 2abn^3A^3Y^3 \\ & - 2abn^3A^3Y\sigma^2 + \tfrac{1}{4}\, b^2n^4A^4\mu_4 + b^2n^4A^4\mu_3 \\ & + b^2n^4A^4Y^2\sigma^2 - \tfrac{1}{4}\, b^2n^4A^4\sigma^4 \quad . \end{aligned} \tag{16}$$

As with the variance of producers' and consumers' surplus, the derivation of equation (16) is given in section A5 of Appendix A.

IMPACTS OF RISK AVERSION

We now turn our attention to the central topic of this paper, namely, the impact of risk averse decision making on the aggregate welfare of consumers and producers. Results for the impact of a change in risk behavior are developed at both the individual and the aggregate market level. This phenomenon is studied by developing for some of the basic results shown above expressions for the derivative with respect to the coefficient of risk aversion.

Impacts at the Individual Level

At the individual level, the consequences of increased risk aversion can be developed for the acreage allocation decision rule, the total quantity produced, and the expected value and variance of net producer income.

Non-Rational Expectations

Taking the derivative of the individual optimal acreage decision rule (equation (5)) with respect to the risk parameter, ϕ_i, yields the well known result that an increase in the level of risk aversion results in a lower level of resource use (see for example, Anderson, Dillon, and Hardaker). As the producer becomes more risk averse, the number of acres that are planted is reduced.

Because total output for the ith producer is directly related to the acreage planted, output will also decline as the individual producer becomes more risk averse. In this model, an increase in risk averse behavior is tantamount to a restriction in production at the individual level.

The producer's net farm income is given by equation (2) where the profit realized in a particular year can be measured as

$$\pi_i(\phi_i) = p_i^* \, y_i' \, A_i(\phi_i) - c_i \, A_i(\phi_i) \qquad (17)$$

Because profits vary from year to year according to the outcome of the random yield variable, the producer will have an expected mean net income of

$$E(\pi_i(\phi_i)) \doteq A_i(\phi_i) \, (p_i^* \, Y_i - \zeta_i - c_i) \qquad (18)$$

with the variance of net income given by

$$\begin{aligned} Var(\pi_i(\phi_i)) = A_i^2(\phi_i) \, (p_i^{*2} \, \sigma_i^2 + Y_i^2 \, Var(p_i) \\ - 2 \, p_i^* \, Y_i \, \zeta_i) \qquad (19) \end{aligned}$$

By taking the derivative of equations (18) and (19) with respect to the risk parameter it can be seen that as the individual becomes more risk averse both expected profits and the variance of profits decline.[7] The coefficient of variation for individual net income when calculated with non-rational price and yield expectations does not depend on ϕ_i and, therefore, remains constant as the level of risk averse behavior is increased.

Rational Expectations

As indicated in an earlier section, when a rational expectation formulation is employed, the optimal acreage decision rule must be determined analytically. However, because both A and ϕ are included as terms in the profit maximization expression, the implicit function theorem can be used to determine the effects of an increase in risk averse behavior on the individual acreage decision. The implicit choice equation is given by the first-order equation for expected utility maximization. Principal arguments of the implicit equation are given by acreage and the risk aversion parameter. Second order conditions for a maximum guarantee that an explicit functional relationship between A and ϕ can be defined and that a solution to $\partial A/\partial\phi$ can be found.

To determine the implicit function of acreage and the risk aversion parameter, it is first necessary to determine the first order conditions for expected utility maximization under the hypothesis of rational expectations. From the expressions developed earlier, the expected value and variance of individual net farm income are given by

$$E(\pi_i) = aYA - bnA^2Y^2 - bnA^2\sigma^2 - cA \tag{20}$$

and

$$\begin{aligned} Var(\pi_i) = {} & a^2A^2\sigma^2 - 2abnA^3\mu_3 - 4abnA^3Y\sigma^2 \\ & + b^2n^2A^4\mu_4 + 4b^2n^2A^4Y\mu_3 + 4b^2n^2A^4Y\sigma^2 \\ & - b^2n^2A^4\sigma^4 \end{aligned} \tag{21}$$

Upon examination, it can be seen that expected individual producer profit can be rewritten as a function of expected producers' surplus. Recall from equation (8) expected producers' surplus is given by

$$E(\pi) = aYnA - bn^2A^2Y^2 - bn^2A^2\sigma^2 - cnA$$

It can easily be seen that $E(\pi_i)$ can be rewritten as $E(\pi_i) = E(\pi)/n$. Under the rational expectations hypothesis, expected individual profit is directly proportional to expected producers' surplus in the aggregate market.

A similar result holds for the variance of individual net farm income. Because the producer incorporates the true parameters of market demand into the joint price-yield expectation, the variance of individual profit is directly proportional to the variance of producers' surplus. With rational expectations, the variance of individual profit is given by $Var(\pi_i) = Var(\pi)/n^2$, where the variance of producers' surplus, $Var(\pi)$, is given in equation (9).

The individual producer maximizes expected utility according to the mean-variance specification in equation (3). Substituting equations (20) and (21) into the expression, the first order condition for a maximum is given by

$$\begin{aligned} &aY - 2bnAY^2 - 2bnA\sigma^2 - c + \phi(-a^2A\sigma^2 + 3abnA^2\mu_3 \\ &+ 6abnA^2Y\sigma^2 - 2b^2n^2A^3\mu_4 - 8b^2n^2A^3Y\mu_3 - 8b^2n^2A^3Y^2\sigma^2 \\ &+ 2b^2n^2A^3\sigma^4) = 0 . \end{aligned} \tag{22}$$

The left-hand side of equation (22) is defined as the implicit function of A and ϕ, $h(A, \phi) = 0$. The derivative of acreage with respect to the risk aversion parameter is thus given by

$$dA / d\phi = -(h_\phi / h_A) \quad . \tag{23}$$

where h_ϕ is the derivative of $h(A,\phi)$ with respect to ϕ and h_A is the derivative with respect to A. The denominator in the expression above is given by the second order condition for a maximum and is therefore, less than zero. Consequently, the sign of the derivative will depend upon the sign of the numerator. If h_ϕ is positive, an increase in individual risk averse behavior will lead to an increase in acreage planted. A negative value of h_ϕ would indicate a decrease in acreage planted.

The expression for h_ϕ is given by the parenthetic term in equation (22), or

$$h_\phi = -a^2A\sigma^2 + 3abnA^2\mu_3 + 6abnA^2Y\sigma^2 - 2b^2n^2A^2\mu_4 - 8b^2n^2A^3Y\mu_3 - 8b^2n^2A^3Y^2\sigma^2 + 2b^2n^2A^3\sigma^4 \quad . \tag{24}$$

From the first order conditions, it can be shown that h_ϕ is also given by

$$h_\phi = (-1/\phi)\,(aY - 2bnAY^2 - 2bnA\sigma^2 - c) \quad . \tag{25}$$

The sign of h_ϕ cannot be determined immediately from either equation (24) or (25), indicating that the effect of increasing risk aversion on the acreage decision is not immediately evident.

With rational expectations the consequences of an increase in risk averse behavior on the expected value and variance of profits at the individual level will be recognized as being the same as those at the aggregate level. A cursory examination of the derivatives of equations (20) ($E(\pi_i)$) and (21) ($Var(\pi_i)$) with respect to the risk aversion parameter indicates that the impacts are unclear. That is, the derivatives cannot be signed immediately. An important relationship can be shown to exist however, between the impact of risk averse behavior on the acreage decision and the subsequent impacts on the mean and variance of individual profits. This will be examined in a later section in more detail. It should also be noted that the impacts of increased risk avoidance behavior on the coefficient of variation of individual profits cannot immediately be determined. The effects will however, coincide with impacts at the aggregate level.

Summary of Impacts at the Individual Level

In the rational expectations model an increase in risk averse behavior may lead to an increase or decrease in acreage planted and hence to an increase or decrease in total output produced by the individual farmer. When non-rational expectations are assumed, both acreage planted and total output decline; the mean and variance of profits decline as a result. The effects of increased risk averse behavior on the mean and variance of profits under rational expectations are unclear, though the results will correspond to those at the aggregate level. We look next at the effects of increased individual risk aversion at the market level to determine whether the impacts at the individual level in the non-rational expectations solution carry over to the aggregate. Additionally, it is determined under what conditions the rational expectations solution corresponds to results derived under the non-rational expectations hypothesis.

Impacts at the Aggregate Level

In the aggregate model an increase in individual risk averse behavior affects market prices and quantities as well as the aggregate measures of social welfare. The effect on market quantity follows directly from the result for individual output. As risk averse behavior is increased, individual acreage placed in production is either increased or decreased. Given that the market is composed of identical producers, the change in total acreage and hence total expected output will correspond to the individual acreage decision. It can be shown that the effect on the variance of total aggregate output also corresponds to the impact on individual acreage.

Differentiating the expected price equation with respect to the risk aversion parameter indicates that expected market prices will increase when acreage is decreased and will decline when acreage is expanded. Movements in the variance of price are the reverse of those for the mean.

Impacts on Producers' Surplus

The impact of increasing risk aversion on expected producers' surplus can be found by taking the derivative of equation (8) with respect to the risk aversion parameter, ϕ , or

$$\partial E(\pi)/\partial\phi = (aYn - 2bn^2A\sigma^2 - 2bn^2AY^2 - cn)\ \partial A/\partial\phi. \quad (26)$$

Whether or not expected producers' surplus increases depends on two factors: i) the impact of increased risk avoidance on the individual acreage decision ($\partial A/\partial\phi$), and ii) the sign of the parenthetic expression in the equation above.

To explore this relationship more closely, it is necessary to redefine the parenthetic expression in terms of h_ϕ , as given in equation (25). Substituting, equation (26) can be rewritten as

$$\partial E(\pi)/\partial\phi = -\ \phi n h_\phi \partial A/\partial\phi\ . \quad (27)$$

If $h_\phi < 0$, risk avoidance behavior will lead individuals in the rational expectations model to decrease acreage planted. The result is a decrease in expected producers' surplus. If $h_\phi > 0$, acreage is increased and the result is again, a decrease in expected producers' surplus. It was shown that the impacts of risk avoidance behavior at the individual level will reflect those at the aggregate. Therefore, with rational price expectations producers will recognize the impact of their acreage decision on aggregate farm income and hence, on individual profits. Accordingly, the individual acreage decision will always result in a decline in both individual and aggregate expected net farm income.

With non-rational price expectations at the individual level $\partial A/\partial \phi$ is less than zero. Therefore, expected producers' surplus will increase or decrease according to the sign of the parenthetic expression. When the expression is positive expected producers' surplus declines; a negative relationship indicates that expected producers' surplus will increase with increased risk avoidance actions.

Conditional Expression for Expected Producers' Surplus

It is of some interest to note under what conditions the paranthetic expression in equation (25) will be positive or negative. In the rational expectations model acreage planted declines when the term is greater than zero. In the non-rational expectations model this would indicate a decline in producers' surplus. The paranthetic term will be greater than zero if

$$aYn > 2bn^2A\sigma^2 + 2bn^2AY^2 + cn \quad . \qquad (28)$$

Using the result derived in section A6 of Appendix A, equation (28) will hold:

$$\text{iff} \quad \eta \; > \; (\xi_y^2 + 1)\ E(TR)/E(\pi) \qquad (29)$$

where

η = the elasticity of demand at the point of intersection with the expected supply curve,

with

$$\eta \; = \; -(dQ/dp)\ (p/Q) = (a\text{-}bYnA)/(bYnA), \quad (\eta > 0),$$

and

ξ_y = the coefficient of variation of yield,

$E(TR)$ = expected total return to aggregate production, and

$E(\pi)$ = expected aggregate net farm income.

Expected net farm income has been previously defined and is given by the producers' surplus measure specified in equation (8). Anticipated total returns to production are given by the first three terms on the right-hand side of the same equation.

An Example

To illustrate the use of equation (29), an approximation is made using national-level historical data. First, referring to the period 1968-1982 the ratio of total production returns to net farm income has been approximately 8.789.[8] Secondly, Hazell[9] has estimated a state-level series of coefficients of yield variations for several agricultural commodities. These parameters are given in Table 3.1. Using the coefficient of variation of U.S. corn yields as an example and substituting into equation (29), the parenthetic expression in equation (25) will be positive only if the elasticity of demand for corn is greater than 8.87. Tweeten (1979) has reported a farm level price elasticity for corn with an absolute value of 0.03. Clearly, this is far less than the critical value of 9.66. In this example then, the parenthetic term in equation (25) can be concluded to be negative. With rational expectations, an increase in risk avoidance behavior leads to an increase in acreage planted. Similar results hold for the case of wheat and barley.[10]

When the parenthetic expression is negative, non-rational price expectations on the part of individual producers will lead to an increase in expected producers' surplus (equation (27)). With rational expectations

Table 3.1. Coefficients of Variation of Yields (1960-1980)

	Corn	Winter Wheat	Sorghum	Barley
Arkansas	-	17.9	18.1	
Colorado	6.91	21.9	12.9	8.8
Georgia	25.16	-		
Idaho		14.3		10.9
Illinois	12.2	14.5		
Indiana	10.9	11.2		
Iowa	12.97	-		
Kansas	14.2	15.8	17.8	14.4
Kentucky	14.95			
Michigan	10.2			
Minnesota	16.2			
Missouri	21.2	12.3	16.7	
Nebraska	14.3	13.4	19.8	
North Carolina	16.4			
Ohio	8.9	10.6		
Pennsylvania	10.3	9.4		11.0
South Dakota	24.6	21.9	27.7	26.9
Tennessee	18.7			
Texas	18.4	34.3	6.4	
Wisconsin	13.1			
Montana		14.6		
Oklahoma		19.5	13.8	19.3
Oregon		13.5		12.1
U.S.A.	9.86	7.81	9.89	8.19

Source: Data obtained from Hazell were used in the Hazell bibliographic item.

expected producers' surplus declines. In this case, producers recognize the relationship between individual actions and market behavior and adjust their acreage decision so that both individual and aggregate income declines.

The Variance of Producers' Surplus

The effect of increasing risk aversion on the variance of net farm income is found by differentiating equation (9) with respect to the risk parameter, ϕ , or

$$\begin{aligned}\partial Var(\pi)/\partial\phi = (&2a^2\sigma^2n^2A - 6ab\mu_3n^3A^2 - 12abY\sigma n^3A^2 \\ &+ 4b^2\mu_4n^4A^3 + 16b^2n^4A^3Y\mu_3 + 16b^2Y\sigma^2n^4A^3 \\ &- 4b^2\sigma^4n^4A^3)\ \partial A/\partial\phi \quad . \end{aligned} \tag{30}$$

With non-rational expectations, the variance of producers' surplus will decline only if the expression in parentheses above is positive.

To determine the consequences under rational expectations, equation (30) must first be rewritten in terms of h_ϕ . From equation (24) it follows that

$$\partial Var(\pi)/\partial\phi = -2n^2h_\phi\ \partial A/\partial\phi \quad . \tag{31}$$

If $h_\phi > 0$, the producer increases acreage planted and the variance of aggregate net farm income declines. Similarly, if $h_\phi < 0$, the producer decreases the acreage planted and the variance again declines; the variance of individual profit also declines in both cases. Therefore, when the producer has available complete market information, the impact of increasing risk aversion on the acreage decision will always be such that the variance of net income at both the farm and market level is reduced. With rational expectations an increase in risk averse behavior will lead the producer to act to simultaneously decrease the mean and variance of both individual and aggregate net farm income.[11]

With non-rational expectations an increase in risk aversion on the part of agricultural producers will reduce the variance of aggregate net farm income only if the parenthetic term in equation (30) is positive, or if

$$(2a^2\sigma^2n^2A + 4b^2\mu_4n^4A^3 + 16b^2n^4Y\mu_3 + 16b^2Y\sigma^2n^4A^3)$$
$$> \quad (6ab\mu_3n^3A^2 + 12abY\sigma^2n^3A^2 + 4b^2\sigma^4n^4A^3) \quad . \qquad (32)$$

The derivation given in section A7 of Appendix A shows that the parenthetic term in the equation above will be greater than zero only if

$$\eta^2 - \eta\ (4 + 3\gamma_1\xi_y) > -\ (4 + 2\gamma_2)\xi_y^2 - 5\gamma_1\xi_y - 3. \qquad (33)$$

Thus, whether or not increasing risk aversion will reduce the variance of net farm income depends on the elasticity of the demand curve (η), and the coefficients of skewness (γ_1), kurtosis (γ_2), and variation (ξ_y) of the random yield variable.

If we assume yield is normally distributed then $\gamma_1 = \gamma_2 = 0$ and equation (33) reduces to

$$\eta^2 - 4\eta > 4\xi_y^2 - 3 \quad . \tag{34}$$

Equation (34) can be solved using the quadratic formula to determine a range of values for the demand elasticity and the coefficient of variation of yield for which the variance of producers' surplus will decline as the risk aversion parameter increases. A graph of this relationship is presented in Figure 3.1. For elasticity values greater than three and less than one, the variation in producer surplus will decline regardless of the value of the coefficient of yield variation. Elasticity values which lie in the range between one and three will be associated with increasing variation in producers' surplus for only a limited range of values for the coefficient of variation.

Again referring to Table 3.1, the estimated values of the coefficient of variation of yield lie generally in the range 0.00 to 0.30 thereby making them subject to the

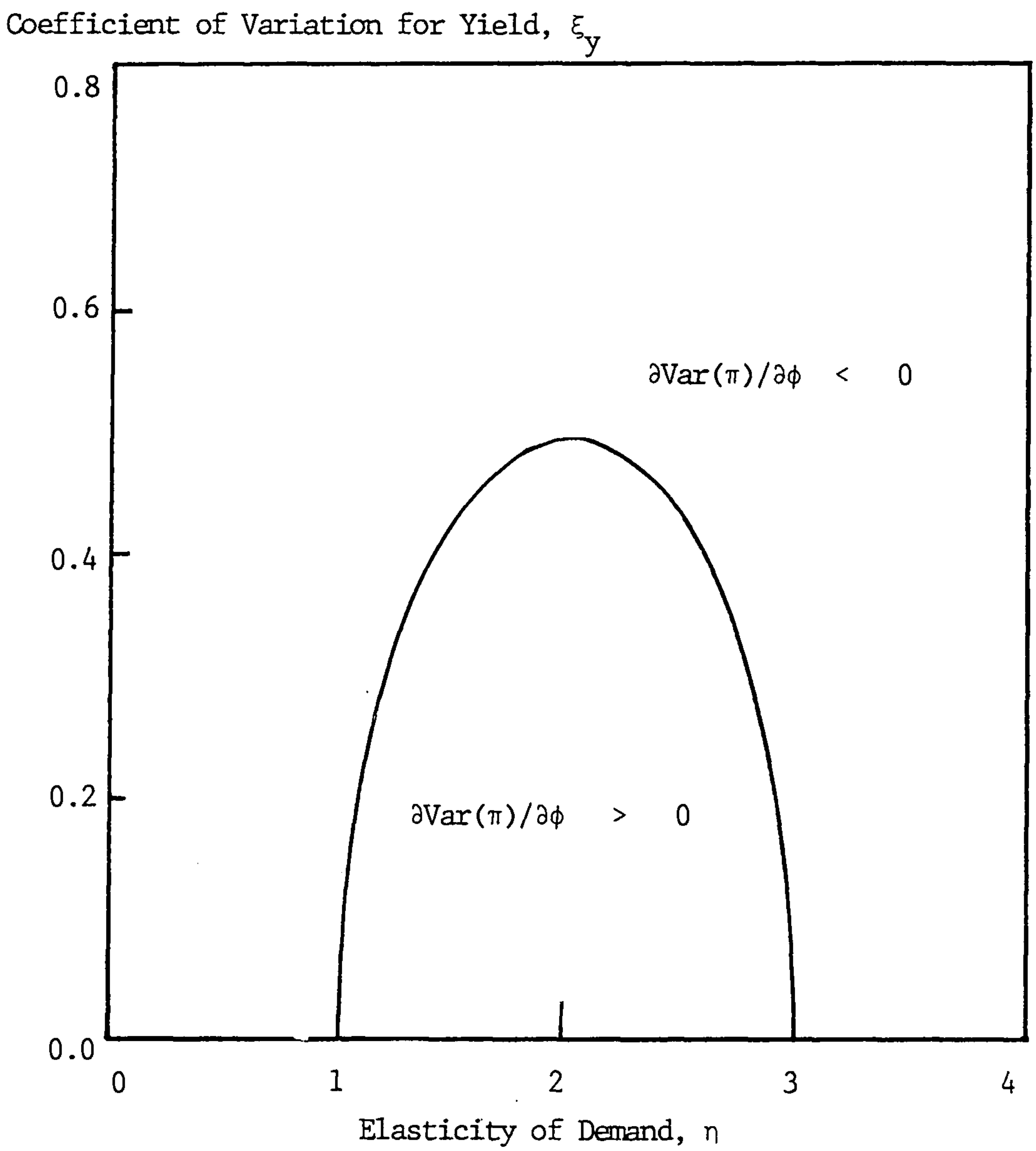


Figure 3.1. The Effects of Increasing Risk Aversion on the Variance of Producers' Surplus for Alternative Values of ξ_y and η. ($\partial A/\partial\phi < 0$)

conditional test in equation (34). For example, Hazell has estimated the coefficient of variation for corn yield in South Dakota to be 24.6 percent (0.246). Inserting this value into equation (34) and solving, the elasticity of demand must be greater than 2.87 or less than 1.13 for increasing risk aversion on the part of agricultural producers to result in a decline in the variation in producers' surplus. Otherwise, the increase in individual risk averse behavior leads to an increased variance of possible producers' surplus outcomes. A similar range of elasticity values can be found for the other state and national level crop groups identified in Table 3.1.

For yield distributions other than the normal, equation (33) remains too complicated to establish a range of values for η and ξ_y wherein the variation in producers' surplus declines. However, some general comments can be made. When the yield distribution is negatively skewed ($\gamma_1 < 0$) and the coefficient of kurtosis is set equal to zero, the range of values in which increasing risk aversion results in an increase in the variance of producers' surplus is somewhat narrowed and skewed to the left relative to the range depicted in Figure 3.1. Similarly, when the yield distribution is positively skewed the range of values corresponding to an increase in the variance is widened and skewed to the right. Shown in Figure 3.2 are the range of η and ξ_y values consistent with increasing producers' surplus variance for the cases of positively and negatively skewed yield distributions. A long-tailed, symmetric distribution ($\gamma_1 = 0$, $\gamma_2 > 0$) also implies a narrower range while a flat-topped, symmetric distribution ($\gamma_1 = 0$, $\gamma_2 < 0$) will result in a wider range of critical values for the demand elasticity and coefficient of yield variation.

Coefficient of Variation for Producers' Surplus

To determine whether the aggregate level of risk to producers increases or decreases as individual producers become more risk averse the coefficient of variation of producers' surplus can be differentiated with respect to the risk aversion parameter. The coefficient ξ_π is defined as the standard deviation of the aggregate producers' surplus divided by its expected value.

Using the quotient rule, the derivative of the coefficient of variation of producers' surplus with respect to ϕ , the risk aversion parameter, is given by

$$\partial\xi_\pi / \partial\phi = (E(\pi)\ (\partial(Var(\pi))^{\frac{1}{2}}/\partial\phi) - (Var(\pi))^{\frac{1}{2}} \cdot \partial E(\pi)/\partial\phi\ )\ (1/(E(\pi))^2) \quad . \qquad (35)$$

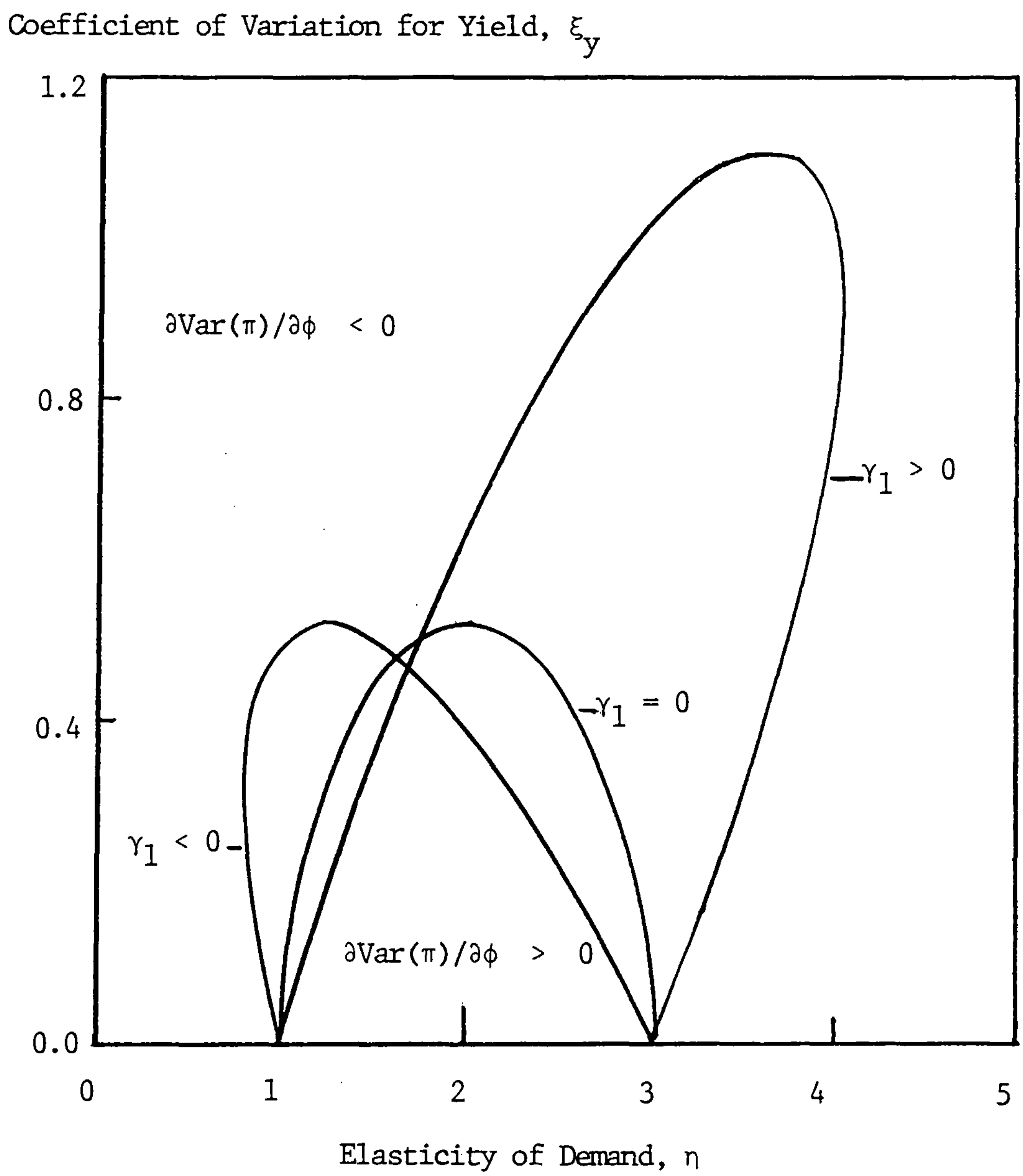


Figure 3.2. The Effects of Increasing Risk Aversion on the Variance of Producers' Surplus for Positively and Negatively Skewed Distributions of Yield.

