MACHINERY SHARING BY AGRIBUSINESS FIRMS: METHODOLOGY, APPLICATION, AND SIMULATION

A Dissertation

by

JARED L. WOLFLEY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2008

Major Subject: Agricultural Economics

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ABSTRACT

Machinery Sharing by Agribusiness Firms: Methodology, Application, and Simulation.

(December 2008)

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Machinery investments represent a substantial portion of agribusiness firms' costs. Because of high machinery costs, variable profit margins, and increasing competition, agribusiness managers continually seek methods to maintain profitability and manage risk. One relatively new method is jointly owning and sharing machinery. Contract design issues to enhance horizontal linkages between firms through machinery