($\partial A/\partial\phi < 0$)

The denominator in equation (35) is positive indicating that the sign of the derivative will depend upon the sign of the numerator, which can be rewritten as

$$\tfrac{1}{2} E(\pi) \, (Var(\pi))^{-\frac{1}{2}} (2a^2n^2A\sigma^2 - 6abn^3A^2\mu_3 - 12abn^3A^2Y\sigma^2$$
$$+ 4b^2n^4A^3\mu_4 + 16b^2n^4A^3Y\mu_3 + 16b^2n^4Y^2\sigma^2 - 4b^2n^4A^3\sigma^4$$
$$- (Var(\pi))^{-\frac{1}{2}} (aYn - 2bn^2AY^2 - 2bn^2A\sigma^2 - cn)\partial A/\partial\phi . \quad (36)$$

Equations (26) and (30) have been substituted for $\partial E(\pi)/\partial\phi$ and $\partial Var(\pi)/\partial\phi$, respectively.

If $\partial A/\partial\phi$ is less than zero and the yield variable is normally distributed, then the coefficient of variation for producers' surplus will decrease as the risk aversion parameter is increased if

$$\eta < (\xi_y^2 \, (1 - \tfrac{1}{2} \, \xi_\pi^2 \, (1 - (TC/E(TR))))/((\xi_y^2 \, / \, (\xi_y^2 + 1))$$
$$- \tfrac{1}{2} \, \xi_\pi^2 \, (1 - (TC/E(TR)))) \quad (37)$$

where the total cost of aggregate production is given by TC. All other terms have been defined previously. This result is fully developed in section A8 of Appendix A. The conditional expression above holds for either price expectation formulation. However, in the rational expectations model where the acreage variable may in fact increase, equation (37) indicates the conditions under which the coefficient of producers' surplus will increase with increased risk avoidance behavior.

An Example

Using data on returns to agricultural production for the period 1968-1982, a value of 0.530 was estimated for the coefficient of variation for producers' surplus. Substituting this value into equation (37) and using the coefficient of variation for US corn yields, the dispersion of possible producers' surplus outcomes will increase with increasing risk aversion (for $\partial A/\partial\phi < 0$) for elasticity of demand values greater than -1.36. Because the elasticity has been defined to be greater than zero (from page 65), producer returns in the aggregate market will in this example become riskier subsequent to individual actions. Only in the rational expectations model where the producer may expand acreage in response to an increase in risk avoidance will the aggregate market actually become less risky in response to individual behavior.

Impact on Consumers' Surplus

Under conditions of an uncertain yield variable the relevant consumer welfare measures to be evaluated in the agricultural market are given by the expected value and variance of consumers' surplus. Both measures depend on the level of the individual risk aversion parameter vis-a-vis' its effect on the acreage variable. This section of the paper will analyze the effects of increasing producer risk avoidance behavior on the consumer welfare measures.

The effect of increased risk averse behavior on expected consumer surplus is found by taking the derivative of equation (12) with respect to the risk aversion parameter, where

$$\partial E(CS)/\partial\phi = bnA(Y^2 + \sigma^2)\ \partial A/\partial\phi < 0. \tag{38}$$

With non-rational expectations the result will be a decline in expected consumer surplus. When rational expectations are assumed, E(CS) will increase or decrease according to the impact of increasing risk avoidance on the acreage decision.

The impact of increasing risk aversion on the variance of consumers' surplus is found by taking the derivative of equation (13) with respect to ϕ, where

$$\partial Var(CS)/\partial\phi = (b^2n^4A^3\mu_4 + 4b^2Yn^4\mu_3 + 4b^2n^4A^3Y^2\sigma^2 - b^2n^4A^3\sigma^4)\ \partial A/\partial\phi < 0. \tag{39}$$

The sign of the derivative will depend on the sign of $\partial A/\partial\phi$ and the sign of the parenthetic term. Multiplying the parenthetic expression through by A/4, it can be easily seen that this results in the expression for the variance of consumers' surplus. The variance, by definition, is always positive. Therefore, the sign of the expression in equation (39) will depend only on the effect of increasing risk aversion on the acreage variable. If acreage is decreased the variance of consumers' surplus will decline; when acreage is expanded the variance of consumers' surplus increases.

When non-rational price expectations are assumed, acreage is decreased and the result is a decline in the variance as well as the expected value of consumers' surplus. Conditions under which the acreage variable will increase or decrease in the rational expectations model have been previously identified. In the example given it was shown that increasing risk avoidance behavior is likely to result in an increase in acreage planted. Therefore, the effect of an increase in risk avoidance behavior in the rational expectations model is to increase the mean and variance of consumers' surplus. The impact of an increase in individual risk aversion on consumer welfare depends critically on the underlying expectations behavior in the producer model.

The coefficient of variation for consumers' surplus is not affected by changes in the risk aversion parameter. The expression, given by the standard deviation of consumers' surplus divided by the mean, simplifies to a set of parameters that remain constant with changes in risk aversion. From the consumer's point of view, market riskiness, defined by the coefficient of variation for consumers' surplus, is unaffected by changes in producer risk behavior.

Impact on Total Social Welfare

From the previous two sections we have found that with non-rational expectations an increase in individual risk averse behavior will lead to a decline in expected consumers' surplus and a probable increase in expected producers' surplus, but will have the opposite impact under a rational expectations formulation. To find the net effect on total social welfare, equation (15) can be derivated with respect to the risk aversion parameter, or

$$\partial E(TSW)/\partial\phi \;=\; (aYn - bn^2A(Y^2 + \sigma^2) - cn)\partial A/\partial\phi \; . \quad (40)$$

When $\partial A/\partial\phi$ is less than zero, expected total social welfare will decline with increasing risk aversion if the parenthetic term is positive. Multiplying this term by acreage (A), expected total social welfare will decline if

$$aYnA - bn^2A^2(Y^2 + \sigma^2) - cnA > 0 \quad . \tag{41}$$

The expression in equation (41) is the same as that in equation (8); it is the expression for expected aggregate net farm income, or producers' surplus. Therefore, if expected producers' surplus is greater than zero, an increase in the level of the individual risk aversion coefficient will result in a decline in expected total social welfare for $\partial A/\partial\phi < 0$. Expected total social welfare will increase when acreage is expanded.

The effect of increasing risk aversion on the variance of total social welfare is found by taking the derivative of equation (16) with respect to ϕ, or

$$\begin{aligned}\partial Var(TSW)/\partial\phi = {} & (2a^2n^2\sigma^2A - 3abn^3\gamma_1\sigma^3A^2 + 6abn^3Y^3A^2 \\ & - 6abn^3Y\sigma^2A^2 + b^2n^4\gamma_2\sigma^4A^3 + 2b^2n^4\sigma^4A^3 \\ & + 4b^2n^4Y\gamma_1\sigma^3A^3 + 4b^2n^4Y^2A^3)\ \partial A/\partial\phi \ .\end{aligned} \tag{42}$$

Following the results given in section A9 of Appendix A, the parenthetic term, which must be positive for an increase in ϕ to result in a decline in the variance of TSW if $\partial A/\partial\phi < 0$, can be transformed to the following conditional expression:

$$\partial Var(TSW)/\partial\phi \quad < \quad 0 \quad \text{iff}$$

$$\eta^2 - \eta\ (3/2\ \gamma_1\ \xi_y + 1) + (1 + \tfrac{1}{2}\ \gamma_2)\ \xi_y^2 + \tfrac{1}{2}\ \gamma_1\ \xi_y \quad > \quad 0\ . \tag{43}$$

As in the discussion for producers' surplus, whether increasing risk aversion will reduce the variance of total social welfare depends on the elasticity of demand (η), and the coefficients of skewness (γ_1), kurtosis (γ_2), and variation (ξ_y) of the random yield variable.

When the yield variable is assumed to be normally distributed the expression in equation (43) is somewhat simplified. As for the producer case, a range of values for η and ξ_y can be calculated whereby an increase in the level of individual risk aversion will result in a decrease in the variance of total social welfare. These values are shown in Figure 3.3. For elasticity values greater than 1.0 the variance of total social welfare will decline unconditionally with an increase in the level of risk aversion (for $\partial A/\partial\phi < 0$). Otherwise, the conditional test in equation (43) must be employed to determine the subsequent impacts. When an increase in avoidance behavior results in an expansion of acreage, the variance of total social welfare will increase if the conditional expression in equation (43) is satisfied.

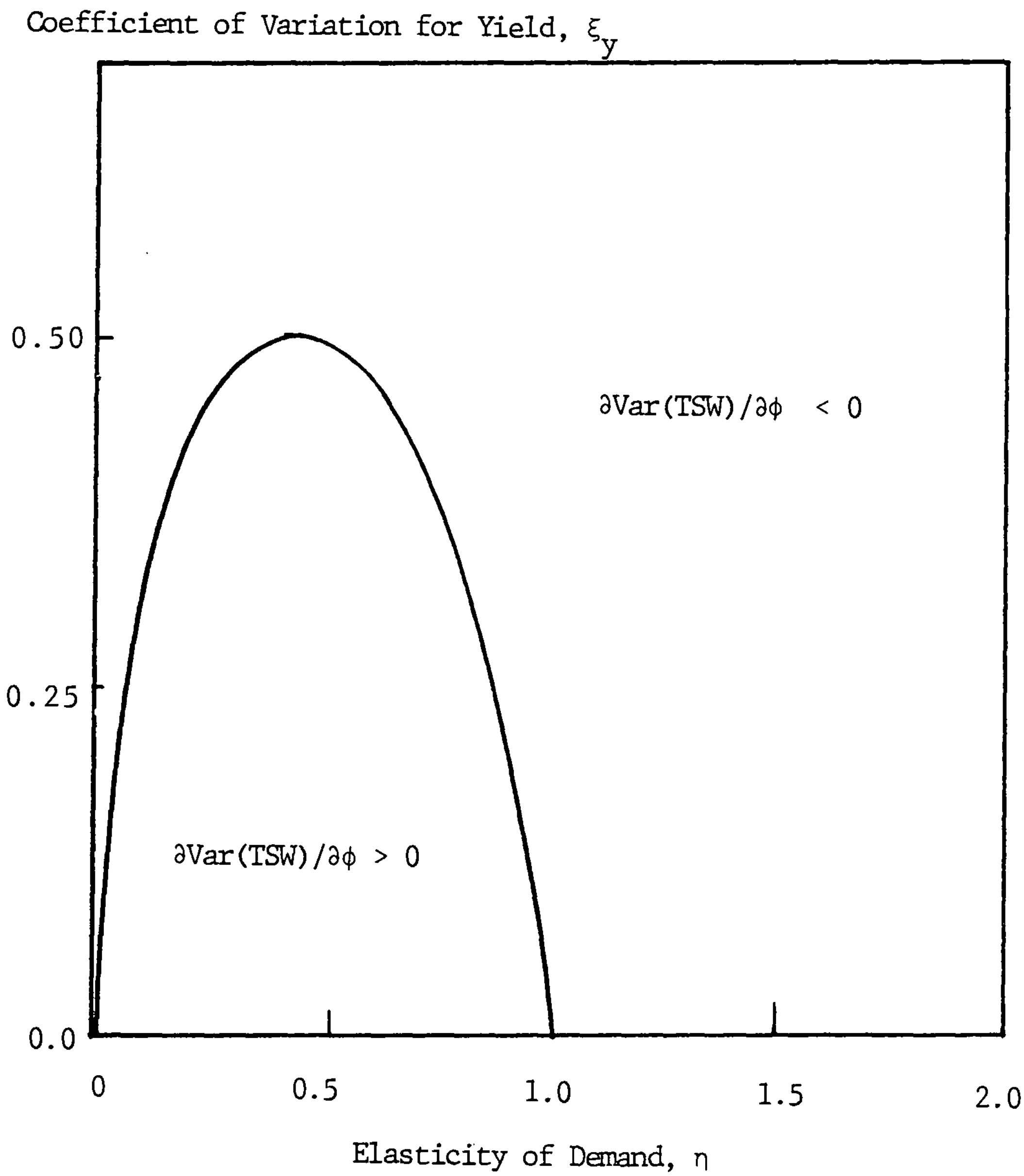


Figure 3.3. The Effects of Increasing Risk Aversion on the Variance of Total Social Welfare for Alternative Values of ξ_y and η.

($\partial A/\partial\phi < 0$)

The coefficient of variation of total social welfare can be expressed as a function of the acreage variable and hence, will change as the level of the risk aversion parameter increases. The coefficient is given by

$$\xi_{TSW} = (Var(TSW))^{\frac{1}{2}} / E(TSW) \quad . \tag{44}$$

Under conditions of a normally distributed yield variable, the derivative of equation (44) with respect to ϕ will be less than zero for $\partial A/\partial\phi < 0$ if

$$\eta < (\xi_y^4 + 2 - \tfrac{1}{2}\,\xi_{TSW}^2\,\xi_y^2\,(1 - (TC/E(TR)))\,(1 + \xi_y^2) + \tfrac{1}{4}\,\xi_{TSW}^2\,(1 + \xi_y^2)^2) \,/\, (2\xi_y^2 - 2 - \tfrac{1}{2}\,\xi_{TSW}^2 \cdot (1 - (TC/E(TR))\,(1 + \xi_y^2)) \quad . \tag{45}$$

All terms in the expression above have been defined previously. Equation (45) is fully derived in section A10 of the Appendix A. Because of the complexity of the expression it is necessary to derive an analytical solution to equation (45) to determine the actual effect of an increase in the risk aversion parameter on the coefficient of variation of total social welfare.

SUMMARY AND CONCLUSIONS

In this analysis we have attempted to show that risk averse actions on the part of individual producers do not necessarily result in a less risky aggregate market situation. If the producer forms price expectations according to a non-rational construct an increase in risk averse behavior leads to a decline in expected individual net farm income. However, after market price adjustments have been made, it was shown that expected aggregate net farm income is likely to increase. Similarly, the variation in individual net income declines at the individual level but may increase at the aggregate level.

We have assumed that "income riskiness" can be defined by the measure of the dispersion of the income distribution about its expected value, that is, by the coefficient of variation of income. With non-rational expectations the value of the coefficient of variation of net farm income at the individual level is unchanged by an increase in risk averse behavior. However, under our assumptions, aggregate market riskiness can increase even though the individual has become more risk averse. Whether or not the aggregate market does indeed become riskier in terms of an increase in ϕ is given by the conditional expression in equation (37) for the case when yield is normally distributed.

When the individual model is formulated with a rational expectations construct, impacts at the producer level are identical to those at the aggregate level. That is, the producer adjusts the acreage decision so that expectations of individual impacts coincide with the aggregate consequences of changes in risk avoidance behavior. It was illustrated by means of an example that in the rational expectations model an increase in individual risk aversion is likely to lead to a decline in the mean and variance of both individual profits and aggregate producers' surplus.

We have also shown that risk averse behavior can have negative impacts on both consumer welfare and total social welfare as measured in the aggregate market. However, these results depend critically on the expectations formulation of the producer model. With non-rational expectations the mean and variance of consumers' surplus, as well as the mean of total social welfare, decline as risk aversion on the part of the individual producer increases. When rational expectations are incorporated the results will correspond to those just indicated as long as increasing risk aversion leads to a decrease in acreage planted. Referring again to the example, acreage may in fact increase. Therefore, the mean and variance of consumers' surplus, along with expected total social welfare, will increase with an increase in risk avoidance behavior. The variance of total social welfare may increase or decrease according to the conditional expression given in equation (43). Similarly, the coefficient of variation of total social welfare may rise or fall with an increase in individual risk averse behavior according to the expression given in equation (45). These results hold with either expectation formulation.

The analysis above would seem to indicate the importance of recognizing the aggregate consequences of policies designed to reduce risk at the micro-level. After market adjustments have been taken into account, efforts to stabilize producer incomes may, in fact, lead to destabilization in the aggregate market in terms of both the variance and the coefficient of variation of producers' surplus. Additionally, the distributions of expected consumers' surplus and expected total social welfare may be adversely affected. It appears therefore, that both the micro and the macro effects of risk management strategies need to be considered in the design of effective policy. Further, the analysis has indicated the importance of correctly identifying the price-expectation strategy employed by the producer. The model construct plays a crucial role in determining the aggregate consequences of changes in individual risk avoidance behavior.

ENDNOTES

1. The Henderson and Quandt reference is only one example of the numerous microeconomic textbooks in which the relationship between the price elasticity of demand and fluctuations in market revenues resulting from price changes is described.
2. Development of the adaptive expectations hypothesis is generally attributed to Cagan in a study of hyperinflation; Nerlove was the first to introduce the concept to the study of agricultural markets.
3. Bernoulli's principle states that for a decision-maker whose preferences are well-ordered, a utility function can be shown to exist reflecting these preferences. Accordingly, the choice between risky prospects is shown to be equivalent to the maximization of expected utility (Anderson, Dillon and Hardaker).
4. The approximation is presented for clarity of exposition. No alteration in later analysis results from use of the approximation formula.
5. For ease of presentation the subscript i has been dropped from the right hand side of the $E(\pi_i)$ and $Var(\pi_i)$ equations.
6. The expression for $Var(\pi_i)$ is derived in section A2 of Appendix A.

7. Expected net farm income declines so long as there are positive returns to production.

8. Expected total returns to production are approximated using data for total receipts from farm marketings. Net farm income is estimated as the difference between these receipts and total production expenses. The data were taken from Agricultural Statistics, United States Department of Agriculture, 1983, Table 598 - Farm Income: Gross and Net Income from Farming, United States, 1968-1982.

9. Thanks to Peter Hazell for making these data available.

10. Tweeten (1979) reports a farm level elasticity for wheat of 0.02 (absolute value) and for barley of 0.07 (absolute value).

11. Consequent with the EV formulation is the fact that a decrease in the variance of profits cannot be achieved without also accepting a decline in the mean value of profits.

CHAPTER 4

DISTRIBUTION OF THE LONG TERM IMPACTS OF DECLINING SOIL PRODUCTIVITY

> The long-term social threat posed by uncontrolled soil erosion raises profound questions of intergenerational equity. If our generation persists in mining the soils so that we may eat, many of our children and their children may go hungry as a result. Agricultural economist Lloyd K. Fischer of the University of Nebarska observes that the quality of our diet in the future will be "substantially lower and costs dramatically higher if the management of our land and water resources is not improved." He notes further that "we must cease to behave as if there were no tomorrow, or tomorrow will be bleak indeed for those who must spend their lives there."
>
> Lester R. Brown
> <u>State of the World 1984</u>

CHAPTER 4

DISTRIBUTION OF THE LONG TERM IMPACTS OF DECLINING SOIL PRODUCTIVITY

INTRODUCTION

Soil erosion is purported to be one of the most pervasive problems occurring in agriculture today (Office of Technology Assessment). Scientists in the USDA estimate that 53% of U.S. sheet, wind, and rill erosion occurs on agricultural cropland (USDA, 1982). The effects of erosion have both private and social repercussions. From the point of view of the individual producer, soil erosion can adversely affect crop yields. A positive relationship has been shown to exist between topsoil depth and crop yields (Crosson and Stout; Hoag and Young). Potential crop yields decline as soil is removed from the land base. The yield-soil depth relationship however, is often masked by yield increases stimulated by technological improvements and increases in the usage of other production inputs.

Crop yields are also dependent on the relationship between soil erosion and the °effectiveness' of technical improvements. It has recently been argued that the yield increases associated with the technological improvement of other production inputs are lower on shallow soils than on deeper soils (Taylor and Young). Continued erosion may lead to a relative decline in crop yields even in the presence of technological improvements.

The effects of erosion from a social perspective are generally seen as being two-fold. First, soil erosion results in the increased sedimentation and siltation of nearby waterways. Sedimentation can reduce the recreation values associated with the waterway, reduce the useful life of reservoirs used for power generation, flood control, and irrigation, and increase the cost of municipal water cleanup (Crosson and Brubaker). Second, because of the adverse effect of erosion on crop yields, the long-term productivity of the soil base is diminished by soil loss.

McConnell has argued that because the individual producer internalizes the productivity costs of erosion, society need only consider the off-site damages not accounted for in the private decision. However, because the farmer's planning horizon may be much shorter than that of society's (20 years as compared to 200), the private producer may not fully consider the long term productivity effects of erosion. Society's concern for declining soil productivity is related to implications for the well-being of future generations. High rates of soil erosion over time can lead to higher prices and lower quantities of agricultural commodities than would occur in the absence of erosion. The result is a decline in total economic surplus relative to conditions where soil loss is controlled over time. It is this aspect of the soil erosion problem to which the present paper is addressed.

In the first section of the paper issues surrounding the establishment of rules for determining the optimal rate of resource depletion over time are examined. A methodology whereby the potential long-term welfare effects of declining soil productivity can be examined is presented in the second portion of the paper. An agricultural market simulation model is developed with the supply and demand for agricultural products described in a single aggregate commodity market. A series of analyses are carried out that examine the benefits of erosion control over time.

To accomplish this, a base scenario is defined where no attempt to control cropland erosion is made. Alternative scenarios are specified by the presence of erosion control on increasing proportions of total cropland. Conditions defining the relationship between erosion, crop yield, and technology are varied under each of the scenarios and the simulation results are evaluated relative to the base scenario. The final portion of the paper looks at potential policy implications which may be drawn from the simulation results.

THE INTERGENERATIONAL QUESTION

In 1977 Congress passed the Soil and Water Resources Conservation Act (RCA) directing the USDA to assess the state of the nation's soil and water resources and to identify programs to conserve the integrity of the resource base. This legislation is a recent example of the long history of national concern for maintaining the long-term productivity of the agricultural land base (Rasmussen). In the 1982 U.S. Dept. of Agriculture's RCA Final Program Report it was estimated that approximately 22 percent of the nation's cropland is eroding at a rate in excess of the tolerable level of annual soil loss, or T-value. The T-values are defined by the Soil Conservation Service as the "maximum rate of annual soil erosion that will permit a high level of crop productivity to be maintained economically and indefinitely" (Crosson and Stout, p.79).

Crosson and Stout argue that the rationale for T-values lies in the obligation of one generation to provide an unimpaired resource base to the next generation. As such, it is necessary that a set of soil loss standards be defined and maintained to ensure that each generation bears the burden of its responsibility. They argue however, that soil loss standards should be based on economic rather than physical criteria. Crosson and Stout propose that soil conservation measures should be instituted not when soil loss exceeds some accepted T-value but when "the present value of the cost of the measure falls below the present value of the productivity loss" (p. 82). The controversy over whether to use physical or economic criteria in determining acceptable levels of soil loss was a major point of dissention in drafting the 1980 RCA Program Report (Leman).

Much of the recent literature on the economic effects of erosion has examined the long-term productivity impacts of soil loss. Seitz et al, in a static linear programming analysis of the impacts of soil erosion control on yields in the corn-belt region, showed that improvements in soil conservation could be made without imposing significant hardship on the farm sector. They argued that "barring the development of some radically new technology which will reduce the reliance on land, maintaining soil resources will tend to mitigate the increase in food costs for future generations" (p. 29). Timmons, in an essay on the causes and implications of soil erosion on the nation's cropland, also warned of the need to implement conservation strategies in order to "insure future food supplies for the nation" (p. 10). However, in a dynamic analysis of optimal tillage choice at the farm level Miranowski found that the private decision to protect the productivity of the agricultural land base was dependent on the producer's expectations of future crop prices. If prices were expected to increase over time, conservation methods were employed; decreasing price expectations encouraged more exploitative production practices.

A general concern has been expressed that the private decision to conserve the soil may not coincide with socially preferred levels of erosion control. Brubaker and Castle note that if "society is to endure at current levels, then people collectively must accept an obligation to leave the future with access to resources equal to what we all now enjoy" (p. 504). While recognizing that with many resources this is done by means of a legacy of improved technology, they argue that because land exists in a fixed quantity the physical resource must be left to the future intact. Therefore, soil conservation becomes a social objective even if it is not a private one. The importance of society's responsibilty to leave a viable resource base to the future is also noted by Seitz, and Crosson and Brubaker. The latter also note, however, that "if we wish to protect the rights of a future generation in a productive soil, the equitable way of meeting the current cost of doing so would be to make them broadly borne" (p. 178).

Given that there may exist a responsibility to protect the long-term productivity of the agricultural land base, the problem becomes one of determining the socially preferred rate of erosion. Ferejohn and Page note that the most commonly used method of determining the optimal rate of depletion is the maximization of discounted net benefits. An alternative intertemporal choice rule is the conservationist's ethic. Under the former criterion the first generation necessarily acts as a 'dictator' over all other generations by selecting the optimal rate of soil loss over time according to its own rate of time preference (Page). Ferejohn and Page raise the following concern regarding the application of maximization of discounted net benefits criterion: "What happens if the discounted net expected benefit of an affirmative decision is positive, yet only the first generation prefers the affirmative decision, while the next ten or more generations prefer the negative decision?" (p. 274). They argue that the use of the discount rule as a criterion of intertemporal choice requires fundamental rethinking; a broader set of principles for social choice may need to be established to be used in conjunction with the discount rule. In this way gross intergenerational inequities that may arise with discounting can be avoided.

The conservationist criterion requires that natural resources be depleted over time according to their sustainable yield (Page). That is, if the environment is to be sustained into perpetuity then the rate of resource depletion should not exceed the natural rate of regeneration. This criterion is generally criticized on the grounds that it does not maximize the present value of the flow of resource benefits. Page notes however, that this is not an appropriate criticism. The criteria derive from different streams of logic and therefore cannot be used to criticize one another. "The most one can say at this point is that the two criteria conflict; they imply different states of the world" (Page, p. 188). To reconcile these antithetic values of intertemporal choice, Page suggests that the conservationist's criterion be used to establish long-term goals with the discounting rule used as an 'efficient' instrument to achieve these ends. In order to insure that the economy 'sails safely into the future' it is necessary to recognize that to "set and balance the sails requires considerations of economic efficiency; to adjust the rudder requires considerations of fairness" (Page, p. 211).

In this paper the long term productivity impacts of soil loss from cropland are examined by looking at the distribution of impacts across several generations of agricultural producers and consumers. Producers' and consumers' surplus measures are calculated from a series of market equilibrium solutions generated under alternative levels of erosion control over time. In this way it is possible to determine who benefits and who loses from aggregate levels of erosion control and to determine the distribution of impacts over time.

THE MODEL

To examine the effects of soil erosion on the current and future productivity of cropland an agricultural market simulation model is developed. A simple analytical framework is designed whereby alternative assumptions regarding the relationships between soil erosion, technology, crop yields, and total output can be evaluated. The interaction between these supply parameters and a set of assumptions regarding future levels of commodity demand furnish a series of equilibrium price and total output values.

A set of initial market conditions is identified using 1980 data for cropland acreage and value of agricultural production. Given the base conditions and the set of relationships defined in the model, market equilibrium is simulated over a period of 250 years. The aggregate equilibrium price and quantity values obtained from the simulation, along with the hypothesized supply and demand relationships, are used to calculate measures of producers' and consumers' surplus. The trade-offs, in terms of producer and consumer welfare, among potential levels of soil erosion control are expressed as changes in the surplus values under alternative model scenarios.

The off-site damages associated with eroding cropland are not taken into account in the simulation model. In this sense the welfare implications that are derived provide only a partial analysis. The measures provided by the model simulate the impacts of soil erosion on the level of available agricultural commodity supplies over a specified time horizon. The trade-offs among potential levels of aggregate erosion control indicate whether producers and consumers are better or worse off as the rate and level of soil loss is altered over time.

Market Supply

Agricultural output is assumed to be provided by a large number of independent producers, each providing a homogeneous product and having no individual influence on the price received for that product. Total agricultural supply is defined to include three components: i) supply associated with production on non-erosive land, ii) supply associated with production on erosive land where farmers participate in conservation programs, and iii) supply associated with production on erosive land where farmers do not participate in conservation programs. For each of these components total supply is given as a function of the level of per acre production , the rate of technological progress, the relationship between topsoil depth (defined as a function of the rate of erosion) and crop yield, and the total acreage in production.

Per Acre Production

The level of per acre production is determined by two components. The first indicates the manner in which the producer affects his input decision given current market price conditions. An important determinant of this supply response is the underlying technological production relationship. The Cobb-Douglas specification is one of the most widely used forms of the production function for empirical estimation (Intrilligator). This type of production relationship leads to a constant price elasticity supply function and is the form used in characterizing the producer's per acre production decision in the present model. The second component of the per acre supply relationship is the base level of per acre yield. Because the yield parameter is determined from the initial market equilibrium solution it will be discussed in more detail in the latter part of this section.

The per acre production relationship is given by

$$Q_{t,A} = Y_o P_t^{els} \tag{1}$$

where

$Q_{t,A}$ = the quantity supplied per acre in time period t,

P_t = the equilibrium price in time period t as calculate in the simulation model,

Y_o = the base level of per acre crop yield, and

els = the price elasticity of supply.

Because of the nature of the agricultural production process, a shift in market price has little influence on the production decision in the short run. Aggregate supply elasticities tend to be relatively inelastic, even over a period of several years. Tweeten (1979) has estimated the short-run supply elasticity for crop production to be 0.17; the short-run supply elasticity for total farm output (including both crop and livestock production) was estimated to be 0.26. In an earlier study by Heady and Tweeten the aggregate elasticity of farm output was estimated to be 0.1 in one to two years, and 0.2 in three to four years (Tweeten, 1979). Given the results of these studies, a supply elasticity of 0.2 was selected for use in the simulation.

Yield-Topsoil Relationship

Technological improvements and topsoil are recognized as complementary inputs in agricultural production; an increase in the use of one boosts the productivity of the other (Pimental; Young). When the influence of technology is held constant crop yields decline as topsoil is removed from the land base, though a great deal of uncertainty exists regarding the exact nature of the yield-topsoil relationship. Recent work however, has suggested that the marginal returns to crop yield diminish with increasing increments of topsoil depth; crop yields have been found to be more adversely affected by erosion on shallow soils than on deep soils (USDA, 1981b; Crosson and Stout). Another important feature of the yield-topsoil relationship is the self-reinforcing nature of the adverse effects of erosion. As erosion continues over time, topsoils become shallower and the negative impacts on crop yield become increasingly severe.

Yield reductions due to soil loss are caused in part by the reduced water retention capacity of the soil. With less plant growth there is less post harvest crop residue and hence more eosion than may have otherwise occured. The lower level of plant residue also diminishes the ability of the soil to retain necessary nutrients and, on already shallow soils, reduces the available root zone for plant growth (Office of Technology Assessment). These factors combine to encourage greater erosion and the cycle continues.

A yield index taking into account the adverse effects of soil loss on crop yield is incorporated into the simulation model. The index has the following functional form:

$$I_t = D_t^b \tag{2}$$

where

I_t = the yield-soil depth index value in time period t,

D_t = the topsoil depth in time period t, and

b = the coefficient describing the relationship between topsoil depth and crop yield.

The coefficient b can be defined as the elasticity of crop yield with respect to soil depth. The elasticity indicates the percentage change in yield associated with a one per cent change in soil depth. Because of the diminishing returns to crop yield associated with increasing soil depth, b will lie in the range from zero to one. A value of b greater than one would indicate that given sufficient topsoil depth crop yields could increase indefinitely.

Topsoil depth is defined as a function of the annual rate of soil erosion so that

$$D_t = (1 - er)^t D_0 \qquad (3)$$

where

D_0 = topsoil depth in the initial time period, and
er = the annual rate of soil erosion.

The initial soil depth, D_o, is assumed to be equal to 1.0. Soil depth is defined as a numeraire because it is the relative changes in depth rather than physical quantity measures which are of interest in the present study. Substituting the erosion-topsoil relationship above into equation (2) leads to

$$Y_t = (1 - er)^{tb} D_0 = (1\text{-}er)^{tb} .$$

Crop yield is directly related to the annual rate of soil erosion. In the initial time period t=0, making the yield-topsoil index equal to one.

Soil erosion is generally measured in terms of the number of tons of soil lost per acre per year. A recent report by the U.S. Dept. of Agriculture has indicated that one acre inch of soil weighs approximately 150 tons (USDA, 1981b). If erosion occurs at the rate of ten tons per year then 15 years would be needed to lose one acre inch of soil. Erosion rates measured in terms of tons of soil lost per year are translated to indicate an annual percentage rate decline in soil depth. The translation is shown in Table 4.1. For example, an erosion rate of 20 tons per year would require 7.5 years to remove one acre inch of soil. If initial soil depth is 20 inches, erosion is causing soil depth to decline at an annual rate of 0.68 percent per year; at an initial soil depth of 10 inches the rate of decline would be 1.39 percent per year.

In the simulation model an erosion rate of 0.32 percent per year is assumed. This is approximately equal to the loss of 5 tons per year on an initial depth of 10 inches or the loss of 10 tons per year at an initial depth of 20 inches. The model is also evaluated using alternative soil loss rates of 0.16 percent per year and 0.71 percent per year. When compounded over fifty years the latter indicates a 30 percent decline in soil depth while the former yields a 7.5 percent decline. An annual soil loss rate of 0.32 percent compounds to a 15 percent decline after fifty years.

Although the rate of erosion is considered to be constant over time, the effects on soil depth are cumulative. The result is a non-linear relationship between soil depth and crop yield. Empirical support for this type of relation is given in Walker, and Walker and

TABLE 4.1. Soil Erosion Rates Measured in Tons Per Acre and Percentage Decline in Soil Depth.

Erosion Rate Tons/Year	Years to Remove One Acre Inch[a]	Initial Soil Depth	Percentage Decline in Soil Depth
5	30	10 inches	0.35%
		20 inches	0.71%
10	15	10 inches	0.70%
		20 inches	0.34%
15	10	10 inches	1.05%
		20 inches	0.51%
20	7.5	10 inches	1.39%
		20 inches	0.68%

[a] Estimate based on the USDA approximation that one acre inch of soil weighs 150 tons (USDA, 1980).

Young. An illustration of the functional relationship identified in equation (2) is shown in Figure 4.1. Alternative yield-topsoil elasticity values are specified. As the value of b is increased the effects of soil loss on crop yield become increasingly more severe.

To determine a value for the yield-topsoil elasticity b, the following equation was estimated using ordinary least squares:

$$Y_i = \beta_0 D_i^{\beta_1} e^{u_i} \qquad (4)$$

where the variables Y_i and D_i measure winter wheat yield and topsoil depth, respectively. The data, drawn from Hoag and Young, are 180 field level observations from the Pine Creek Conservation District in northeastern Whitman County, Washington. The data was collected over the period 1970 to 1979 though do not represent time series observations on a particular site.[1] In the model above, the estimated coefficient for β_1 is used as an approximation for the yield-soil depth elasticity defined in equation (2). Regression results for equation (4) are presented in Table 4.2. The estimated coefficient values for β_1 generally lie in the range between 0.15 and 0.25, indicating that a ten percent decrease in soil depth leads to an approximate two percent decrease in crop yield.

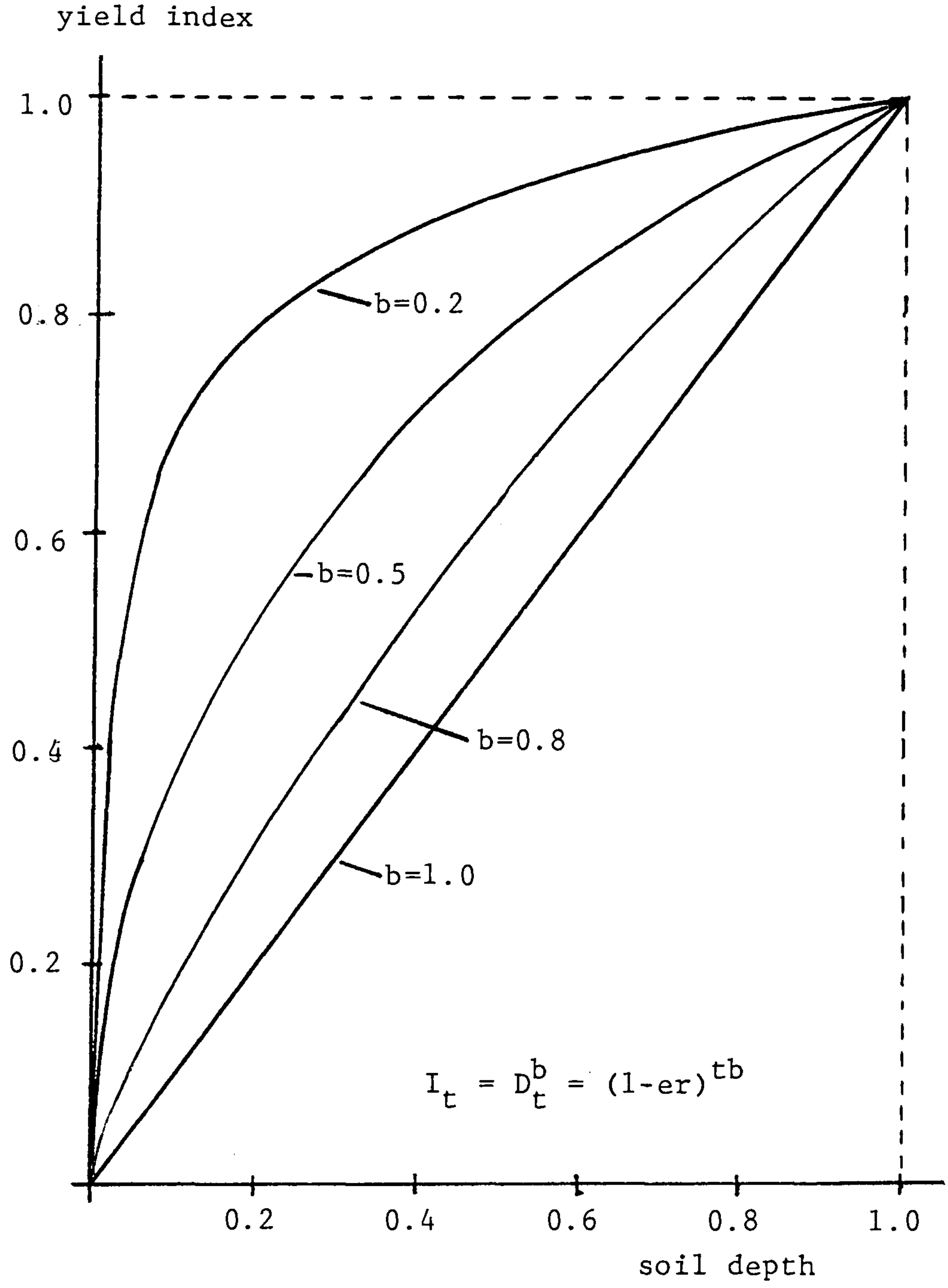


Figure 4.1. Functional Relationship Between Soil Depth and Yield.

Table 4.2. Estimated Yield-Topsoil Depth Elasticity Values[a]

Data Year	Number of Observations	Elasticity Estimate	Significance Level of of Estimator
1970	19	0.2569	0.01
1971	14	0.0406	NS
1972	19	0.2541	0.01
1974	37	0.2362	0.01
1975	26	0.2117	0.05
1976	18	0.0701	NS
1977	18	-0.0325	NS
1978	12	0.1583	0.10
1979	17	0.1574	0.10
All Data	180	0.2159	0.01
1970-72, 1974	89	0.2283	0.01

NS = Not Significant

[a] Estimated Equation: $\ln Y = \beta_0 + \beta_1 \ln D$ where

Y = crop yield, D = topsoil depth, and
β_1 = the elasticity estimate.

Source: Hoag, D.L. and D.L. Young, Yield-Topsoil Depth Response Functions: Linear vs. Mitscherlich-Spillman, STEEP Ag Econ Working Paper, 82-2, Dept. of Agricultural Economics, Washington State University, Pullman, Washington, March 1983.

The yield-soil depth elasticities estimated from equation (4) were checked against elasticity values derived from the yield -topsoil response functions fitted by Hoag and Young in their study of winter wheat production in northeastern Washington. To estimate the yield-soil depth relationship, Hoag and Young fitted a Mitscherlich-Spillman (MS) response function. The relationship has the following form (Hoag and Young):

$$Y = A + B\,(1.0 - R^{D}) \tag{5}$$

where

- Y = winter wheat yield (bushels/acre),
- A = expected yield from subsoil (zero topsoil),
- B = maximum yield increment from topsoil,
- D = topsoil depth, measured in inches, and
- R = a constant ratio between consecutive terms of the declining yield increment series ($0 < R < 1$).

The yield-soil depth elasticity is found by taking the derivative of equation (5) with respect to D and multiplying by the ratio D/Y, or

$$Elas_{Y-D} = (-B\,R^{D}\,\ln(R)) \,/\, (A + B - B\,R^{D})\,. \tag{6}$$

As can be seen from the equation above, the elasticity measure derived from the MS response function varies according to the topsoil level.

Empirical estimates of the MS elasticity values were calculated for soil depths of ten inches and twenty inches. The results are shown in Table 4.3. For a soil depth of ten inches the elasticities range from 0.13 to 0.27 while on soils of twenty inches the values range from 0.08 to 0.16; these results would seem to indicate that yield is more responsive to changes in soil depth on shallow soils relative to deep soils. The values in Table 4.3 lie in the same approximate range as those calculated using the constant elasticity yield-depth function defined in equation (2). Consequently, a mid-range elasticity value of 0.20 was selected for use in the simulation model. The model was also run with an alternative value for the elasticity.

Technology-Topsoil Relationship

One of the primary reasons the adverse effect of soil loss on agricultural productivity has not stimulated more interest in utilizing conservation practices have been the yield increases associated with other production inputs (Burt; NSERPC). Productivity increases generated by expanded machinary capacity, high-yield crop

Table 4.3. Yield-Topsoil Elasticity Values Calculated from the Mitscherlich-Spillman Function Estimated by Hoag and Young.[a]

Data Year	Number of Observations	Elasticity Estimate (Depth = 10")	Elasticity Estimate (Depth = 20")
1970	19	0.2688	0.1608
1972	19	0.2494	0.1508
1974	37	0.2266	0.1386
1975	26	0.2251	0.1378
1976	18	0.2507	0.1514
1978[b]	12	0.1272	0.0822
1979	17	0.1862	0.1164
All Data	180	0.2346	0.1429
1970-72 1974	89	0.2279	0.1393

[a] Estimated parameter values were found by Hoag and Young to be not significant for data years 1971 and 1977.

[b] Estimated parameter values found to be just significant at = 0.05 (all other parameter values significant at = 0.01).

Source: Hoag, D.L. and D.L. Young, Yield-Topsoil Depth Response Functions: Linear vs. Mitscherlich-Spillman, STEEP Ag Econ Working Paper, 82-2, Dept. of Agricultural Economics, Washington State University, Pullman, Washington, March 1983.

varieties, and improved herbicides and fertilizers have in general more than compensated for any decline caused by erosion (Heady). There is a growing concern however, that the historical trends in technology-induced productivity improvements will not be sustained into the future (Office of Technology Assessment). Continued soil degradation may limit the effective rate at which productivity increases associated with technology can be maintained.

Citing historical trends in agronomic data, Walker and Young argue that technology tends to shift the yield-topsoil relationship outward in a non-uniform fashion. Technological improvements bring greater yield increases on deeper topsoils. Like the yield-topsoil response, this relationship is self-reinforcing. As the soil base becomes shallower, technical improvements become less effective (in terms of yield increase) relative to adoptions made on deeper soils. Walker and Young describe this non-uniform relationship as complementary technical change.

Alternative types of technology related yield improvements include land substituting and land neutral technical change. In the former case technical advance is greatest on shallow soils. An example is a technological advance that helps to conserve soil moisture; because shallow soils suffer from reduced water retention capabilities, yield improvements can be expected to be greater on those soils (Walker and Young). With land neutral technical change, yield improvements accrue equally on all levels of soil depth.

While the nature of the relationship between soil depth, crop yield, and technology is not well understood, several studies have argued that land complementary technical change is the manner in which technology affects crop yields (Walker and Young; Taylor and Young; Walker). Complementary technical change is therefore, the type of technical advance incorporated into the simulation model.

The relationship between technology and soil depth is included as follows:

$$r_e = r D^a \qquad (7)$$

where

r_e = the actual rate of technology-induced yield increase,

r = the maximum rate of technology-induced yield increase, i.e. the yield increase on soils of maximum depth,

a = coefficient describing the relationship between technology related yield improvements and topsoil depth, and

D = soil depth, as defined for equation (2).

The left hand side of equation (7) can be described as the effective rate of yield improvment. As soil depth declines the yield improvements associated with technical change also decline. The coefficient a signifies the elasticity of the effective rate of technology-related yield improvements with respect to soil depth. It describes the per unit change in the effective technology rate for unit increments (or decrements) in soil depth. Equation (7) indicates that if crop yield in year t is given by Y_t then, with technological progress, yield in year t+1 will be given by $Y_t(1 + r D_{t+1}^a)$.

The actual rate of technological advance is calculated using a fixed annual rate of maximum technology increase of two percent per year. This value is derived from a simple linear regression estimating the annual rate of increase in U.S. aggregate farm output. Results show that for the period 1962 - 1980 total grain production per harvested acre has increased at an annual rate of 2.19 percent per year while total grain production has increased at an annual rate of over 3 percent per year. Using the index of aggregate farm output for the period 1954 - 1980, the annual rate of increase in farm output was estimated to be 1.75 percent per year.[2] Taken together, an annual rate of increase of two percent was felt to approximate general trends in U.S. agricultural output over the past several years.[3]

Because the rate of yield improvement is given as two percent per year on non-erosive land the effective rate of increase on erosive acreage is somewhat less than two percent. As more and more of the soil base is lost to erosion, the effective rate of technical advance on eroded soils continues to decline in a constant fashion.

The technology-topsoil elasticity (a) is defined to lie in the range between zero and one since technology related yield increases are likely to exhibit decreasing returns to topsoil. The relationship between the effective rate of technological improvement and alternative values for the technology elasticity is presented in Figure 4.2. From the diagram it can be seen that lower elasticity values are associated with higher rates of effective yield improvement on all levels of soil depth. Regardless of the elasticity value however, the rate of improvement levels off as the maximum soil depth is approached.

No data were available to empirically estimate a value for the technology-soil depth elasticity according to the relationship defined in equation (7). However, an elasticity value was estimated from empirical work done by Walker and Young. In a study of the Palouse region of eastern Washington, Walker and Young fitted a Mitscherlich-Spillman response function to wheat yields. The function was modified to include the rate of

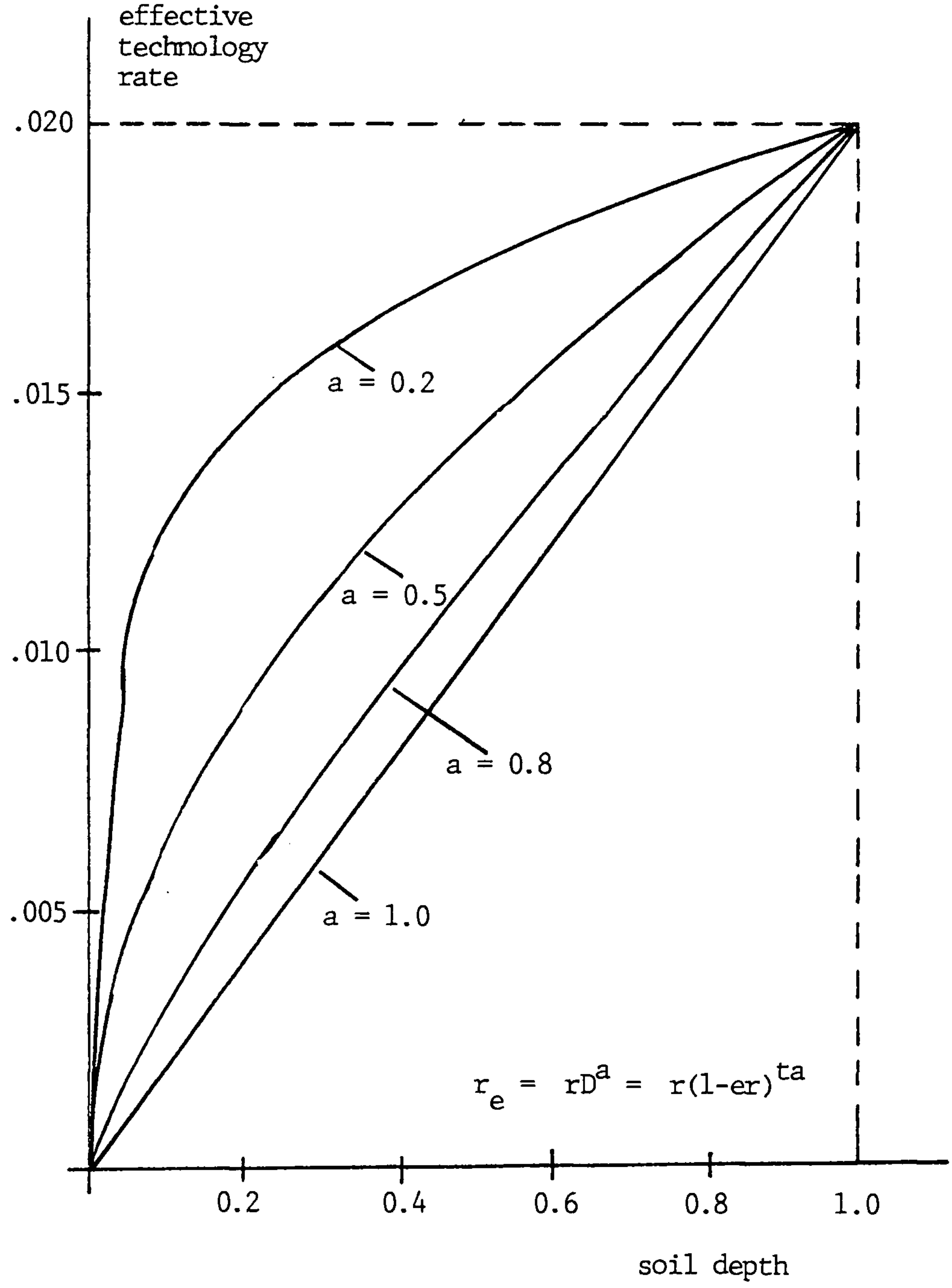


Figure 4.2. Functional Relationship Between Soil Depth and Technology.

technical progress over time. The response function had the following form (Walker and Young):

$$Y_t = (A + A't) + (B + B't)\ (1-R^D t) \qquad (8)$$

where

A' = average annual rate of adjustment in coefficient A,

B' = average annual rate of adjustment in coefficient B, and

t = a trend variable (t = 0,1,2,....).

The parameters Y, A, B, R, and D were previously defined for equation (5).

Walker and Young note that A' can be interpreted as the annual rate of change in yields on topsoils of zero depth (subsoils) while A'+B' can be interpreted as the annual rate of change in yields on topsoils of maximum depth. Therefore, the effective rate of technology-related yield increase for alternative soil depth levels is given by

$$r_{e,t} = A' + B'\ (1-R^D t)\ . \qquad (9)$$

The technology-soil depth elasticity can be calculated by taking the derivative of equation (9) with respect to soil depth and multiplying by the ratio D/r_e, or

$$Elas_{T-D} = (-B' R^{D} \ln(R) D)/(A'+ B' (1-R^{D})) . \quad (10)$$

When derived from the MS response function, the technology-soil depth elasticity (like the yield-soil depth elasticity) varies according to the depth of the topsoil. Using the parameter values calculated by Walker and Young (A'=0.251, B'=0.493), the elasticity is calculated for alternative soil depth levels. The results are shown in Table 4.4. The elasticity has a maximum value of 0.1647 at a topsoil depth of eight inches, though generally lies in the range from 0.05 to 0.15. A slightly larger elasticity value of 0.20 was selected for use in the simulation model. However, the model was also run using a smaller elasticity value; these results are presented later in the paper.

The cumulative technology index is defined as

$$T_{t} = (1 + r D_{t}^{a}) T_{t-1}$$

or

$$T_{t} = \prod_{i=0}^{t} (1 + r D_{i}^{a}) . \quad (11)$$

where

T_{t} = the technology index in time t.

Because erosion causes soil depth to decline over time, the effective rate of technology advance will decrease with each succeeding period. Therefore, while the

Table 4.4. Technology-Topsoil Depth Elasticity Values Calculated from the Mitscherlich-Spillman Yield Response Function Estimated by Walker and Young.

Soil Depth (inches)	Estimated Technology-Topsoil Elasticity
40	0.0212
36	0.0327
32	0.0445
28	0.0598
24	0.0790
20	0.1020
16	0.1276
12	0.1519
8	0.1647
4	0.1398

Source: Elasticity values based on coefficient estimates from Walker, D.J. and D.L. Young, "Assessing Soil Erosion Productivity Damage," manuscript for publication in a National Academy of Science Proceeding, March 1985.

cumulative technology index will increase over time, it will do so at a slower rate than if technology improvements were unaffected by soil erosion (see Figure 4.3).

Total Supply

Total agricultural supply is given by the sum of the quantities supplied by each of the three producer groups. These groups again, are: i) producers on non-erosive acreage, ii) producers on erosive acreage who participate in some type of soil conservation program, and iii) producers on erosive acreage who do not participate in conservation activities. As indicated earlier, each of these supply components is a function of acreage, a yield-soil depth relationship, a technology-soil depth relationship, and a per acre market production response. The total supply equations for each of the producer groups are derived below.

The total quantity supplied from non-erosive acreage is given by

$$S_{1,t} = A_1 I_{1,t} T_{1,t} Q_{t,A} \qquad (12)$$

where

$S_{1,t}$ = total quantity produced on non-erosive acreage in time period t,

A_1 = total acreage considered non-erosive,

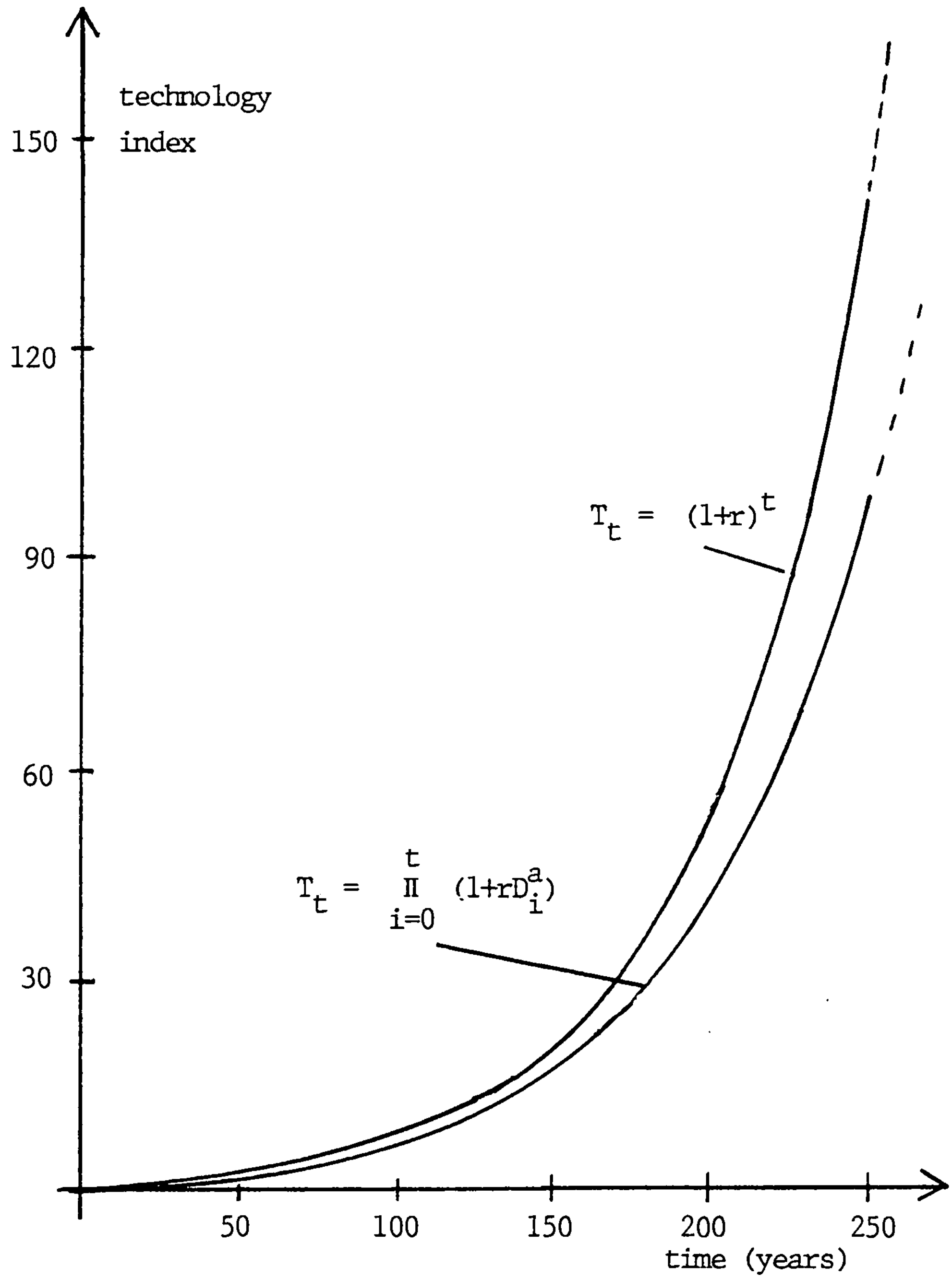


Figure 4.3. The Technology Index Over Time.

$I_{1,t}$ = yield-topsoil index for non-erosive acreage in time period t,

$T_{1,t}$ = technology-topsoil index for non-erosive acreage in time period t, and

$Q_{t,A}$ = per acre market price response in time period t (includes a base yield parameter).

Because topsoil depth is assumed to remain constant over time on non-erosive acreage, there is no change in the yield-topsoil index from its initial value of one. Similarly, because soil depth is constant the technology index reduces to the relatively more simple expression

$$T_{1,t} = (1 + r) T_{1,t-1} = (1 + r)^t . \quad (13)$$

Equation (12) can therefore be rewritten as

$$S_{1,t} = A_1 (1 + r)^t Q_{t,A} . \quad (14)$$

Total output supplied on non-erosive acreage is given as a function of the total acreage in production, the rate of technical progress over time, and a per acre supply repsonse.

The total supply function for output on erosive acreage tilled using conservation methods is similar to the supply function for non-erosive acreage. It is assumed that when conservation methods are employed soil erosion is completely checked; that is, topsoil depth remains constant throughout the length of the simulation. However, the use of conservation methods is assumed to impose a yield penalty on crop production. In a study of the Palouse region of eastern Washington Walker notes that some conservation practices may require that land be moved out of production or may "show reduced germination in poor stands due to weeds, plant disease, or insects" (p.691). A 3% yield reduction due to minimum tillage usage is selected by Walker for application in his analysis. Crosson and Stout also indicate that in many instances conservation practices will result in yield penalties in production relative to the use of more conventional tillage practices.

In the simulation model the tillage-yield penalty, YP, is defined as (1-yr) where yr is the percentage reduction in crop yield associated with the use of conservation tillage. The yield reduction is given as five percent per year and is assumed to be constant throughout the length of the simulation.

The total supply equation for producers on erosive acreage employing conservation practices is therefore given by

$$S_{2,t} = A_2 (1 + r)^t \, YP \, Q_{t,A} \, . \qquad (15)$$

The total number of acres on which conservation practices are employed is given by A_2. All other terms have been previously defined.

The final supply group is associated with production on erosive acreage using conventional tillage methods. Total output for this group is given by

$$S_{3,t} = A_3 I_{3,t} T_{3,t} Q_{t,A} . \tag{16}$$

where A_3 refers to the total number of erosive acres on which conventional tillage methods are employed. Topsoil depth declines over time; therefore, the functional forms of the yield-topsoil index and the technology-topsoil index are as given in equations (2) and (11). Equation (16) can be rewritten as

$$S_{3,t} = A_3 D_t^b \left(\prod_{i=0}^{t} (1 + r D_i^a) \right) Q_{t,A} . \tag{17}$$

Agricultural output in this group is highly dependent on the relationship between topsoil depth, crop yield, and the effective rate of technology advance.

Total agricultural output from all three producing groups is given by the sum of equations (14), (15), and (17), or

$$S_t = (A_1 (1 + r)^t + A_2 (1 + r)^t YP + A_3 D_t^b (\prod_{i=0}^{t} (1 + r D_i^a))) Q_t^A . \qquad (18)$$

The relative influence of erosion on total output depends on the proportion of total acreage involved in conservation programs ($A_2/(A_2+A_3)$). As the use of conservation practices is increased the effects of erosion on crop yield and technology adoption diminish and total output increases.

Acreage Allocation

Total acreage in the model is equal to 353 million acres, the 1980 USDA estimate of total U.S. harvested acreage (USDA, 1981a). In the 1982 RCA Final Program Report it was estimated that approximately fifty percent of the nation's cropland is eroding at a rate in excess of two tons per acre per year. Therefore, one-half of total acreage, or 176.5 million acres, is considered to be non-erosive while the remaining acreage is assumed to be characterized by a fixed rate of soil loss over time. Division of the erosive acreage among soil conservation and no erosion control characterized the alternative simulation scenarios.

The best case simulation run is defined as the scenario where all farmers producing on erosive acreage participate in conservation programs. In this case, soil conservation programs are assumed to be 100% effective in mitigating soil loss. Conversely, the worst case simulation run is given as the scenario where no conservation tillage practices are implemented on erosive acreage. In alternative scenarios the rate of participation corresponds exactly to the percentage of erosive land on which soil loss is assumed to be completely checked.

Market Demand

In the model the demand for agricultural products is defined in terms of two components; i) domestic demand for U.S. agricultural commodities, and ii) export demand for these products. At any point in time each of the demand components is considered to be a function of a per capita demand relationship and the current population level. The total demand equation for U.S. agricultural commodities is given by the product of the per capita domestic demand relationship and the current domestic population level plus the product of the per capita export demand relationship and the current world population level (minus U.S. population), or

$$D_t = Q_{d,t} (Pop_d (1 + dpg)^t) + Q_{e,t} (Pop_e (1 + epg)^t) \quad (19)$$

where

D_t = total demand for U.S. farm commodities in time period t,

$Q_{d,t}$ = the per capita domestic demand function in time period t,

Pop_d = U.S. population level in time period 0 (in millions),

dpg = domestic population growth rate,

$Q_{e,t}$ = the per capita export demand function in time period t,

Pop_e = world population level (excluding U.S.) in time period 0 (in millions), and

epg = aggregate world population growth rate.

The per capita demand functions are assumed to be of the constant elasticity type, or

$$Q_{d,t} = g\, P_t^{eld} \quad (20)$$

and

$$Q_{e,t} = h\, P_t^{ele} \quad (21)$$

where

P_t = market price in time period t,

eld = the price elasticity of domestic demand,

ele = the price elasticity of export demand, and

g,h = functional parameters of the demand equations.

Demand Elasticities

Studies have shown that estimates of aggregate elasticities for agricultural products tend to be relatively price inelastic in the short run. In the intermediate and long run the elasticities tend to be more price elastic. Tweeten (1979) has estimated intermediate run (3-4 years) food and feed elasticities for both domestic and export demand. The domestic elasticity was estimated to be -0.18 while an elasticity of -1.91 was reported for export demand. In a later study Tweeten (1983) identifies the short run aggregate domestic demand elasticity as -0.20 and the aggregate export demand elasticity as -0.40. Long run estimates in the later study are -0.40 and -1.40 for domestic and export demand, respectively.

The simulation model was run with a domestic demand elasticity of -0.20 and an export demand elasticity of -1.90; these values correspond to those presented in the earlier study by Tweeten. However, the model was also run using the (-0.20, -0.40) elasticity combination.

Domestic and Export Population Levels

Figures for the starting population levels were taken from the 1980 world population estimates of the

U.N. Statistical Office. Initial U.S. population is set at 226.5 million people while the initial export population level is fixed at 4205.5 million. Population is assumed to increase at a fixed rate over the length of the simulation period.[4] Figures for population growth rates were also taken from U.N. estimates. The rate of U.S. population growth was estimated to be 1.0% per year while the export population growth rate was given as 1.7% per annum. These values are incorporated into the simulation model.

Market Equilibrium

Given current levels of population, acreage allocation, and the various yield-related indicies, a supply and demand equilibrium point can be calculated for each time period of the simulation. For the initial period however, it is necessary to exogenously define the equilibrium in order to calculate the functional parameters of the demand relationships (g and h) and to determine the base level of yield (Y_0) in the supply equation. Because the supply and demand curves have been defined in terms of a composite of agricultural goods, price is defined as a numeraire, or index value. For the initial time period the value of the price index is set equal to one. The equilibrium quantity for the beginning time period is assumed to be equal to the 1980 value of aggregate farm income from crop production divided by the value of the price numeraire. The estimated value of 1980 total farm income from crop production is 69,026 million dollars (USDA, 1981a). The initial equilibrium quantity is, therefore, set equal to 69,026 million units of agricultural supply.

During the first period of the simulation the yield-soil depth index and the technology index are both equal to one. Hence, from equation (18) it can be seen that the base level of per acre yield is simply found by dividing the equilibrium quantity supplied, 69026 million units, by the number of acres in production, 353 million. Base yield, Y_0, is therefore equal to 195.643 supply units per acre. It should be noted that the base yield has been calculated by presuming a zero percent yield penalty associated with conservation tillage in the first period.

The functional parameters of the demand relationships are found by means of equations (19)-(21) and the relative values of domestic and export demand. In 1980 the value of all agricultural crop exports was 36,711 million dollars. Because price is equal to one in the first period export demand is set equal to 36,711 million units and domestic demand is given as 32,315 million units.[5] Therefore, from equations (19)-(21) it must hold that, for t=0

$$32{,}315 = g\ 226.5 \quad \text{or} \quad g = 142.671\,, \quad \text{and}$$

$$36{,}711 = h\ 4205.5 \quad \text{or} \quad h = 8.729 \quad .$$

These parameters are substituted into equation (19) to complete the specification of the demand equation.

Solving for Equilibrium Price and Quantity

Equilibrium price and quantity values are calculated over a period of 250 years with output given at 10 year intervals. Equilibrium price is found by equating quantity supplied (equation (18)) with quantity demanded (equation (19)) for each time period, or

$$Y_0 P_t^{els} \left(A_1 (1+r)^t + A_2 (1-yr) (1+r)^t + A_3 D_t^b \left(\prod_{i=0}^{t} (1+rD_i)^a \right) \right) = g P_t^{eld} \left(Pop_d (1+dpg)^t \right) + h P_t^{ele} \left(Pop_e (1+epg)^t \right) \qquad (22)$$

where equations (1), (20), and (21) have been substituted for $Q_{A,t}$, $Q_{d,t}$, and $Q_{e,t}$, respectively. Dividing by P_t^{els} and moving all terms to the left hand side, equation (22) can be rewritten as

$$g P_t^{eld-els} X + h P_t^{ele-els} Y - Z = 0 \tag{23}$$

where

$$X = Pop_d (1+dpg)^t ,$$

$$Y = Pop_e (1+epg)^t , \text{ and}$$

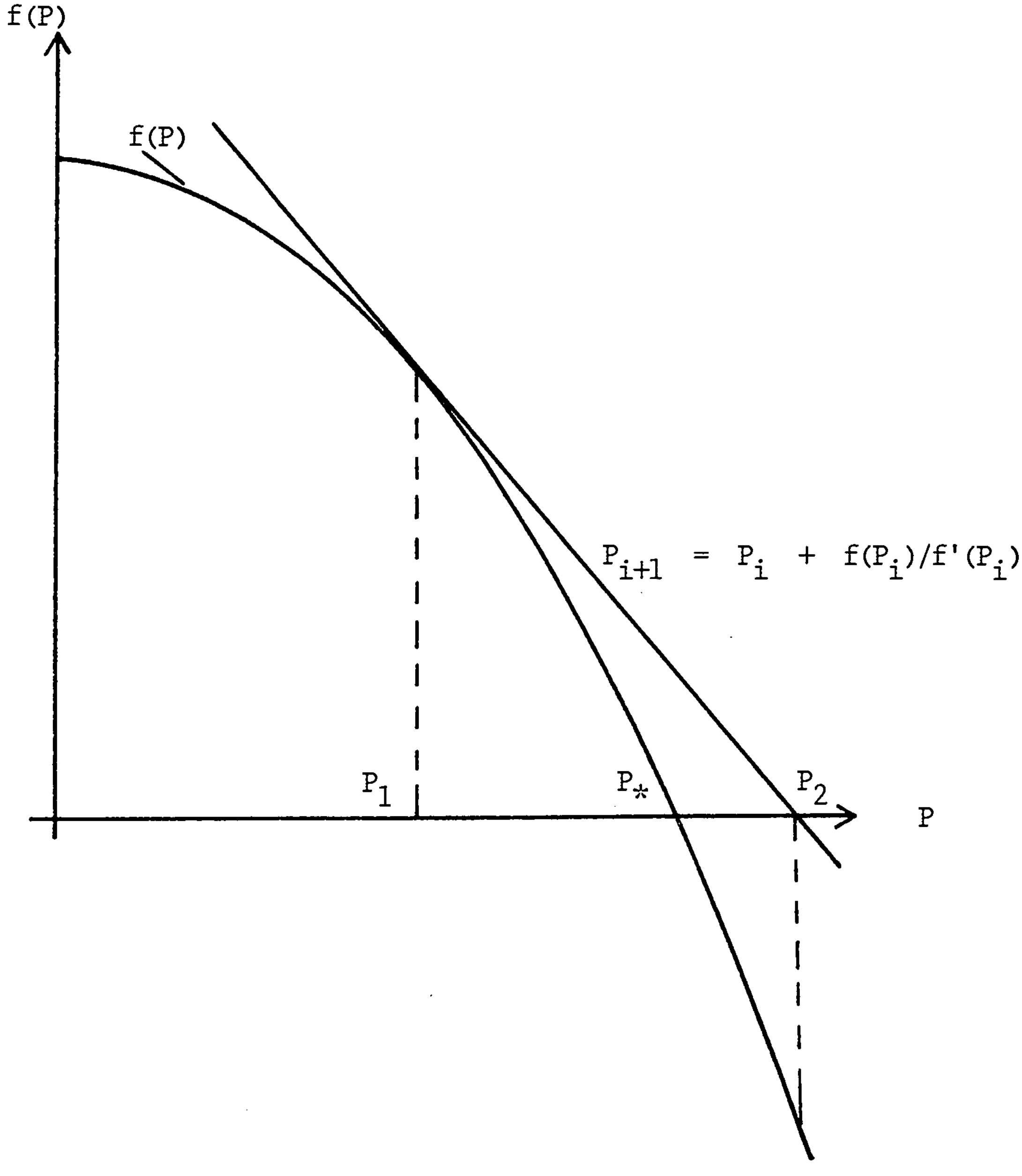
$$Z = Y_0 (A_1 (1+r)^t + A_2 (1+r)^t + A_3 D_t^b (\prod_{i=0}^{t} (1+rD_i^a))).$$

Because the equation above is in the form of a nonlinear function of P_t, the Newton-Raphson iteration technique is used to solve for price (Conte). The methodology essentially solves for P using a first order Taylor's series approximation for the nonlinear function. That is, a linear approximation of the function f(P) in equation (23) is solved for price such that the solution to the linear equation is equal to zero (see Figure 4.4). For the function f(P) the first order Taylor's approximation is given by (Silberberg):

$$P_i = P_{i-1} + f(P_{i-1})/f'(P_{i-1}). \tag{24}$$

where

P_i = the value about which the approximation is evaluated,



Referring to equation (24), the 'initial guess', p_i, is given by P_1 while the 'revised guess', p_{i+1}, is equal to P_2.

Figure 4.4. Linear Approximation Using the Newton-Raphson Method.

P_{i+1} = the value for which the equation for the linear approximation is equal to zero, and

$f'(P_i)$ = the first derivative of the function $f(P)$.

The Newton-Raphson method is an iterative technique that requires a first 'guess' for the value of price that sets the linear equation equal to zero. The new value of price p_{i+1} is estimated; if the estimated value is not equal to the approximated value, the new estimate p_{i+1} becomes the revised 'guess', p_i. The process continues until p_{i+1} and p_i converge.

An iterative solution for equilibrium price is found for each time period. The starting value used for each period's iterative process is given by the prior period's equilibrium price value.

Once equilibrium price has been calculated, total output for each of the three producer groups is found by a straightforward application of the supply equations defined in the previous section. Similarly, total output demanded by each of the consumer groups is found by application of the demand equations above. The equilibrium price and output values are then used to calculate the social welfare measures associated with the particular market conditions outlined in the simulation scenario.

Presentation of Model Results

In order to evaluate the impacts of declining soil productivity on the well-being of current and future generations, measures of consumer and producer surplus are calculated for each time period of the model. The case where 0% participation in conservation programs is assumed to occur is defined as the base scenario. Welfare measures calculated from alternative scenarios (alternative levels of erosion control) are then expressed relative to measures calculated from the base specification. For example, let

$$CS^{*}_{50} = CS_{50} - CS_{0} \tag{25}$$

where

CS^{*}_{50} = the relative consumers' surplus value for the case where soil loss is controlled on 50% of the erosive acreage,

CS_{50} = the actual consumers' surplus value for the case with 50% erosion control, and

CS_{0} = the consumers' surplus value calculated for the base scenario.

The relative consumers' surplus value indicates the maximum willingness to pay on the part of consumers for some level of effective erosion control rather than be left with the case where soil loss is unmitigated on erosive cropland. Similarly, the relative producers' surplus value indicates the maximum willingness to pay on the part of producers for some level of erosion control rather than no control. The surplus values can, of course, be either positive or negative. Welfare measures are calculated for each of five producer and consumer groups included in the model.

Annuity Calculations

To compare the welfare impacts of declining soil productivity over time eight successive generations of producers and consumers are defined. The first five generations are assumed to have twenty year planning horizons while the last three have planning periods of fifty years. A greater number of generations are included during the early part of the simulation period in order to examine more thoroughly the trade-offs in terms of social welfare among 'near' generations relative to those further off in time.

The net present value of the stream of welfare values accruing over the planning period of the generation are calculated. A discount rate of 5% is used in the computation. An annuity value is calculated for each of the discounted producer and consumer welfare streams. The annuity corresponds to a constant annual payment over the time period of the generation. A positive annuity value is interpreted as the constant annual payment producers or consumers would be willing to make to maintain a higher level of erosion control relative to that designated by the base scenario. A negative value for the annuity indicates the minimum constant annual payment producers or consumers would be willing to accept to maintain some level of erosion control. Final results of the simulation are expressed in terms of the annuity measures.

By identifying a series of generations over the time period of the simulation it is possible to determine whether the effects of soil loss on social welfare are similar during different periods of time. If erosion control is not preferred by first and second generation producers, can the same be said of third and fourth generation farmers? If impacts do vary in later generations, what is the relative magnitude of the effects as compared to those that occur in earlier years? Discounting separately the erosion-related welfare changes associated with each generation allows the computationally similar values to be compared, at least from a visual perspective. The annuity values calculated for each generation are discounted back to different time periods and therefore, cannot be explicitly compared.

However, the values represent similar perspectives across generations and can be compared in terms of the direction and relative magnitude of welfare changes.

SIMULATION RESULTS

Results of the simulation are presented in two parts. First, the impacts of declining soil productivty on equilibrium market prices and quantities over time are examined. The basic results are presented for the case where the simulation is run using the initial parameter values. A discussion follows indicating the effect on long-term market equilibrium of changing some of these initial values. Secondly, the long term effects of declining soil productivity on producer and consumer welfare are presented. Again, the basic results are presented using initial values with variations in these results examined using alternative parameter values.

Supply and Demand Over Time

All price changes calculated from the simulation model indicate trends in real prices relative to the base scenario. No mechanism is included to describe the impacts of inflation on market prices over time. Results of the simulation provide some insight to the potential impacts of soil loss on agricultural market conditions over time. Price and quantity equilibrium levels are significantly influenced by the degree to which soil loss is controlled over the length of the simulation as well as by variations in many of the other factor values. Table 4.5 contains a list of the parameters included in the model. The initial value assigned to each parameter is indicated along with any alternative values that incorporated into the simulation. The final column of the table identifies the supply or demand curve directly affected by changes in the parameter value. For example, changes in the erosion rate affect only the supply curve for producers on erosive acreage while a change in the rate of technical progress shifts the supply curves of all three producer groups. The magnitude of the relative shifts in the supply and demand curves determine whether price will increase or decrease over time.

Price Trends Using Initial Values

When the simulation is run using the initial values of all model parameters, market price decreases over time. The relative decline in price however, is determined by the level of erosion control on erosive acreage. In the base scenario where no application of conservation practices is assumed, price declines by 17% after 50 years and by 26% after 100 years. If 100% participation in conservation programs is assumed, price decreases slightly more over time, 18% and 29% after 50 years and 100 years, respectively.

Table 4.5. Parameter Values Used in the Simulation Model[a].

Parameter	Initial Value	Alternative Value	Supply/Demand Curve Affected by Value Change
Domestic Population	226.5 million	none	----
Export Population	4205.5 million	none	----
Total Acreage	353 million	none	----
Nonerosive	176.5 million		
Erosive	176.5 million		
Domestic Pop. Growth Rate	1.00%/ year	none	D_d
Export Pop. Growth Rate	1.70%/ year	3.40%/ year	D_e
Erosion Rate	0.32%/ year	0.71%/ year 0.16%/ year	S_3
Yield Reduction for Conservation Tillage	0.00%	5.00% 3.00%	S_2
Domestic Demand Elasticity	-0.20	-0.40	D_d
Export Demand Elasticity	-1.90	-0.40 -1.40	D_e

Table 4.5 Continued.

Parameter	Initial Value	Alternative Value	Supply/Demand Curve Affected by Value Change
Supply Elasticity	0.20	0.60	S_1, S_2, S_3
Rate of Technical Progress	2%/year	1%/year 4%/year	S_1, S_2, S_3
Yield-Topsoil Depth Elasticity	0.20	0.05	S_3
Technology-Topsoil Depth Elasticity	0.20	0.05	S_3
Discount Rate	5.00%	0.00%	----

[a]

S_1 = Supply curve for producers on nonerosive acreage

S_2 = Supply curve for producers on erosive acreage who participate in conservation activities

S_3 = Supply curve for producers on erosive acreage who do notparticipate in conservation activities

D_d = Domestic demand curve

D_e = Export demand curve

The explanation for this is illustrated using Figure 4.5. The supply curve S represents the case where soil loss is completely mitigated while S' indicates the supply curve with no erosion control. Soil erosion is assumed to adversely affect crop yields; where it is not controlled yields will be lower than in the case where soil loss is checked. Therefore, S will lie to the right of S', leading to a lower relative price (for some level of demand). Intermediate levels of erosion control will result in prices lying in the range between P and P'.

Price Trends with Alternative Parameter Values

When a yield penalty on conservation tillage is included the effect is to shift the supply curve S slightly to the left. Prices continue to decline over time though at a slightly higher level than when no yield penalty is assumed. The supply curve S' is unaffected by the yield penalty since the curve represents the case where erosion is left unmitigated.

Of the alternative simulation scenarios evaluated only a few led to increasing prices over time. Reducing the rate of technical progress to one percent per year causes prices to rise by approximately 16% after 50 years and 37% after 100 years. Increasing the rate of growth in export demand to 3.4 percent per year also causes

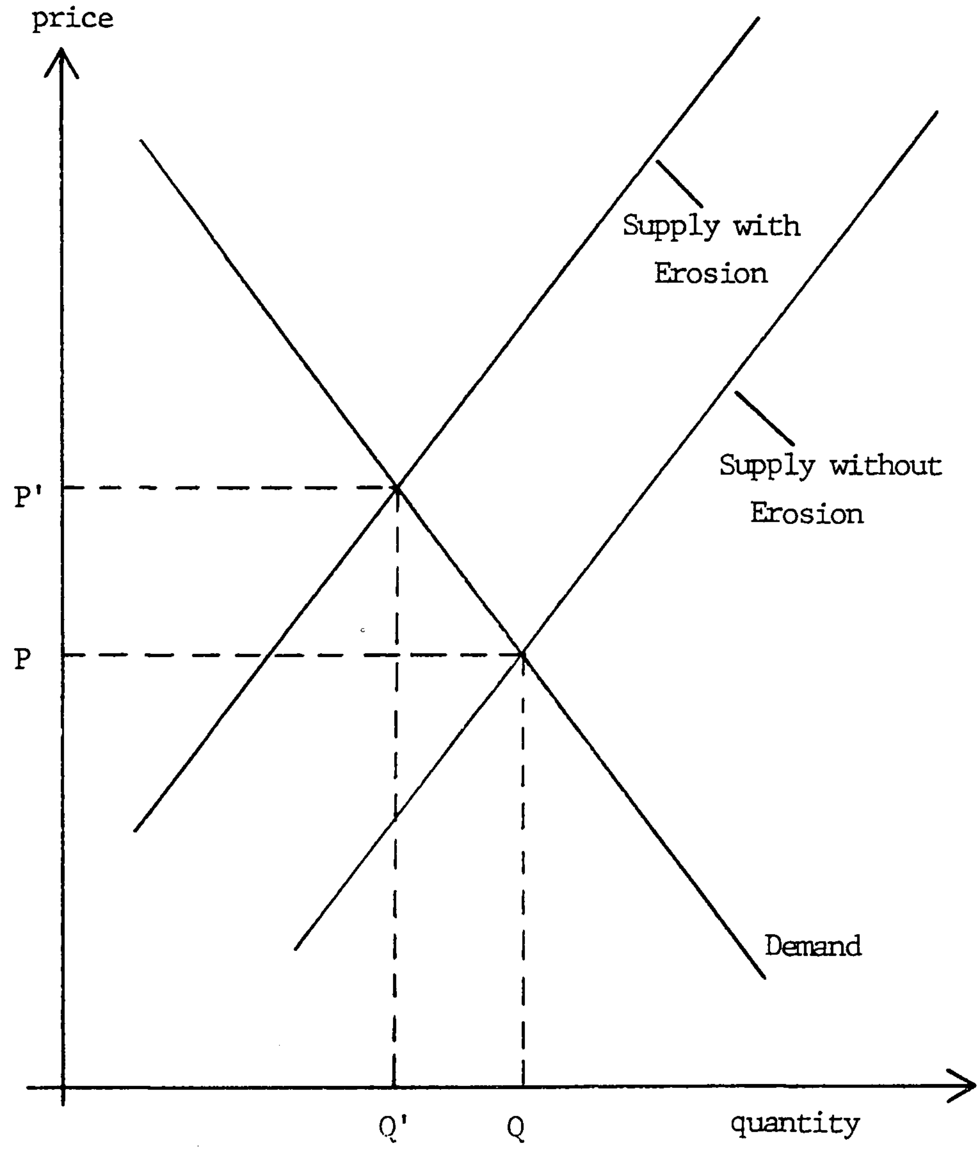
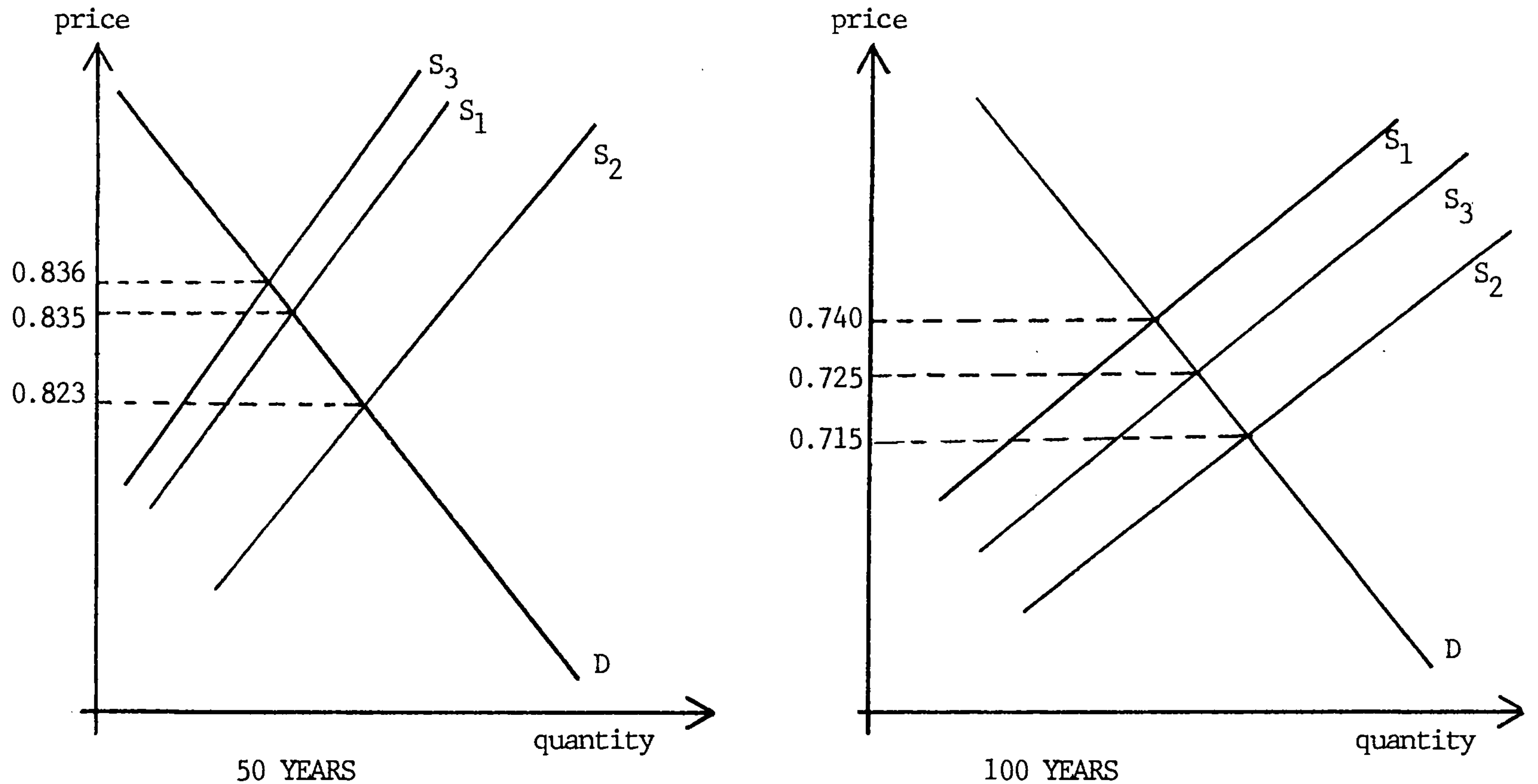


Figure 4.5. Supply Curves With and Without Erosion.

prices to increase rather than decrease over time. In this case prices increase by 20% after 50 years and by over 55% after 100 years. Allowing growth in export demand to increase and the rate of technical progress to decline at the same time leads to the most significant increses in price, doubling after 70 years and increasing by fourteen times at the end of the 250 year simulation. This last scenario represents the only time two parameter values were changed together; in all other cases only a single parameter value is altered.

Examples of movements in the supply and demand curves over time are shown in Figures 4.6-4.9. The relative locations of the curves after 50 and 100 years are indicated. Although the curve shapes are only approximate, their position relative to one another is accurate. The effect of imposing a yield penalty on erosion control is illustrated in Figure 4.6. With no penalty, the supply curve with no erosion lies to the right of the curve with erosion after both 50 and 100 years. This was the case discussed in Figure 4.5 above. When a yield penalty is assumed it can be seen that after 50 years the negative impact of the yield reduction is still greater than the cumulative adverse effects of erosion on soil productivity. The supply curve with erosion, therefore lies to the right of the curve without erosion. After 100 years the effect of soil loss on crop



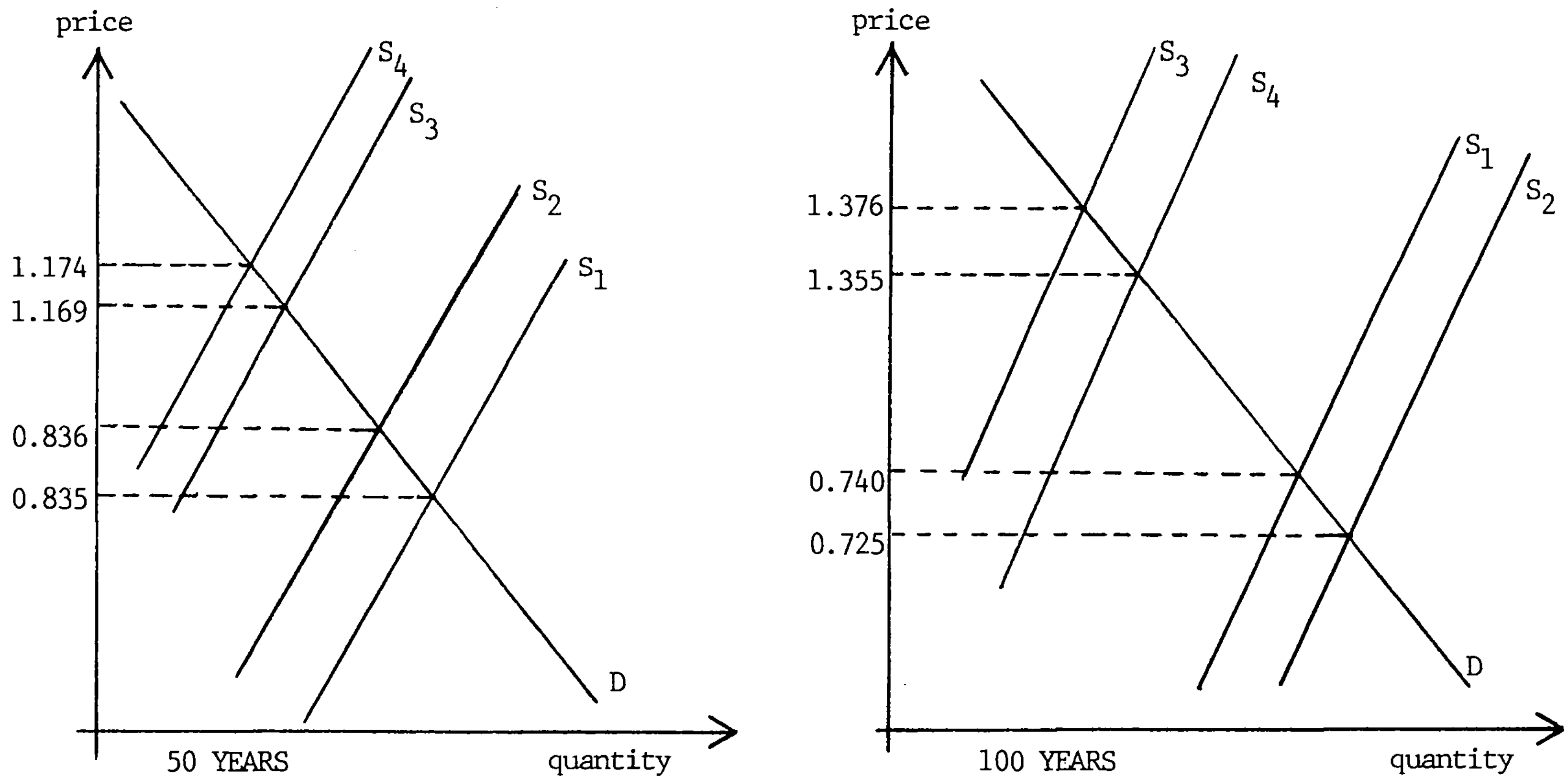
S_1 = Supply with 0% erosion control
S_2 = Supply with 100% erosion control, yield penalty = 0%
S_3 = Supply with 100% erosion control, yield penalty = 5%

Figure 4.6. Supply and Deman Over Time; Yield Penalty = 0%, 5%.

yield is greater than the yield penalty from conservation tillage and the position of the two curves is reversed. The time period during which the negative impacts of erosion exceed the value of the yield penalty is determined by running the simulation. In this example it occurs after approximately 60 years.

In the second example, illustrated in Figure 4.7, the rate of technical progress is lowered from two to one percent per year. As a result the rightward shift of the supply curve over time is slowed, leading to higher prices than those observed under the initial value of the technical progress rate. Because technology is improving at a less rapid rate the adverse effects of erosion are somewhat mollified. Consequently, the supply curve without erosion shifts right of the curve with erosion after approximately 70 years, slightly later than the shift occured in the previous example.

In the final two examples, increasing the export growth rate has the effect of shifting the demand curve to the right (Figure 4.8) while increasing the erosion rate shifts the supply curve with erosion to the left (Figure 4.9). (The supply curve without erosion is unaffected by changes in the erosion rate.) Shifting the demand curve does not alter the time period during which the adverse effects of erosion on soil productivity exceed the negative yield penalty. Therefore, in Figure



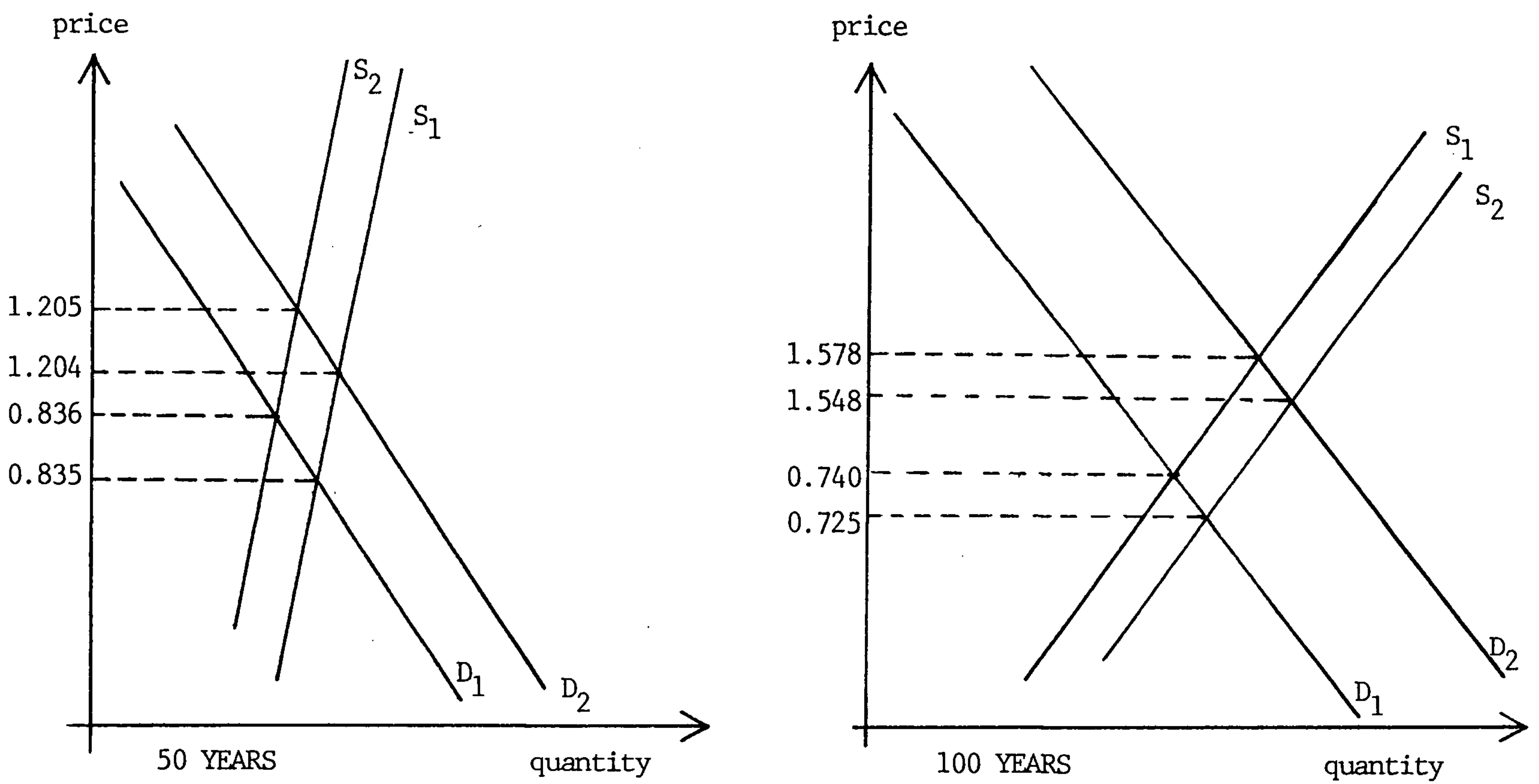
S_1 = Supply with 0% erosion control, technology rate = 2%

S_2 = Supply with 100% erosion control, technology rate = 2%

S_3 = Supply with 0% erosion control, technology rate = 1%

S_4 = Supply with 100% erosion control, technology rate = 1%

Figure 4.7. Supply and Demand Over Time; Rate of Technology = 2%, 1%. (5% yield penalty included)



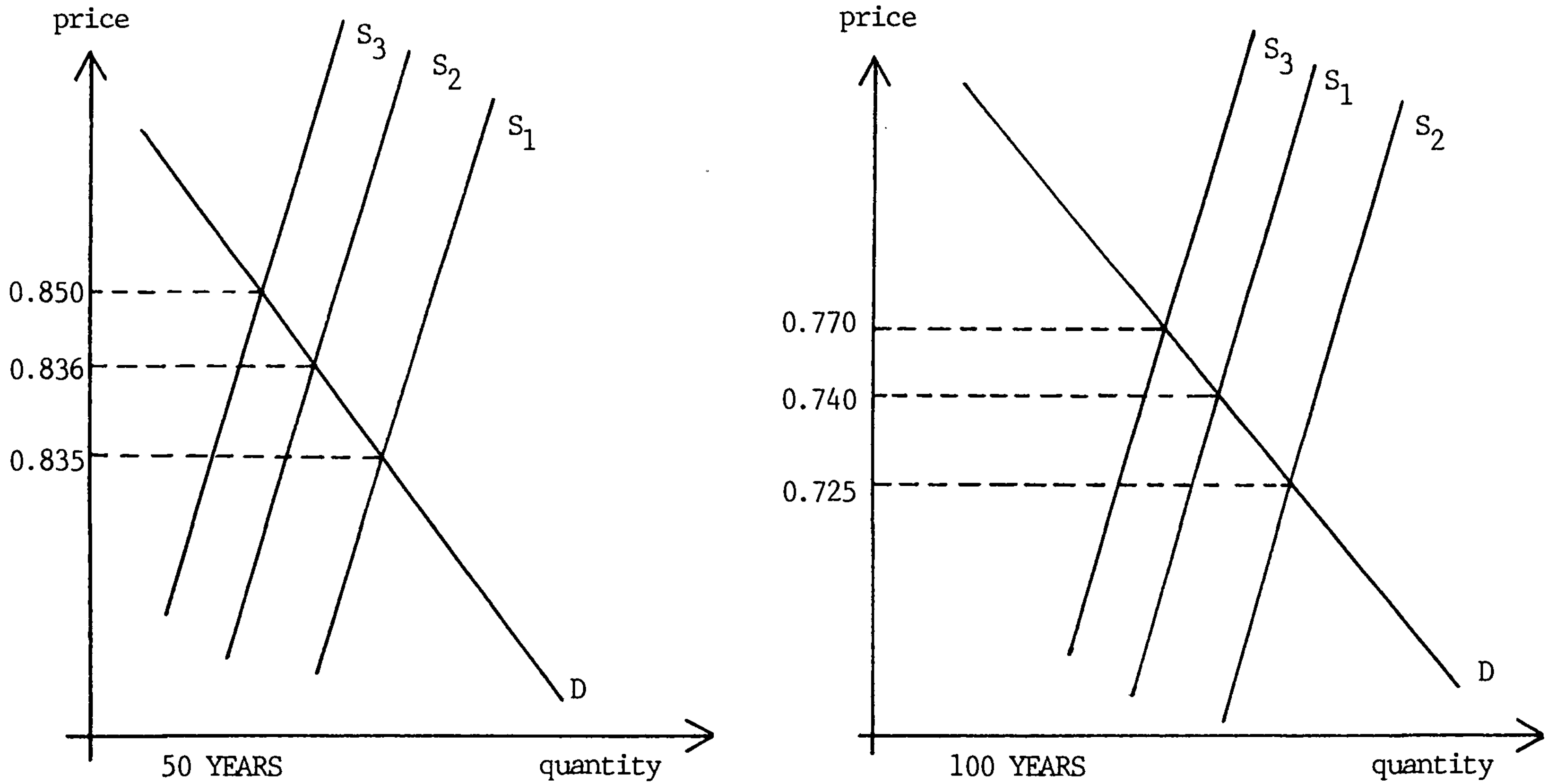
S_1 = Supply with 0% erosion control

S_2 = Supply with 100% erosion control

D_1 = Demand with 1.7% export growth rate

D_2 = Demand with 3.4% export growth rate

Figure 4.8. Supply and Demand Over Time; Export Growth Rate = 1.7%, 3.4%. (5% yield penalty included)



S_1 = Supply with 0% erosion control, erosion rate = 0.32%

S_2 = Supply with 100% erosion control

S_3 = Supply with 0% erosion control, erosion rate = 0.71%

Figure 4.9. Supply and Demand Over Time; Erosion Rate = 0.32%, 0.71%. (5% yield penalty included)

4.8 (as in Figure 4.6) the supply curve without erosion shifts to the right of the curve with erosion after approximately 60 years. When the rate of erosion is made more severe as in Figure 4.9 the adverse impacts on soil productivity accrue more rapidly. In this case the supply curve without erosion shifts to the right of the curve with erosion after only 30 to 40 years.

Long Term Welfare Implications

Economic welfare measures have been calculated to simulate the willingness to pay on the part of producers and consumers for some level of erosion control greater than zero percent. Results show that the measures vary considerably among the five groups for which values were computed. Perhaps more interesting however, is that willingness to pay also varies significantly across generations of the same producer or consumer group. Producers unwilling to pay for erosion control in early years may be willing to make substantial payments in later generations to avoid the adverse impacts of soil loss on crop yields.

The long term social welfare implications of soil erosion are presented first for the initial parameter values used in the simulation model. Results are next presented for alternative values of the parameters directly characterizing the crop yield-topsoil-technology relationship. For example, what happens to simulated willingness to pay among generations of producers and consumers when the rate of erosion increases or when the rate of technological progress declines? The final portion of the section examines the effects on willingness to pay of altering market conditions not directly related to the crop yield-soil loss relationship.

Basic Results--Producers

The long term effects of declining soil productivity on producer welfare will depend not only on the farm level impact of soil erosion on crop yields but also on the aggregate impact of erosion on total agricultural output and market prices. Welfare measures are calculated for producers on non-erosive acreage, for producers on erosive acreage where erosion control practices have been implemented, and for producers on erosive acreage where soil loss is left unmitigated. The distribution of erosive acreage among control and no control directly affects total agricultural output. Producers on nonerosive acreage supply the same level of output regardless of the amount of acreage on which soil loss is mitigated. The income received by this group however, does depend on erosion control as the market price is determined by the level of output supplied by all of the producer groups.

Surplus measures for producers on nonerosive acreage are calculated according to equation (23). Measures computed for the other two groups include a slight modification. Because the alternative scenarios refer to a distribution of erosive acreage different from that under the base scenario, the change in producer surplus is calculated relative to the acreage level in the alternative scenario. For example, if ten percent erosion control is assumed then the change in producer surplus for those producers implementing erosion control is calculated as the difference between the surplus accruing to that group under the alternative scenario and the surplus that accrues to ten percent of the erosive acreage under the base scenario. The value measures the change in welfare associated with implementing erosion control. Similarly, the change in the surplus value for producers on the remaining ninety percent of erosive acreage is calculated as the difference between the producer surplus calculated for erosive acreage with no control under the alternative scenario and ninety percent of the producer surplus value accruing to erosive acreage in the base scenario. This value measures the change in welfare associated with the decision by <u>other</u> producers to mitigate soil loss on erosive land.

Annuity values corresponding to the discounted stream of surplus values for the three producer groups are shown in Table 4.6. The measures are calculated with and without a yield penalty and are presented for three alternative levels of erosion control: ten percent, fifty percent, and one hundred percent.

The long term income effects of soil loss are slightly different for each of the producer groups. Looking first at the case where the yield penalty is assumed to be zero percent, producers on nonerosive acreage are made worse off over time with erosion control because of the effect of soil loss on market price described in Figure 4.5. Erosion control leads to lower market prices relative to the base scenario. Income received by producers on nonerosive acreage is therefore lower. The relative change in the negative surplus values increases as the level of erosion control is increased. Higher levels of erosion control lead to a greater change in market price relative to the base scenario and therefore to a greater negative change in the surplus values.

Producers on erosive acreage are affected not only by the change in relative market price but also by the effect of erosion on crop yields. For producers implementing erosion control, the relative increase in

Table 4.6. Producers' Surplus Per Acre With and Without a Yield Penalty* ($/acre).

0% Yield Penalty

	10% Erosion Control			50% Erosion Control			100% Erosion Control		
	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC
G1	-0.05	1.17	-0.05	-0.27	0.96	-0.26	-0.53	0.69	--
G2	-0.26	5.96	-0.25	-1.27	4.94	-1.24	-2.53	3.68	--
G3	-0.64	15.78	-0.61	-3.19	13.23	-3.04	-6.31	10.11	--
G4	-1.36	34.50	-1.26	-6.68	29.18	-6.20	-13.13	22.73	--
G5	-2.62	108.58	-2.35	-12.84	58.36	-11.54	-25.08	46.13	--
G6	-6.30	169.07	-5.33	-30.61	144.77	-25.87	-59.09	116.29	--
G7	-24.95	674.01	-18.73	-119.04	579.91	-89.39	-225.31	473.64	--
G8	-90.62	2397.80	-58.71	-423.73	2064.70	-274.58	-784.66	1703.76	--

5% Yield Penalty

	10% Erosion Control			50% Erosion Control			100% Erosion Control		
	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC
G1	0.38	-8.09	0.38	1.91	-6.63	1.90	3.88	-4.76	--
G2	0.29	-6.63	0.28	1.45	-5.52	1.42	2.93	-4.12	--
G3	0.07	-1.58	0.06	0.33	-1.32	0.32	0.67	1.00	--
G4	-0.41	10.33	-0.37	-2.01	8.80	-1.86	-4.00	6.91	--
G5	-1.32	34.62	-1.19	-6.54	29.66	-5.87	-12.92	23.60	--
G6	-4.22	113.27	-3.56	-20.69	97.62	-17.44	-40.37	78.93	--
G7	-19.93	537.86	-14.94	-95.92	465.67	-71.95	-183.38	382.58	--
G8	-77.85	2058.24	-50.40	-367.29	1783.27	-237.85	-686.70	1479.84	--

* Gi = Generation i for i = 1,...,8; PS-NE = Producer Surplus for Nonerosive Acreage; PS-EWC = Producer Surplus for Erosive Acreage With Control; PS-ENC = Producer Surplus for Erosive Acreage - No Control

crop yields is sufficient to make up for the decline in market price and they are made better off. With each successive generation the adverse effects of erosion on crop yield become increasingly severe compared to the decline in price and the relative income position of producers on erosive acreage with control improves. The benefits from conservation received by these producers declines however, as the level of erosion control increases. This is because of the downward pressure on market price caused by higher levels of conservation.

The welfare effects of conservation to producers on erosive acreage without control are similar to those that accrue to producers on nonerosive acreage. The same level of output is supplied regardless of the level of erosion control; income effects are therefore determined by changes in market price.

Including a five percent yield penalty in the analysis leads to some interesting and important variations in the results discussed above. As described in Figure 4.6, the effect of the yield penalty is to cause market prices in the alternative scenario to first increase then decrease relative to the base scenario. The period after which relative prices began to decline was generally found to range between forty and seventy years. Because market price initially rises relative to the base scenario, producers on nonerosive acreage are made better with erosion control. The group produces the same level of supply but now receives a higher price. As market prices decline relative to the base scenario, these producers become increasingly worse off with the decision by producers on erosive acreage to mitigate soil loss.

Producers on erosive acreage with control are initially made worse off with the conservation decision. The five percent yield penalty causes output to decline relatively more than prices increase so that income levels accruing under the alternative scenarios are lower than those calculated with the base scenario. After several generations (generally after price has trended downward), the change in producer surplus under the alternative scenario is positive. The negative effect of soil loss on crop yields in the base scenario outweighs the yield penalty associated with conservation and the relatively lower market prices in the alternative scenario.

Producers on erosive acreage without control are made better off or worse off under the alternative scenario according to the effect of the conservation decision on market price. Again, the level of output produced is the same regardless of the degree of erosion control. Relative income levels are therefore determined by fluctuations in price.

Basic Results--Total Social Welfare

To more fully examine the long term implications of declining soil productivity, consumer surpus values are also calculated for each of the simulation scenarios. Because soil loss eventually leads to lower levels of agricultural output and higher market prices, it was expected that consumers would generally be made better off under increasing levels of erosion control relative to the base scenario. Surplus measures are calculated for both domestic and export consumers.

Total social welfare measures the net impact of soil loss on both producers and consumers. Total welfare is given by the sum of the annuity payments to all producers and consumers. A second welfare measure is defined to reflect the change in total domestic welfare; the measure sums together annuity payments to domestic consumers and all producers.

Annuity values calculated for the discounted streams of consumers' surplus and total social welfare are given in Table 4.7. The values are computed for levels of fifty percent, and one hundred percent erosion control and for a yield penalty of zero and five percent. With a zero percent yield penalty all generations of consumers are made better off relative to the base scenario when soil loss is mitigated on some portion of the erosive

Table 4.7. Total Social Welfare Measured With and Without a Yield Penalty* ($1,000,000).

0% Yield Penalty

	50% Erosion Control				100% Erosion Control			
	CS-D	CS-E	TSW-D	TSW-A	CS-D	CS-E	TSW-D	TSW-A
G1	39.16	54.09	53.62	107.72	78.11	108.08	107.10	215.18
G2	164.54	281.09	265.66	546.75	327.16	560.91	529.74	1090.65
G3	349.32	757.74	684.75	1442.49	691.50	1509.40	1362.55	2871.94
G4	615.43	1678.86	1464.28	3143.14	1212.08	3337.30	2907.00	6244.30
G5	992.03	3368.55	2857.09	6225.64	1942.81	6680.59	5658.04	12338.62
G6	1793.17	8381.47	6883.82	15265.28	3478.79	16553.01	13574.35	30127.36
G7	4430.56	33640.97	26707.58	60348.55	8447.10	65949.32	52277.69	118227.00
G8	9914.07	119732.19	93103.83	212836.00	18540.72	232774.61	180761.10	413535.80

5% Yield Penalty

	50% Erosion Control				100% Erosion Control			
	CS-D	CS-E	TSW-D	TSW-A	CS-D	CS-E	TSW-D	TSW-A
G1	-298.25	-371.27	-377.87	-749.14	-603.36	-745.58	-760.31	-1505.89
G2	-193.61	-312.40	-298.84	-611.25	-389.91	-626.39	-599.76	-1226.15
G3	-40.92	-75.06	-69.93	-144.99	-82.19	-150.38	-140.19	-290.57
G4	181.36	504.34	438.71	943.05	360.75	1006.47	875.10	1881.58
G5	501.23	1704.93	1445.78	3150.71	991.43	3394.70	2876.50	6271.20
G6	1197.37	5629.81	4621.55	10251.35	2344.97	11160.45	9151.99	20312.44
G7	3551.37	26910.39	21366.58	48276.98	6831.33	52950.01	41989.61	94939.62
G8	8565.35	103022.67	80122.12	183144.70	16155.18	201012.78	156144.60	357157.40

*Gi = Generation i for i = 1,...,8; CS-D = Domestic Consumers' Surplus; CS-E = Export Consumers' Surplus; TSW-D = Total Domestic Social Welfare; TSW-A = Total Social Welfare acreage. For a given level of demand, the decline in prices associated with erosion control directly affects the value of the consumers' surplus. The higher the level of erosion control, the greater the decline in relative prices and the larger the value of the surplus accruing to consumers.

When the five percent yield penalty is included in the analysis, the effects on consumers are somewhat different. Because the yield penalty causes prices to rise relative to the base scenario during the first forty to seventy years of the simulation, relative consumers' surplus declines over the same period. Consequently, consumers in the first three generations are made worse off with erosion control while later generations are made better off.

Aggregate social welfare, measured with a zero percent yield penalty, increases when erosion is controlled. The negative impact of conservation on producers on nonerosive acreage and on producers on erosive acreage with no control is outweighed by the positive effect on domestic and export consumers and on producers on erosive acreage with control.

Including the five percent yield penalty causes aggregate social welfare to first decrease then increase over time. During the first several generations the combined adverse impacts of erosion control on all consumers and on producers on erosive acreage with control outweigh the benefits that accrue to the other two producer groups. Domestic social welfare also declines over time, increasing relative to the base scenario after three generations.

Alternative Assumptions for the Yield-Soil Loss-Technology Relationship--Erosion Rate

The effect of soil erosion on agricultural output depends critically on the relationship between crop yield, soil loss and technology. Historically, technological advance and the increased usage of other production inputs have been sufficient to mask the adverse impacts of soil erosion on crop yields. Increases in supply have kept pace with increasing levels of both domestic and export demand, causing real prices for agricultural products to fall over time (Crosson and Stout). Although this important relationship between technology, soil loss, and crop yield has been studied extensively in the United States and elsewhere around the world, a great deal of uncertainty still remains regarding the long term impacts of erosion on soil productivity (Brown).

The effects of erosion on crop yields vary according to crop type, soil structure, soil depth, climate, tillage methods, and the application of other production inputs. The effectiveness of technology related yield improvements also depends on the interrrelationship between these factors. To address the uncertainties regarding the effects of soil loss on crop yields, several model parameters describing the yield-soil loss-technology relationship are altered. In particular, the model is rerun with alternative values for the rate of erosion, the rate of the technological progress, the yield-topsoil elasticity, and the topsoil-technology elasticity. In this way , the sensitivity of the basic results to changes in the yield-related parameters can be examined. The five percent yield penalty is included hereafter in all model simulations. Results are generally presented for a fifty percent level of erosion control.

The basic results of the model are generated with an erosion rate of 0.32% per year. This is equivalent to a fifteen percent decline in the topsoil layer after a period of approximately fifty years. To examine the impacts of alternative erosion rates, the model was rerun with soil loss values of 0.71% per year (a cumulative loss of thirty percent in fifty years) and 0.16% per year (a cumulative loss of seven and one half percent in fifty years). The reslulting simulated impacts on producer surplus per acre are shown in Table 4.8. Again, the results are distributed among producer groups and across

Table 4.8. Producers' Surplus Per Acre Under Alternative Rates of Erosion* ($/acre). (Measured with 50% erosion control)

	Erosion Rate = 0.16%			Erosion Rate = 0.32%			Erosion Rate = 0.71%		
	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC
G1	2.04	-7.10	2.04	1.91	-6.63	1.90	1.60	-5.47	1.58
G2	2.08	-7.97	2.05	1.45	-5.52	1.42	-0.08	0.39	-0.07
G3	1.90	-7.86	1.86	0.33	-1.32	0.32	-3.54	14.28	-3.17
G4	1.27	-5.55	1.22	-2.01	8.80	-1.86	-10.14	42.54	-8.58
G5	-0.23	1.11	-0.21	-6.54	29.66	-5.87	-22.16	95.50	-17.49
G6	-5.64	27.56	-5.15	-20.69	97.62	-17.44	-57.54	253.27	-39.81
G7	-37.49	191.01	-32.38	-95.92	465.67	-71.95	-233.96	1031.90	-126.03
G8	-160.74	832.73	-128.83	-367.29	1783.27	-237.85	-824.59	3562.92	-326.56

Results include a 5% yield penalty

*See footnote for Table 4.6

generations.

By increasing the rate of erosion, the effects of soil loss on crop yield are magnified in both the yield-soil depth relationship and in the soil depth-technology relationship. A higher rate of soil loss leads to a lower level of aggregate output, causing higher market prices relative to similar scenarios with the initial model parameters. Decreasing the rate of erosion slows down the effects of soil loss on aggregate output, diminishing somewhat the adverse impacts found in the basic results.

As in the basic results, the five percent yield penalty causes market price to first increase then decrease relative to the base scenario.[6] Increasing the erosion rate causes the adverse impacts of erosion on aggregate output to outweigh the negative effect of the yield penalty much sooner than in the previous analysis. Therefore, the positive effect of higher prices on income received by producers on nonerosive acreage and producers on erosive acreage without control accrues to fewer generations. The results in Table 4.8 indicate that the declining real prices associated with erosion control adversely affect relative income by the second generation. The higher rate of erosion also shortens the time period over which producers on erosive acreage with control are adversely affected by the yield penalty.

With the relative decline in market price in the alternative scenario hastened by the higher rate of erosion, the benefits of improved crop yields are obtained by an earlier generation than in the basic analysis.

A lower rate of erosion mitigates the effects of soil loss on crop yield. A longer period of time is therefore required before the decline in aggregate output caused by erosion is greater than the decline in ouptut caused by the yield penalty. Consequently, market price in the alternative scenarios exceeds market price in the base scenario over a greater number of generations than in the basic analysis. The benefits from conservation that accrue to producers on nonerosive acreage and erosive acreage without control therefore occur over a greater number of generations.

Alternative Assumptions for the Yield-Soil Loss-Technology Relationship--Technology Rate

The simulated impacts from altering the technical progress rate are similar to those that result from changing the rate of erosion. Increasing the technology rate causes the yield impacts from erosion to be magnified while lowering the technology rate tends to lessen the adverse impacts. A multiplicative relationship is defined between the rate of erosion and the maximum rate of technological yield improvement (equation (7)). For a given rate of soil loss, the percentage change in yield between the alternative and base scenarios will be greater as the maximum rate of technological progress is increased.

Results derived from the simulation analysis using alternative technology rates are presented in Table 4.9. When the technology rate is increased to four percent per year the distribution of impacts to producers on erosive acreage with control is magnified somewhat relative to the basic analysis. The more rapid accumulation of technology related yield improvements allows the adverse effects of the yield penalty to be overcome in an earlier time period. The simulated benefits of a fifty percent level of erosion control therefore becomes available by the second rather than the third generation.

The distribution of impacts resulting from a higher rate of technology advance among the other producer groups is similar to that in the basic analysis. Producers on nonerosive acreage and erosive acreage without control benefit initially from conservation because of the higher prices that result relative to the base scenario. As overall output increases and relative prices fall however, they become worse off. With the higher rate of technology the magnitude of the benefits

Table 4.9. Producers' Surplus Per Acre Under Alternative Rates of Technological Progress* ($/acre). (Measured with 50% erosion control)

	Technology Rate = 1%			Technology Rate = 2%			Technology Rate = 4%		
	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC
G1	1.97	-6.58	1.96	1.91	-6.63	1.90	1.84	-6.76	1.83
G2	1.70	-5.72	1.66	1.45	-5.52	1.42	1.16	-5.12	1.13
G3	0.91	-3.09	0.88	0.33	-1.32	0.32	-0.80	4.12	-0.74
G4	-0.73	2.49	-0.68	-2.01	8.80	-1.86	-6.22	32.74	-5.58
G5	-3.73	12.81	-3.43	-6.54	29.66	-5.87	-19.84	106.35	-16.94
G6	-12.13	41.84	-10.71	-20.69	97.62	-17.44	-80.93	432.31	-62.00
G7	-49.65	171.55	-40.72	-95.92	465.67	-71.95	-590.51	3036.87	-369.88
G8	-157.67	542.70	-118.24	-367.29	1783.27	-237.85	-3574.71	17390.55	-1728.03

Results include a 5% yield penalty

*See footnote for Table 4.6

is decreased while the magnitude of the costs (the negative change in income) is increased. This results because the relative increase in price is lower than that in the basic analysis; the rapid rate of technology increase diminishes the adverse effects of the yield penalty on aggregate supply. Similarly, the relative decline in prices is more significant with the higher technology rate because of the accelerated rightward shift of the aggregate supply curve; the result is a greater divergence in income between the alternative and base scenarios.

Decreasing the rate of technical progress to an annual rate of one percent reduces the magnitude of the adverse effects of conservation to producers on nonerosive acreage and erosive acreage without control while increasing slightly the magnitude of the positive impacts that occur in early generations. The impact of the lower technology rate on relative prices parallels that described in the paragraph above. The initital increase in relative price is slightly greater and extends slightly longer than that which occurs in the basic analysis, the decrease in relative price is slightly less.

For those producers on erosive land where erosion control has been implemented, a lower rate of technical progress modifies the welfare changes that occured in the basic analysis. The relative yield improvements associated with erosion control are less, cauisng benefits in later generations to decline.

Alternative Assumptions for the Yield-Soil Loss-Technology Relationship--Elasticities

Modifying the yield-soil depth and soil depth-technology elasticities had similar impacts on the basic results. In separate runs, the elasticities were decreased from 0.2 to 0.05, diminishing the impact of soil loss on yield and the effective rate of technical progress (recall Figures 4.1 and 4.2). Simulated impacts on producer welfare are shown in Table 4.10. The initial positive benefits from conservation received by producers on nonerosive land are somewhat magnified while the adverse effects to later generations are diminished. As before, these impacts are directly related to the simulated price trends under the alternative specifications. Although prices for all scenarios in the alternative analysis are slightly lower than their counterparts in the basic analysis, the relative price changes between scenarios are slightly different.

The simulated benefits to producers on erosive acreage without control also increase when the elasticity values are lowered. Because these producers provide the same level of output regardless of the level of erosion

Table 4.10. Producers' Surplus Per Acre For Alternative Yield Elasticities* ($/acre).
(Measured with 50% erosion control)

	Yield-Soil Depth = 0.05 Technology-Soil Depth = 0.20			Yield-Soil Depth = 0.20 Technology-Soil Depth = 0.20			Yield-Soil Depth = 0.20 Technology-Soil Depth = 0.05		
	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC
G1	2.08	-7.25	2.08	1.91	-6.63	1.90	1.94	-6.72	1.93
G2	2.17	-8.34	2.15	1.45	-5.52	1.42	1.67	-6.38	1.64
G3	1.91	-7.90	1.87	0.33	-1.32	0.32	1.11	-4.54	1.07
G4	0.93	-4.03	0.89	-2.01	8.80	-1.86	-0.02	0.13	-0.02
G5	-1.45	6.71	-1.35	-6.54	29.66	-5.87	-2.14	9.85	-1.99
G6	-10.12	48.91	-9.01	-20.69	97.62	-17.44	-8.57	41.50	-7.73
G7	-61.93	308.95	-50.34	-95.92	465.67	-71.95	-41.70	211.68	-35.71
G8	-264.76	1325.69	-190.39	-367.29	1783.27	-237.85	-157.85	818.64	-127.03

Results include a 5% yield penalty

*See footnote for Table 4.6

control, the change in producer surplus is directly is directly related to the relative price trends under the various scenarios.

Producers on erosive acreage with control are worse off with the lower elasticity assumptions. Although the price trend is favorable, the relative improvement in yield is no longer as great. The net effect is to increase the magnitude of the initial adverse impacts of the conservation decision and decrease the magnitude of the positive effects in later generations.

Over the first one hundred years lowering the yield elasticity has a more significant impact on yields than lowering the technology elasticity. From Table 4.10 it can be seen that for the the first five generations lowering the yield elasticity has a greater impact on producer welfare than lowering the technology elasticity. After the fifth generation however, the lower technology elasticity has a more significant effect on crop yield, leading to a greater relative effect on producer welfare. Within the constraints of this analysis, the long term implications of the uncertainties regarding the yield-soil loss and yield-technology relationships are potentially greater for the latter case.

Alternative Market Assumptions

In addition to the parameters describing the yield-soil loss-technology relationship, several other important relationships in the model were varied in order to simulate the long term impacts of erosion under alternative economic conditions. Much of the concern regarding the long term productivity impacts of ersoion is linked to the uncertainty with respect to the the economic environment that will exist in the future. Not only are the parameters of the agricultural supply relationships somewhat unclear, but also the conditions that will describe future demand--paricularly those that will describe future export requirements.

In order to simulate some aspects uncertainty with repect to economic conditions, several parameter values were adjusted and the corresponding results were compared to those derived from the basic analysis. The varibles examined were the export demand elasticity, the rate of growth of export demand, and the discount rate. Results of the analysis are described below.

The basic runs of the simulation were made using an export demand elasticity of -1.90, the value estimated by Tweeten (1979). In a later study the aggregate export elasticity was estimated as -0.40, a significantly more inelastic value than that from the prior study (Tweeten, 1983). The sensitivity of the simulated results to the presence of an inelastic rather than elastic export demand was examined by evaluating the model with the -0.40 elasticity estimate. The domestic demand elasticity was held constant (-0.20). By decreasing the absolute value of the export demand elasticity the absolute value of the aggregate demand elasticity is also decreased. Similar movements of the aggregate supply curve along the demand curve result therefore, in greater price changes than those that occured in the basic analysis.

Results of the simulation are shown in Table 4.11. The magnitude of the positive impacts to producers and consumers are greater while the negative effects are diminished. Because the demand curve is more inelastic, price increases caused by the effect of the tillage penalty on yield are greater. The positive benefits from conservation that accrue to early generations of producers on nonerosive acreage and producers on erosive acreage with no control are therefore magnified. Consumers also are more adversely affected by the greater relative increase in price.

Only the relative position of producers on erosive acreage with control is improved in early generations. The higher prices that now occur with erosion control help to diminish, to a greater extent, the initial adverse impacts of the tillage penalty on yield. In

Table 4.11. Producers' Surplus Per Acre and Total Social Welfare for Alternative Export Elasticities*
($/acre and $1,000,000).
(Measured with 50% erosion control)

	Export Elasticity = -1.9			Export Elasticity = -0.4		
	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC
G1	1.91	-6.63	1.90	4.77	-3.39	4.75
G2	1.45	-5.52	1.42	3.28	-2.42	3.21
G3	0.33	-1.32	0.32	0.72	-0.54	0.69
G4	-2.01	8.80	-1.86	-3.52	2.77	-3.26
G5	-6.54	29.66	-5.87	-10.33	8.31	-9.27
G6	-20.69	97.62	-17.44	-27.60	22.81	-23.32
G7	-95.92	465.67	-71.95	-100.53	85.28	-75.60
G8	-367.29	1783.27	-237.85	-309.30	265.28	-200.87

	Export Elasticity = -1.9				Export Elasticity = -0.4			
	CS-D	CS-E	TSW-D	TSW-A	CS-D	CS-E	TSW-D	TSW-A
G1	-298.25	-371.27	-377.87	-749.14	-758.13	-912.08	203.33	-708.75
G2	-193.61	-312.40	-298.84	-611.25	-469.79	-672.36	179.58	-492.78
G3	-40.92	-75.06	-69.93	-144.99	-96.38	-151.60	43.67	-107.93
G4	181.36	504.34	438.71	943.05	383.42	816.38	-280.38	536.00
G5	501.23	1704.93	1445.78	3150.71	998.11	2485.11	-909.85	1575.26
G6	1197.57	5629.81	4621.55	10251.35	2162.91	6951.64	-2754.84	4196.79
G7	3551.37	26910.29	21366.58	48276.98	5516.10	26423.74	-11373.10	15050.56
G8	8565.35	103022.67	80122.12	183144.70	11562.09	82398.87	-37345.40	45053.46

Results include a 5% yield penalty

*See footnotes for Tables 4.6 and 4.7

later generations however, these producers become worse off relative to the basic analysis. The relative deline in market price that results from the decision to control soil loss is significantly greater in the alternative analysis, implying that a longer period of time is required before the increase in yield associated with conservation outweighs the negative income effect of lower price.

Another important factor influencing future demand for agricultural commodities is the rate of growth in export demand. Growing concern has been expressed in recent years regarding the impact of increasing export demand on the long-term productivity of the nation's agricultural land base (Heady and Short, Brubaker and Castle, and Cory and Timmons).[7] It is argued that the higher levels of export demand in the last decade and a half led to both a more intensive use of the soil base already in production during this period and to an increase in the amount of land placed into production, particularly grain production. It is expected that continued strong levels of export demand will place long term pressure on the soil resource, indicating that uncertainty with regard to the levels of export demand that will prevail in the future will play an importnat role in determining the long term welfare implications of soil erosion to agricultural producers and consumers.

The simulation model, as specified, is unable to examine a causal relationship between growth in export demand and an accelerated rate of erosion or an increase in the number of erosive acres over the time period of analysis. Instead, changes in export demand are translated directly into changes in relative price that in turn determine whether producers and consumers are made better off or worse off with increasing levels of erosion control. The simulated effects of export growth on price trends over time were discussed in the previous section (see Figure 4.8). Because the increase in export demand results in higher equilibrium prices for agricultural commodities, the 'cost' (negative or positive) of soil erosion is increased.

Doubling the export growth rate to 3.4% per year causes the price changes among the base and alternative scenarios to increase relative to the basic analysis. The relative benefits to producers from increased levels of erosion control are therefore magnified. Increasing the rate of export growth does not however, alter the simulated distribution of the positive and negative benefits of erosion control among generations of producers. Simulated changes in producer welfare are shown in Table 4.12.

It has been argued in this paper and elsewhere that one of the primary reasons the effects of soil erosion on

Table 4.12. Producers' Surplus Per Acre for Alternative Export Growth Scenarios* ($/acre).
(Measured with 50% erosion control)

	Exprt Growth Rate = 1.7%			Export Growth Rate = 3.4%			Technology Rate = 1% Export Growth Rate = 3.4%		
	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC
G1	1.91	-6.63	1.90	2.02	-7.11	2.01	2.08	-7.05	2.07
G2	1.45	-5.52	1.42	1.77	-7.02	1.73	2.04	-7.25	2.00
G3	0.33	-1.32	0.32	0.44	-1.80	0.42	1.24	-4.56	1.20
G4	-2.01	8.80	-1.86	-3.64	16.96	-3.37	-1.24	4.83	-1.16
G5	-6.54	29.66	-5.87	-14.08	67.96	-12.62	-7.16	28.43	-6.58
G6	-20.69	97.62	-17.44	-60.93	305.30	-51.13	-30.02	123.78	-26.44
G7	-95.92	465.67	-71.95	-454.65	2316.91	-339.06	-183.52	787.31	-150.07
G8	-367.29	1783.27	-237.85	-2835.84	14279.54	-1823.52	-894.42	3930.12	-668.26

Results include a 5% yield penalty

*See footnote for Table 4.6

crop yield have not been easily observable is that technology related yield improvements have been associated with other production inputs. In the current model lower rates of technology advance were found to decrease the relative benefits of soil conservation to those producers implementing erosion control while higher rates were found to increase the benefits. When a lower rate of technological progress (1%) was combined with the accelerated rate of export growth the net effect was to diminish the benefits of the conservation decision relative to the basic analysis (see Table 4.12). The adverse effects of the lower rate of technology more than outweighed the positive effects of increased export demand. Uncertainty with respect to future rates of technological growth rather than uncertainty with regard to long term export market conditions has relatively greater impact on simulated changes in producer welfare over the time period of the analysis, at least for producers on erosive acreage. Producers on nonerosive acreage are relatively more influenced by changes in export demand.

The final market assumption to be altered is the level of the discount rate used in calculating the present value of the producer and consumer welfare measures accruing over the time period of a generation. The rate is changed from 5% to 0%, implying that welfare measures in each time period are weighted equally. The discount rate used in calculating the annuity payments was also change to 0%. Where the welfare payments for a generation are fairly constant over time, the effect of lowering the discount rate is to decrease the annuity payment the generation is willing to make (or receive). If the surplus measures increase or decrease significantly over time then the annuity payment is increased (see Table 4.13).[8]

When the discount rate is assumed to be zero, the annuity payments can be directly compared across generations. Farmers in one generation may be willing to pay those in another generation to implement erosion control if the positive benefits to the later producers more than offset the negative income effects experienced by earlier producers. For example, in Table 4.13 fourth generation producers on erosive acreage with control would be able to compensate producers in the second and third generations for the adverse effects of their conservation decision and still remain better off than if soil erosion was left unmitigated. Consumers in later generations would also be willing to compensate those in earlier generations for the initial adverse effects of conservation on market price. The example serves to

Table 4.13. Producers' Surplus Per Acre and Total Social Welfare for Alternative Discount Rates* ($/acre and $1,000,000).
(Measured with 50% erosion control)

	Discount Rate = 5%			Discount Rate = 0%		
	PS-NE	PS-EWC	PS-ENC	PS-NE	PS-EWC	PS-ENC
G1	1.91	-6.63	1.90	1.80	-6.29	1.79
G2	1.45	-5.52	1.42	1.33	-5.07	1.30
G3	0.33	-1.32	0.32	0.19	-0.73	0.19
G4	-2.01	8.80	-1.86	-2.17	9.53	-2.00
G5	-6.54	29.66	-5.87	-6.71	30.51	-6.00
G6	-20.69	97.62	-17.44	-27.29	129.86	-22.52
G7	-95.92	465.27	-71.95	-119.73	582.36	-87.42
G8	-367.29	1783.27	-237.85	-451.88	2188.60	-282.92

	Discount Rate = 5%				Discount Rate = 0%			
	CS-D	CS-E	TSW-D	TSW-A	CS-D	CS-E	TSW-D	TSW-A
G1	-298.25	-371.27	-377.87	-749.14	-277.32	-352.86	-357.09	-709.95
G2	-193.61	-312.40	-298.84	-611.25	-174.61	-287.03	-273.48	-560.58
G3	-116.92	-75.06	-69.93	-144.99	-24.68	-41.57	-39.40	-80.97
G4	181.36	504.34	438.71	943.05	193.42	546.32	474.22	1020.54
G5	501.23	1704.93	1445.71	3150.71	506.93	1753.92	1484.42	3238.33
G6	1197.57	5629.81	4621.55	10251.35	1445.62	7494.18	6102.50	13596.67
G7	3551.37	26910.39	21366.58	48276.98	4046.78	33657.58	26592.11	60249.68
G8	8565.35	103022.67	80122.12	183144.70	9576.24	126404.14	97995.18	224399.30

Results include a 5% yield penalty

*See footnotes for Tables 4.6 and 4.7

illustrate the fact that the absolutue magnitude of the simualted impacts of soil erosion on producer and consumer welfare increases over time.

SUMMARY AND CONCLUSIONS

The decline in agricultural land productivity caused by soil erosion is a problem that has both private and public ramifications. When viewed from the individual perspective, soil erosion directly influences harvestable yields though may not be seen to affect market price. Except on soils where erosion is particularly severe, the relative decline in productivity may not become evident for many years. In many instances the continued development of technology related yield improvements in other production inputs will completely mask the adverse effects of soil loss on crop yields. Because the effects of erosion become significant only after a relatively long period of time, the planning horizon of the individual producer may not be sufficient to provide the incentive to implement soil conserving practices.

The public concern with declining soil productivity is directly related to the long term effect on food costs. Although the historical trend in real price has been downward, it is not known whether the future pace of technology-related yield improvements will be sufficient to maintain the pattern over the long term. Uncertainty with respect to the precise nature of the yield-soil loss relationship and the increased pressure of export demand on the soil and water resource base have magnified concerns over the long term productivity consequences of soil erosion. Because the public planning horizon is much longer than that of the individual producer, the benefits of mitigating soil loss may signal the need for conservation programs even though the incentive is absent at the farm level.

Erosion causes the aggregate supply curve to shift upward relative to conditions of no soil loss, leading to higher equilibrium price levels. The extent to which relative price is affected depends on the functional parameters of the supply and demand relationships and the amount of acreage on which soil erosion is assumed to occur. Uncertainties regarding the precise nature of the yield-soil loss-technology relationship and the strength of future export demand make it difficult to determine the long term influence of soil erosion on the price and quantity of agricultural commodities available in the market place. The degree to which market price is affected by soil erosion directly influences whether producers and consumers are made better or worse off by conservation efforts.

While consumers are clearly made worse off with higher food costs, the effects of erosion on producer welfare are not as clear cut. Because soil loss leads to higher relative commodity prices, producers for whom yield levels are unaffected by erosion are able to achieve higher income levels, making them better off with the presence of soil loss on acreage other than their own. The wider the extent of soil loss, the greater the increase in their relative income levels. Producers on erosive acreage are made better off or worse with soil conservation according to whether the the value of the productivity loss is greater than or less than the cost of erosion control. It is for this group of producers that assumptions regarding the yield-soil loss-technology relationship and the functional parameters of the supply and demand equations have a significant effect on determining the net change in producer welfare that results from conservation efforts.

The soil erosion simulation model developed in this paper has been used to examine the simulated distribution of long term welfare impacts resulting from alternative levels of erosion control. Several important conclusions can be drawn from the analysis. First, the effect of soil erosion on market price and the subsequent impacts on producer and consumer welfare depends critically on the cost of erosion control. In the simulation model, the cost of conservation was measured by a yield penalty, assumed to be constant over the time period of analysis. If soil conservation is achieved at no cost then market price falls as erosion is controlled. Consumers are made better off with lower prices though producers on nonerosive acreage and erosive acreage without control are made worse off by lower relative income levels. Although market price falls with erosion control, the improvement in relative yield leaves producers on erosive acreage with control better off relative to income levels achieved without conservation.

When erosion control is assumed to be achieved at some cost to those implementing conservation, the distribution of impacts is significantly altered. In early generations the yield related cost of erosion control exceeds the productivity gain and market price rises rather than falls. The resulting welfare impacts are the inverse of those described immediately above. Producers on erosive acreage are made worse off with the conservation decision, a private incentive to control erosion would seem not to exist. Only after a period of several generations does the erosion-related productivity decline become significant enough to outweigh the conservation yield penalty, leaving consumers and producers on erosive acreage with control better off with the conservation decision. Because the effects of erosion are magnified over time, the benefits from conservation, once achieved, increase with successive generations.

Another important conclusion that can be drawn from the simulation analysis is that the distribution of erosion-related welfare changes are sensitive to the characterization of the yield-soil loss-technology relationship, particularly to assumptions regarding the future rate of technological progress. It might be expected that a decline in the rate of technology related yield improvements would encourage conservation activities because erosion related productivity declines would become more apparant. However, in the simulation analysis lower rates of technological progress decrease rather than increase the benefits from conservation while an accelerated rate of technology increase would seem to encourage erosion control. Because of the hypothesized relationship between soil erosion and the effective rate of technology increase, an accelerated rate of technological progress magnifies the effect of erosion on yields, causing the divergence between the welfare benefits that accrue with and without erosion to become more significant.

The final observation to be drawn from the simulation anlaysis is that the distribution of erosion related welfare changes is also affected to a significant degree by market demand relationships. Fluctuations in demand lead to price movements that in turn affect the economic value of the productivity loss caused by erosion. An increase in the export growth rate shifts market demand outward, leading to higher relative prices.

With higher prices, the economic value of the productivity loss is increased, causing the benefits from erosion control to increase. Altering the price elasticity of demand changes the magnitude of price changes caused by movements of the supply curve along the demand curve. This also influences the economic value of the productivity loss. Because of the nature of the relationships described in the model, investigation of demand related influences on the benefits of erosion control was somewhat limited.

Some Final Thoughts

To more accurately reflect the effect of erosion control on producer and consumer welfare, several parameters of the simulation model could be changed. First, although eight generations of producers are defined, the decision to control erosion can be made only by the first generation. The subsequent changes in welfare are measured with erosion damage accruing from the first period. The model could be altered to allow the time of the conservation decision to vary. That is, erosion control would occur in that generation where the value of the productivity loss exceeds the cost of erosion control. Results from this analysis could be compared to those from the current analysis, where the decision to control erosion is made in the first generation.

Second, the rate of technological progress (once selected) is assumed to be constant over the time period of analysis. The parameter could be allowed to vary over time in order to determine the impacts of an accelerated or declining rate of technological growth. The functional relationship between technology and erosion could also be altered to allow for land neutral and land substituting technical change, in addition to land complementary change.

Third, a variety of erosion rates could be included simultaneously, each corresponding to percentage of erosive acreage. Measures of welfare change would then be distributed across a greater number of producer groups, allowing the potential benefits of erosion control to be investigated in greater detail. Finally, the amount of erosive acreage could be allowed to vary over the time period of analysis, perhaps responding to a price signal that would bring additional acreage into production.

ENDNOTES

1. The list of yield and soil depth data used in the regression analysis can be found in Appendix B.
2. Data for total grain production, total harvested area in grains, and the index of aggregate farm output can be found in Agricultural Statistics, United States Dept. of Agriculture, Washington, D.C., 1981 (Tables 1, 625, and 631), 1977 (Tables 1 and 612), and 1970 (Table 665).
3. It is recognized that the rate of technical increase empirically estimated is actually the °effective' rate of increase since it includes, implicitly, the effects of erosion on farm output. However, there being no better alternative estimate of the pure rate of technical advance, the annual rate of two percent is used as a best approximation.
4. Although the assumption of constant population growth over time is used in the model as presented here, the simulation can be easily modified to include varying rates of population increase over time.
5. 32,315 (domestic quantity demanded) + 36,711 (export quantity demanded) = 69,026 = total equilibrium quantity demanded in the initial time period.

6. The base scenario is altered to include the alternative parmater value relevant to the particular analysis. For example, if the alternative scenarios evaluate the effects of increasing the rate of erosion, the corresponding base scenario also includes the higher rate of erosion.
7. Similar concerns have been raised with regard to the accelerated use of groundwater supplies in response to increasing levels of agricultural demand.
8. Lowering the discount rate causes the present value of the surplus measures to increase (for positive benefit values) while lowering the annuity payment required for a given value of the discounted surplus. These two factors interact to determine whether the annuity payment will increase or decrease relative to the basic analysis.

CHAPTER 5

CONCLUDING THOUGHTS

The general issue addressed by the manuscripts included in this thesis has been the manner in which individual actions affect long term outcomes in the aggregate market. It was suggested in the first two chapters that the concept of long run risk, though not yet well-defined, must be recognized as an important component in efforts to evaluate longer term consequences of risk and uncertainty on producer behavior.

Chapters 3 and 4 approached the analysis of long term welfare effects that may arise as a consequence of individual producer actions from two very different perspectives. In Chapter 3, the aggregate consequences of individual risk avoidance behavior were examined via a simple one product agricultural market model. It was learned that after market adjustments have taken place, efforts by producers to minimize risk exposure may in fact lead to an increase in the variablity of both producer and consumer surplus as measured in the aggregate market. The manner in which the producer formulates the price expectation was found to be a significant factor in determing whether aggregate risk increased or decreased with producer actions.

In Chapter 4, the potential long term impacts of declining soil productivity were examined in light of the unknown relationship between soil erosion, crop yield and technological change. Soil erosion has a negative impact on crop yields but its influence, except in severe cases, has generally been masked by technology related yield improvements. The degree to which technology improvements can be expected to continue to outweigh the effects of erosion is unknown. Consequently, the future trend in crop prices and farm income is also unknown. Results of a scenario analysis based on a simulation model of a generalized agricultural market is was shown that the adverse consequences of erosion manifest themselves only after a period of several generations. Results however, increasing in severity over time. When producer behavior is based on a planning horizon of only a generation or two, individual actions to control soil erosion in the current period would likely not be made. The implication is to increase the likelihood of adverse impacts some periods into the future.

As a very general conclusion to the research efforts included in this thesis, it has been shown that potential concerns for the longer term uncertainties associated with producer behavior (also referred to as long run risk by McCarl and Musser) can be examined under relatively simple constructs. Though perhaps not of direct use in heated policy discussion, the studies have served a 'what if' purpose. What if soil loss is left unmitigated...? What if future technology advances slow down...? What if price expectations are formed rationally...? By determining those parameter for which model results are most sensitive, potential issues for evaluating long run risk can be identified.

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APPENDICES

APPENDIX A

CALCULATIONS FOR CHAPTER 3

APPENDIX A

CALCULATIONS FOR CHAPTER 3

A1. Central Moments

The calculations in this paper involve several of the higher order central moments of the random yield variable. In particular, the second, third and fourth central moments of yield appear frequently when evaluating the impacts of increasing risk aversion on producer and consumer welfare. Definitions for each of these moments are given as follows:

i) second central moment (variance)

$$\mu_2 = \sigma^2 = E(y - E(y))^2 = E(y^2) - Y^2 \qquad \text{(A1)}$$

and the second moment about the origin is given by

$$E(y^2) = \sigma^2 + Y^2$$

ii) third central moment

$$\mu_3 = E(y - E(y))^3 = E(y^3) - 3YE(y^2) + 3Y^2E(y) - Y^3$$

$$= E(y^3) - 3Y\sigma^2 - Y^3$$

and the third moment about the origin is given by

$$E(y^3) = \mu_3 + 3Y\sigma^2 + Y^3 \qquad \text{(A2)}$$

iii) fourth central moment

$$\mu_4 = E(y - E(y))^4 = E(y^4) - 4YE(y^3) + 6Y^2E(y^2) - 4Y^3E(y) + Y^4$$

$$= E(y^4) - 4Y\mu_3 - 6Y^2\sigma^2 - Y^4$$

and the fourth moment about the origin is given by

$$E(y^4) = \mu_4 + 4Y\mu_3 + 6Y^2\sigma^2 + Y^4 \quad \text{(A3)}$$

The third and fourth central moments can be respecified as parameters that are designed to characterize the frequency curve of the random variable. To measure the departure from symmetry the third central moment of the distribution can be reparameterized using the coefficient of skewness, γ_1, where

$$\gamma_1 = \mu_3 / \sigma^3$$

or

$$\mu_3 = \gamma_1 \sigma^3 \quad \text{(A4)}$$

If $\gamma_1 < 0$, the distribution is negatively skewed and for $\gamma_1 > 0$, the distribution is positively skewed. The fourth central moment can be redefined using the coefficient of kurtosis, γ_2, where

$$\gamma_2 = \mu_4 / \sigma^4 - 3$$

or

$$\mu_4 = \gamma_2 \sigma^4 + 3 \sigma^4 \quad \text{(A5)}$$

This coefficient measures the relative peakedness of the frequency curve. If $\gamma_2 > 0$ the curve tends toward peakedness and is said to be leptokurtotic. For $\gamma_2 < 0$, the curve is flattened. In this case the distribution is said to be platykurtotic.

A2. The Variance of Individual Net Farm Income With Rational Expectations

The variance of net farm income is defined as

$$\text{Var}(\pi_i) = E(\pi_i - E(\pi_i))^2$$

Substituting the text expressions for π_i and $E(\pi_i)$ where the price expectation is equal to the expression for market demand ($p = a - bynA$)

$$\text{Var}(\pi_i) = E((a - bynA)y_iA_i - c_iA_i - (a - bYnA)Y_iA_i + bnA\sigma^2A_i + c_iA_i)^2$$

The subscript i is hereafter ommited because the market is assumed to be made up of producers facing identical sets of production parameters. Per acre yield at the producer level is the same as per acre yield in the aggregate sector (i.e., $y_i = y$, $A_i = A$).

$$\text{Var}(\pi_i) = E(aA(y - Y) - bnA^2(y^2 - \sigma^2 - Y^2))^2$$

$$= E(a^2A^2(y - Y)^2 - 2abnA^3(y - Y)(y^2 - \sigma^2 - Y^2) + b^2n^2A^4(y^2 - \sigma^2 - Y^2)^2).$$

Completing the squares and removing the constants from the expectation

$$\text{Var}(\pi_i) = a^2A^2\sigma^2 - 2anA^3E(y^3) + 2abnA^3E(y^2) + b^2n^2A^4E(y^4) - 2b^2n^2A^4E(y^2) + b^2n^2A^4Y^4 - b^2n^2A^4\sigma^4 .$$

Substituting equations (A1), (A2) and (A3) for the second, third and fourth moments of y,

$$\begin{aligned}\mathrm{Var}(\pi_i) = {} & a^2A^2\sigma^2 - 2abnA^3(\mu_3 + 3Y\sigma^2 + Y^3) \\ & + 2abnA^3Y\sigma^2 + b^2n^2A^4(\mu_4 + 4Y\mu_3 + 6Y^2\sigma^2 + Y^4) \\ & - 2ab^2n^2A^4Y^4 - 2b^2n^2A^4Y^2\sigma^2 + b^2n^4A^4Y^4 \\ & - b^2n^2A^4\sigma^4 \ .\end{aligned}$$

Finally, after collecting terms the variance of individual net farm income with rational expectations is given by

$$\begin{aligned}\mathrm{Var}(\pi_i) = {} & a^2A^2\sigma^2 - 2abnA^3\mu_3 - 4abnA^3Y\sigma^2 + b^2n^2A^4\mu_4 \\ & + 4b^2n^2A^4Y\mu_3 + 4b^2n^2A^4Y^2\sigma^2 - b^2n^2A^4\sigma^4 \ .\end{aligned}$$

A3. The Variance of Producers' Surplus

The variance of producers' surplus is defined as

$$\mathrm{Var}(\pi) = E(\pi - E(\pi))^2$$

Substituting equation (7) for π and equation (8) for $E(\pi)$

$$\begin{aligned}\mathrm{Var}(\pi) &= E(anA(y - Y) - bn^2A^2(y^2 - \sigma^2 - Y^2))^2 \\ &= E(a^2n^2A^2(y - Y)^2 - 2abn^3A^3(y - Y)(y^2 - \sigma^2 - Y^2) \\ &\quad + b^2n^4A^4(y^2 - \sigma^2 - Y^2)^2).\end{aligned}$$

Completing the squares and removing the constants from the expectation

$$\begin{aligned}\mathrm{Var}(\pi) &= a^2n^2A^2\sigma^2 - 2an^3A^3E(y^3) + 2abn^3A^3YE(y^2) \\ &\quad + b^2n^4A^4E(y^4) - 2b^2n^4A^4Y^2E(y^2) + b^2n^4A^4Y^4 \\ &\quad - b^2n^4A^4\sigma^4 \quad .\end{aligned}$$

Substituting equations (Al), (A2) and (A3) for the second, third and fourth moments of y,

$$\begin{aligned}\mathrm{Var}(\pi) &= a^2n^2A^2\sigma^2 - 2abn^3A^3(\mu_3 + 3Y\sigma^2 + Y^3) \\ &\quad + 2abn^3A^3Y\sigma^2 + b^2n^4A^4(\mu_4 + 4Y\mu_3 + 6Y^2\sigma^2 + Y^4) \\ &\quad - 2ab^2n^4A^4Y^4 - 2b^2n^4A^4Y^2\sigma^2 + b^2n^4A^4Y^4 \\ &\quad - b^2n^4A^4\sigma^4 \quad .\end{aligned}$$

Finally, after collecting terms the variance of producers' surplus is given by

$$\mathrm{Var}(\pi) = a^2n^2A^2\sigma^2 - 2abn^3A^3\mu_3 - 4abn^3A^3Y\sigma^2 + b^2n^4A^4\mu_4$$
$$+ 4b^2n^4A^4Y\mu_3 + 4b^2n^4A^4Y^2\sigma^2 - b^2n^4A^4\sigma^4 \quad .$$

A4. The Variance of Consumers' Surplus

By definition, the variance of consumers' surplus is given by

$$Var(CS) = E(CS - E(CS))^2 \quad .$$

Substituting equation (11) for CS and equation (12) for E(CS),

$$Var(CS) = E(\tfrac{1}{2}bn^2A^2(y^2 - Y^2 - \sigma^2))^2$$

$$= \tfrac{1}{4}\, b^2n^4A^4\ (E(y^4) - 2Y^2E(y^2) + Y^4 - \sigma^4)) \; .$$

Substituting equations (A1) and (A3) for $E(y^2)$ and $E(y^4)$, respectively

$$Var(CS) = \tfrac{1}{4}b^2n^4A^4\ (\mu_4 + 4Y\mu_3 + 6Y^2\sigma^2 + Y^4$$

$$- 2Y^2\ (\sigma^2 + Y^2) + Y^4 - \sigma^4) \quad .$$

Collecting terms, the variance of consumers' surplus is given by

$$Var(CS) = \tfrac{1}{4}b^2n^4A^4\mu_4 + b^2n^4A^4Y\mu_3 + b^2n^4A^4Y^2\sigma^2$$

$$- \tfrac{1}{4}b^2n^4A^4\sigma^4 \quad .$$

The variance of consumers' surplus can be characterized completely by the second, third and fourth central moments of the random yield parameter.

A5. The Variance of Total Social Welfare

The variance of total social welfare is given by the formula

$$Var(TSW) = E(TSW - E(TSW))^2 \quad .$$

Substituting equation (14) for TSW and equation (15) for E(TSW)

$$Var(TSW) = E(anA(y - Y) - \tfrac{1}{2}bn^2A^2(y^2 - Y^2 - \sigma^2))^2 \quad .$$

Completing the square and removing constants from the expectation

$$\begin{aligned} Var(TSW) = {} & a^2n^2A^2\sigma^2 - abn^3A^3E(y^3) + abn^3A^3Y^3 \\ & + abn^3A^3Y\sigma^2 + \tfrac{1}{4}b^2n^4A^4E(y^4) - \tfrac{1}{4}b^2n^4A^4Y^4 \\ & - \tfrac{1}{2}b^2n^4A^4Y^2\sigma^2 - \tfrac{1}{4}b^2n^4A^4\sigma^4 \quad . \end{aligned}$$

Substituting equations (A2) and (A3) for $E(y^3)$ and $E(y^4)$, respectively

$$\begin{aligned} Var(TSW) = {} & a^2n^2A^2\sigma^2 - abn^3A^3\mu_3 - 2abn^3A^3Y\sigma^2 \\ & + \tfrac{1}{4}b^2n^4A^4\mu_4 + b^2n^4A^4Y\mu_3 + b^2n^4A^4Y^2\sigma^2 \\ & - \tfrac{1}{4}b^2n^4A^4\sigma^4. \quad . \end{aligned}$$

Finally, substituting equations (A4) and (A5) for the third and fourth central moments of the random yield variable, the variance of total social welfare is given by

$$\mathrm{Var(TSW)} = a^2n^2A^2\sigma^2 - abn^3A^3\gamma_1\sigma^3 - 2abn^3A^3Y\sigma^2$$
$$+ \tfrac{1}{4}b^2n^4A^4\gamma_2\sigma^4 + \tfrac{1}{2}b^2n^4A^4\sigma^4 + b^2n^4A^4Y\gamma_1\sigma^3$$
$$+ b^2n^4A^4Y^2\sigma^2 \quad .$$

A6. Calculating the Effect of Increasing Risk Aversion on the Expected Value of Producers' Surplus

The expected value of producers' surplus is given by equation (8) where

$$E(\pi) = aYnA - bn^2A^2\sigma^2 - bn^2A^2Y^2 - cnA$$

The impact of increasing risk aversion is found by taking the derivative of the above expression with respect to , or

$$\partial E(\pi)/\partial \phi = (aYn - 2bn^2A\sigma^2 - 2bn^2AY^2 - cn)\ \partial A/\partial \phi \ .$$

If $\partial A/\partial \phi$ is considered to be less than zero, then the above expression will also be less than zero if

$$aYn > 2bn^2A\sigma^2 + 2bn^2AY^2 + cn$$

or if

$$Yn(a - bnAY) > 2bn^2A\sigma^2 + bn^2AY^2 + cn \quad .$$

Dividing by bY^2n^2A and noting that the elasticity of demand, η, at the point of intersection to the expected supply curve is given by

$$\eta = -\ (\partial Q/\partial p)\cdot(p/Q) = (a\text{-}bynA)/(bYnA)\ , \quad (\eta > 0)$$

The paranthetic expression above will be greater than zero if

$$\eta > 2\ \xi_y^2 + 1 + c/YbnAY$$

where

$\xi_y = \sigma/Y =$ the coefficient of variation of the random yield variable.

The last term in the expression above can be rewritten as

$$c/YbnAY = (c/YE(p))(E(p)/bnAY) = (c/YE(p))\cdot\eta$$

where $E(p) = a - bYnA$, the expression for expected price as given in the text. Substituting, $\partial E(\pi)/\partial\phi$ will be less than than zero if

$$\eta > (2\,\xi_y^2 + 1)/(1 - c/YE(p)) \quad .$$

Looking only at the term, $c/YE(p)$, multiplying by (nA/nA) results in

$$c/YE(p) = cnA/(aYnA - bn^2A^2Y^2) \quad .$$

Multiplying the numerator and denominator by $(1 - (bn^2A^2\sigma^2/(aYnA - bn^2A^2Y^2))$

$$c/YE(p) = (cnA(1 - (nA\sigma^2(bnA))/(nAY(a - bnAY))))/(aYnA - bn^2A^2Y^2 - bn^2A^2\sigma^2)$$

where

$cnA = TC$ = total aggregate cost of production

$(aYnA - bn^2A^2Y^2 - bn^2A^2\sigma^2) = E(TR)$ = expected total return from production.

Finally, multiplying the second term in the numerator by Y/Y, the expression becomes

$$c/YE(p) = (TC(1 - \xi_y^2/\eta))/(E(TR) \quad .$$

Substituting back into the main expression, $\partial E(\pi)/\partial\phi$ will be less than zero if

$$\eta > (2\xi_y^2 + 1)/(1 - (TC(1 - \xi_y^2/\eta)/E(TR)))$$

or if

$$\eta > (E(TR)/E(\pi))\ (\xi_y^2 + 1) - \xi_y^2 \quad .$$

Because the second term on the right hand side will be insignificant relative to the first term, $\partial E(\pi)/\partial\phi$ will be less than zero if

$$\eta > (E(TR)/E(\pi))\ (\xi_y^2 + 1)$$

A7. Calculating the Effect of Increasing Risk Aversion on the Variance of Producers' Surplus

The variance of producers' surplus is given by equation (9) where

$$\begin{aligned}Var(\pi) = {} & a^2n^2A^2\sigma^2 - 2abn^3A^3\mu_3 - 4abn^3A^3Y\sigma^2 + b^2n^4A^4\mu_4 \\ & + 4b^2n^4A^4Y\mu_3 + 4b^2n^4A^4Y^2\sigma^2 - b^2n^4A^4\sigma^4 \quad .\end{aligned}$$

The effects of increasing risk aversion are found by taking the derivative of the variance of producers' surplus with respect to the risk aversion parameter, ϕ, or

$$\begin{aligned}\partial Var(\pi)/\partial\phi = {} & (2a^2\sigma^2n^2A - 6ab\mu_3n^3A^2 - 12abY\sigma^2n^3A^2 \\ & + 4b^2\mu_4n^4A^3 + 16b^2Y\mu_3n^4A^3 + 16b^2Y^2\sigma^2n^4A^3 \\ & - 4b^2\sigma^4n^4A^3)\ \partial A/\partial\phi \quad .\end{aligned}$$

If $\partial A/\partial\phi$ is considered to be less than zero then increasing risk aversion will reduce the variance if

$$\begin{aligned}& (2a^2\sigma^2n^2A + 4b^2\mu_4n^4A^3 + 16b^2Y\mu_3n^4A^3 + 16b^2Y\sigma^2n^4A^3) \\ & > (6ab\mu_3n^3A^3 + 12abY\sigma^2n^3A^2 + 4b^2\sigma^4n^4A^3) \quad .\end{aligned}$$

Substituting equations (A4) and (A5) for μ_3 and μ_4 respectively, $\partial Var(\pi)/\partial\phi < 0$ if

$$\begin{aligned}& (2a^2\sigma^2n^2A + 4b^2n^4A^3\gamma_2\sigma^4 + 12b^2n^3A^3\sigma^4 + 16b^2Y^2\sigma^2n^4A^3) \\ & > (6ab\gamma_1\sigma^3n^3A^2 + 12abY\sigma^2n^3A^2 + 4b^2\sigma^4n^4A^3) \quad .\end{aligned}$$

Dividing by $2\sigma^2n^2A$ and grouping terms, $\partial Var(\pi)/\partial\phi < 0$ if

$$(a^2 - 2abYnA + b^2Y^2n^2A^2) + (4 + 2\gamma_2)b^2n^2A^2\sigma^2$$

$$> 4abYnA - 7b^2Y^2n^2A^2 - 8b^2n^2A^2Y\gamma_1\sigma + 3ab\gamma_1\sigma nA \quad .$$

Dividing by $(a - bYnA)^2$ and regrouping terms on the right hand side

$$1 + ((4 + 2\gamma_2)b^2n^2A^2\sigma^2 / (a - bYnA)^2) \quad >$$

$$(4bYnA(a - bYnA))/(a - bYnA)^2) - (3b^2Y^2n^2A^2/(a - bYnA)^2)$$

$$- (8b^2n^2A^2Y\gamma_1\sigma/(a - bYnA)^2) + (3ab\gamma_1\sigma nA/(a - bYnA)^2) \quad .$$

Multiplying the second term on the left hand side by Y^2/Y^2 and recalling that the elasticity of demand is given by $\eta = (a - bYnA)/bYnA$, then $\partial Var(\pi)/\partial\phi < 0$ if

$$1 + (4 + 2\gamma_2)\sigma^2/\eta^2Y^2 > 4/\eta - 3/\eta^2 + (3\gamma_1\sigma bnA(a - bYnA)/$$

$$(a - bYnA)^2 - (5b^2n^2A^2Y\gamma_1\sigma/(a - bYnA)^2) \quad .$$

Multiplying the last two terms on the right hand side by Y/Y and reducing terms leads to $\partial Var(\pi)/\partial\phi < 0$ if

$$1 + ((4 + 2\gamma_2)\sigma^2/\eta^2Y^2) > 4/\eta - 3/\eta^2 + 3\gamma_1\sigma/Y\eta$$

$$-5\gamma_1\sigma/Y\eta^2 \quad .$$

Recalling that the coefficient of variation for the random yield parameter is given by $\xi_y = \sigma/Y$, $\partial Var(\pi)/\partial\phi < 0$ if

$$1 + ((4 + 2\gamma_2)\xi_y^2/\eta^2 > 4/\eta - 3/\eta^2 + 3\gamma_1\xi_y/\eta$$

$$- 5\gamma_1\xi_y/\eta^2 \quad .$$

Finally, after multiplying through by η^2 and collecting terms, it can be seen that increasing risk aversion on the part of agricultural producers will reduce the variance of producers' surplus if

$$\eta^2 - \eta(4 + 3\gamma_1\xi_y) > -(4 + 2\gamma_2)\xi_y^2 - 5\gamma_1\xi_y - 3 \quad .$$

A8. Calculating the Effect of Increasing Risk Aversion on the Coefficient of Variation for Producers' Surplus

$$\xi_\pi = (Var(\pi))^{\frac{1}{2}}/E(\pi) = (a^2n^2A^2\sigma^2 - 2abn^3A^3\mu_3 - 4abn^3A^3Y\sigma^2 + b^2n^4A^4\mu_4 + 4b^2n^4A^4Y\mu_3 + 4b^2n^4A^4Y\sigma^2 - b^2n^4A^4\sigma^4)^{\frac{1}{2}}/ (aYnA - bn^2A^2Y^2 - bn^2A^2\sigma^2 - cnA) \quad .$$

Taking the derivative with respect to the risk aversion parameter, ϕ, yields

$$\partial\xi_\pi/\partial\phi = (E(\pi)\cdot\partial(Var(\pi))^{\frac{1}{2}}/\partial\phi - (Var(\pi))^{\frac{1}{2}}\cdot \partial E(\pi)/\partial\phi) / (E(\pi))^2 \quad .$$

The denominator, $(E(\pi))^2$, is positive so that the sign of the derivative will depend on the sign of the numerator, or

$\partial\xi_\pi/\partial\phi < 0$ if

$$E(\pi)\cdot \partial(Var(\pi))^{\frac{1}{2}}/\partial\phi < (Var(\pi))^{\frac{1}{2}}\cdot \partial E(\pi)/\partial\phi$$

or if

$$A(aYn - bn^2AY^2 - bn^2A\sigma^2 - cn)(\tfrac{1}{2}(Var(\pi))^{\frac{1}{2}})(2a^2n^2A\sigma^2 - 6abn^3A^2\mu_3 - 12abn^3A^2Y\sigma^2 + 4b^2n^4A^3\mu_4 + 16b^2n^4A^3Y\mu_3 + 16b^2n^4A^3Y^2\sigma^2 - 4b^2n^4A^3\sigma^4)\ \partial A/\partial\phi \quad < (Var(\pi))^{\frac{1}{2}}\ (aYn - 2bn^2AY^2 - 2bn^2A\sigma^2 - cn)\ \partial A/\partial\phi \quad .$$

Removing $\partial A/\partial\phi$ (for $\partial A/\partial\phi < 0$) from each side and then multiplying through by $(Var(\pi))^{\frac{1}{2}}$ and collecting terms, the numerator will be negative if

$$(aYn - bn^2AY^2 - bn^2A\sigma^2 - cn)\ (Var(\pi) + (-abn^3A^3\mu_3 - 2abn^3A^3Y\sigma^2 + b^2n^4A^4\mu_4 + 4b^2n^4A^3Y\mu_3 + 4b^2n^4A^3Y^2\sigma^2 - b^2n^4A^3\sigma^4)) \ > \ Var(\pi)\ ((aYn - bn^2AY^2 - bn^2A\sigma^2 - cn) + (-bn^2AY^2 - bn^2A\sigma^2)) \quad .$$

Subtracting the common term from each side, $\partial\xi_\pi/\partial\phi < 0$ if

$$(aYn - bn^2AY^2 - bn^2A\sigma^2 - cn)\ (-abn^3A^3\mu_3 - 2abn^3A^3Y\sigma^2 + b^2n^4A^4\mu_4 + 4b^2n^4A^4Y\mu_3 + 4b^2n^4A^4Y^2\sigma^2 - b^2n^4A^4\sigma^4)$$

$$Var(\pi)\ (-bn^2AY^2 - bn^2A\sigma^2) \quad .$$

With normality the equation above becomes ($\mu_3 = 0$, $\mu_4 = 3\sigma^4$)

$$(E(\pi)/A)\ (-2abn^3A^3Y\sigma^2 + 2b^2n^4A^4\sigma^4 + 4b^2n^4A^4Y^2\sigma^2) \ > \ Var(\pi)\ (-bn^2AY^2 - bn^2A^2\sigma^2)$$

or

$$(2abn^3A^3Y\sigma^2 - 2b^2n^4A^4\sigma^4 - 4b^2n^4A^4Y^2\sigma^2) < (Var(\pi)/E(\pi))\cdot (bn^2A^2Y^2 + bn^2A^2\sigma^2) \quad .$$

Dividing through both sides by $2b^2n^4A^4Y^2\sigma^2$

$$((a/bnAY) - \xi_y^2 - 2) < \tfrac{1}{2}(Var(\pi)/E(\pi))\ ((1/b^2n^2A^2Y^2)\cdot (1/\xi_y^2 + 1)) \quad .$$

Adding and subtracting (bnAY/bnAY) to the left hand side and multiplying the right hand side by $(E(\pi)/E(\pi))$, $\partial\xi_\pi/\partial\phi < 0$ if

$$\eta - \xi_y^2 - 1 \quad \tfrac{1}{2} \quad {}_y^2 \; ((E(\;)/bn^2A^2Y^2)(1/\;{}_y^2 + 1)) \quad .$$

Looking only at the right side

$$\tfrac{1}{2}\, \xi_\pi^2 \; ((E(\pi)/bn^2A^2Y^2)(1/\xi_y^2 + 1)) = \tfrac{1}{2}\, \xi_\pi^2 \; ((YnA/YnA)$$

$$((a - bYnA - bnA(\sigma^2/Y) - (c/Y))/(bnYA))(1/\xi_y^2 + 1)$$

$$= \tfrac{1}{2}\, \xi_\pi^2 \; (\eta - \xi_y^2 - (c/YbnAY)) \; (1/\xi_y^2 + 1) \quad .$$

From Appendix A6 we know that

$$c/YbnYA \quad = \quad c/YE(p)$$

and

$$c/YE(p) = \quad TC(1 - \;{}_y^2/\;)/E(TR)$$

Therefore,

$$\tfrac{1}{2}\, \xi_\pi^2 \; ((E(\pi)/bn^2A^2Y^2)(1/\xi_y^2 + 1)) \quad = \quad \tfrac{1}{2}\, \xi_\pi^2 \; (\eta(1 - TC/E(TR))$$

$$- \xi_y^2 \; (1 - TC/E(TR))) \; (1/\xi_y^2 + 1) \quad .$$

Substituting into the full equation, $\partial\xi_\pi/\partial\phi < 0$ if

$$\eta < \tfrac{1}{2}\xi_\pi^2(\eta(1 - TC/E(TR)) - \xi_y^2 \; (1 - TC/E(TR))) \cdot$$

$$(1/\xi_y^2 + 1) \quad + \quad (\xi_y^2 + 1)$$

Factoring the terms containing η to the left hand side,

$\partial\xi_\pi/\partial\phi < 0$ if

$$\eta < ((\xi_y^2 + 1)(1 - \tfrac{1}{2}\xi_\pi^2(1 - TC/E(TR)))/(1 - \tfrac{1}{2}\xi_\pi^2 \cdot$$

$$(1 - TC/E(TR))(1/\xi_y^2 + 1))$$

or if

$$\eta < \xi_y^2 (1 - \tfrac{1}{2}\xi_\pi^2 (1 - TC/E(TR))) / (\xi_y^2/(\xi_y^2 + 1) - \tfrac{1}{2}\xi_\pi^2 (1 - TC/E(TR))) \quad .$$

A9. Calculating the Effect of Increasing Risk Aversion on the Variance of Total Social Welfare

From equation (16) the variance of total social welfare is given by

$$\begin{aligned}\mathrm{Var(TSW)} = {} & a^2n^2A^2\sigma^2 - abn^3A^3\mu_3 - 2abn^3A^3Y\sigma^2 \\ & + \tfrac{1}{4}b^2n^4A^4\mu_4 + b^2n^4A^4Y\mu_3 + b^2n^4A^4Y^2\sigma^2 \\ & - \tfrac{1}{4}b^2n^4A^4\sigma^4 \quad .\end{aligned}$$

The effect of increasing risk aversion is found by taking the derivative of Var(TSW) with respect to ϕ, where

$$\begin{aligned}\partial\mathrm{Var(TSW)}/\partial\phi = {} & (2a^2n^2\sigma^2A - 3abn^3\mu_3A^2 - 6abn^3Y\sigma^2A^2 \\ & + b^2n^4\mu_4A^3 + 4b^2n^4Y\mu_3A^3 + 4b^2n^4Y^2\sigma^2A^3 \\ & - b^2n^4\sigma^4A^3) \quad \partial A/\partial\phi \ .\end{aligned}$$

Assuming that $\partial A/\partial\phi < 0$ and substituting equations (A4) and (A5) for μ_3 and μ_4, respectively $\partial\mathrm{Var(TSW)}/\partial\phi < 0$ if

$$\begin{aligned}& (2a^2n^2\sigma^2A + b^2n^4\gamma_2\sigma^4A^3 + 2b^2n^4\sigma^4A^3 + 4b^2n^2Y\gamma_1\sigma^3A^3 \\ & + 4b^2n^4Y^2\sigma^2A^3) > (3abn^3\gamma_1\sigma^3A^2 + 6abn^3Y\sigma^2A^2) \quad .\end{aligned}$$

Dividing by $2n^2\sigma^2A$ and rearranging terms, $\partial\mathrm{Var(TSW)}/\partial\phi < 0$ if

$$\begin{aligned}& ((a - bnYA)^2 + \tfrac{1}{2}b^2n^2\gamma_2\sigma^2A^2 + b^2n^2\sigma^2A^2 + b^2n^2Y^2A^2) \\ & \quad ((3/2)abn\gamma_1\sigma A - 2b^2n^2\gamma_1\sigma YA^2 + abnYA) \quad .\end{aligned}$$

Dividing by $(a - bnAY)^2$ and substituting ξ_y for σ/Y, $\partial\mathrm{Var(TSW)}/\partial\phi < 0$ if

$$1 + \xi_y^2 (1 + \tfrac{1}{2}\gamma_2)(1/\eta^2) + 1/\eta^2$$

$$(3/2)\ \gamma_1\ \xi_y\ (abnYA/(a - bYnA)^2) - 2\ \gamma_1\ \xi_y\ (1/\eta^2)$$

$$+ (abnYA/(a - bYnA)^2) \quad .$$

Combining terms and multiplying through by η^2, $\partial Var(TSW)/\partial\phi < 0$ if

$$\eta^2 + (\xi_y^2 + \tfrac{1}{2}\ \xi_y^2\ \gamma_2 + 2\ \gamma_1\ \xi_y + 1) - ((3/2)\ \gamma_1\ \xi_y$$

$$+ 1)\ (a/bYnA) \quad > \quad 0 \quad .$$

Adding and subtracting $((bYnA/bYnA) \cdot ((3/2)\gamma_1\xi_y + 1))$ from the left hand side, $\partial Var(TSW)/\partial\phi < 0$ if

$$\eta^2 - \eta((3/2)\ \xi_y + 1) + (1 + \tfrac{1}{2}\ \gamma_2)\ \xi_y^2$$

$$+ \tfrac{1}{2}\ \gamma_1\ \xi_y \quad > \quad 0 \quad .$$

A10. Calculating the Effect of Increasing Risk Aversion on the Coefficient of Variation of Total Social Welfare

The effect of increasing risk aversion on the coefficient of variation of total social welfare is found by taking the derivative of equation (44) with respect to ϕ, or

$$\partial\xi_{TSW}/\partial\phi = (E(TSW)\cdot\partial(Var(TSW))^{\frac{1}{2}}/\partial\phi - (Var(TSW))^{\frac{1}{2}} \cdot \partial E(TSW)/\partial\phi)(1/(E(TSW)^2) \quad .$$

Because the denominator is positive, the sign of the derivative will depend on the sign of the numerator, or $\partial\xi_{TSW}/\partial\phi > 0$ if

$$\partial Var(TSW)/\partial\phi > 2\cdot \partial E(TSW)/\partial\phi \cdot (Var(TSW)/E(TSW)) \quad .$$

Substituting equations (40) and (42) for $\partial Var(TSW)/\partial\phi$ and $\partial E(TSW)/\partial\phi$, respectively, $\partial\xi_{TSW}/\partial\phi$ will be less than zero if $(\partial A/\partial\phi < 0)$

$$2\ Var(TSW) + (-2bn^3YA^3\sigma^2(a - bYnA) + 2abn^3Y^3A^3 + b^2n^4\sigma^4A^4) > 2\ (E(TSW) - \tfrac{1}{2}bn^2A^2(Y^2 + \sigma^2)) \cdot (Var(TSW)/E(TSW))$$

or, by rearranging terms, if

$$(2bn^3YA^3\sigma^2(a - bYnA) - 2abn^3Y^3A^3 - bn^2A^4\sigma^4) < \tfrac{1}{2}\ (Var(TSW)/E(TSW))\ (1 + \xi_y^2) \quad .$$

Dividing by $bn^2A^2Y^2$ and combining terms, $\partial\xi_{TSW}/\partial\phi < 0$ if

$$\xi_y^2\ (2\eta - \xi_y^2) - 2\eta - 2 \quad < \quad \tfrac{1}{2}\ \xi_{TSW}^2(E(TSW)/bY^2n^2A^2) \cdot (1 + \xi_y^2) \quad .$$

The term $E(TSW)/bY^2n^2A^2$ can be expressed as

$$E(TSW)/bY^2n^2A^2 = (YnA/YnA)\ ((a - bYnA) + \tfrac{1}{2}bYnA - \tfrac{1}{2}bnA(\sigma^2/Y) - (c/Y))\ /\ bnYA \quad ,$$

or

$$E(TSW)/bY^2n^2A^2 = \eta + \tfrac{1}{2} - \tfrac{1}{2}\xi_y^2 - c/YbnYA \quad .$$

Substituting the expression for c/YbnYA developed in Appendix A6

$$c/YbnYA = (c/E(p)Y)$$

$$= (TC(1 - (\xi_y^2/\ ))/E(TR))$$

$$(E(TSW)/bY^2n^2A^2) = (\eta - \xi_y^2)\ (1 - TC/E(TR)) + \tfrac{1}{2}\ (1 + \xi_y^2) \quad .$$

Returning the expression above to the main equation and rearranging terms, $\partial\xi_{TSW}/\partial\phi < 0$ if

$$(\xi_y^4 + 2 - \tfrac{1}{2}\xi_{TSW}^2\xi_y^2(1 - TC/E(TR))(1 + \xi_y^2) + \tfrac{1}{4}\xi_{TSW}^2(1 + \xi_y^2)^2)\ /\ (2\xi_y^2 - 2 - \tfrac{1}{2}\ {}^2_{TSW}(1 - TC/E(TR)) \cdot (1 + \xi_y^2)) \quad .$$

APPENDIX B

DATA USED IN ESTIMATING THE YIELD-SOIL DEPTH ELASTICITY

APPENDIX B

DATA USED IN ESTIMATING THE YIELD-SOIL DEPTH ELASTICITY*

Top-Soil Depth (in.)	Winter Wheat Yield (bu/ac)	Year (+1970)
0	29.6	0
18	71.4	0
14	67.6	0
26	70.8	0
18	99.7	0
3	57.8	0
20	72.9	0
19	93	0
21	62.5	0
12	49.9	0
12	64.5	0
24	98.9	0
0	27.7	0
8	59.7	0
0	34.4	0
41	51.6	0
0	38	0
17	99.7	0
11	75.3	0
34	84.6	1
24	91.6	1
48	100.2	1
20	75.5	1
10	26.5	1
14	60.6	1
26	40.6	1
0	76.4	1
20	81	1
14	71.5	1
9	86.9	1
7	75.7	1
12	64.7	1
15	66.7	1

Top-Soil Depth (in.)	Winter Wheat Yield (bu/ac)	Year (+1970)
14	65.4	2
14	80.7	2
0	27.4	2
9	79.3	2
18	66.9	2
0	61.1	2
14	82.8	2
19	63.4	2
0	52.7	2
16	77.4	2
0	21.7	2
41	103.8	2
12	94.6	2
21	81.9	2
0	32.4	2
8	43.6	2
0	48.2	2
18	70.8	2
24	100.3	2
0	23	4
10	40	4
14	71.3	4
24	68.7	4
0	17.1	4
18	73.2	4
22	73.8	4
11	54.8	4
0	35.8	4
28	74	4
26	94.7	4
23	69.5	4
22	78.6	4
16	66.2	4

Top-Soil Depth (in.)	Winter Wheat Yield (bu/ac)	Year (+1970)
18	42	4
26	63.4	4
18	61.3	4
8	78.2	4
0	44.3	4
11	75	4
9	76.1	4
6	33.9	4
14	56.7	4
9	87.6	4
14	78.7	4
0	30.3	4
0	24.1	4
0	39.1	4
13	63.1	4
20	75.7	4
18	44.1	4
20	74.4	4
0	64.9	4
14	58.6	4
22	69.9	4
19	52.3	4
0	49.8	4
0	10	5
13	19.7	5
11	28	5
8	24.3	5
4	17.1	5
8	11.4	5
0	11.9	5
0	23.9	5
13	49.8	5
22	61.8	5
0	45.7	5
12	67.9	5
10	56	5
10	56.3	5
11	56.7	5
8	44.9	5
0	30.1	5
8	42.6	5
0	18.8	5
0	25.4	5
13	74.7	5

Top-Soil Depth (in.)	Winter Wheat Yield (bu/ac)	Year (+1970)
0	37.2	5
0	64.7	5
22	81.8	5
24	19.8	5
14	62.3	5
15	45.1	6
17	52.6	6
0	25.1	6
13	77	6
14	83.7	6
14	86.7	6
14	90.6	6
13	92	6
17	60.7	6
31	79.8	6
7	59.9	6
9	52.3	6
16	62.2	6
0	37	6
4	53.7	6
11	81.3	6
4	66.2	6
13	78.8	6
16	12.4	7
0	11.3	7
11	13.8	7
14	7.3	7
0	16.6	7
0	8.9	7
13	8.5	7
11	15.8	7
8	23.7	7
0	29.1	7
22	21.4	7
14	34.9	7
13	13.4	7
4	14.8	7
14	16	7
19	6.7	7
7	7.5	7
9	20.1	7
14	104.2	8
16	122.4	8

Top-Soil Depth* (in.)	Winter Wheat Yield (bu/ac)	Year (+1970)
.	108.5	8
0	103.2	8
11	101.2	8
14	100.7	8
14	86.7	8
17	89.6	8
7	89.6	8
31	101	8
13	91.5	8
6	111.2	8
0	36.8	8
0	41.3	9
22	81.2	9
14	74	9
14	74.7	9
6	49.2	9
0	26.6	9
14	56.4	9
0	34	9
13	47.6	9
23	68.2	9
22	86.9	9
0	63.6	9
9	60.4	9
16	23.8	9
18	32.9	9
0	27	9
8	32	9

* Data are from Dana L. Hoag and Douglas L. Young, "Yield-Topsoil Depth Response Functions: Linear versus Mitscherlich-Spillman," STEEP Ag Econ Working Paper, 82-2, Dept. of Ag. Econ., Washington State University, March 1983.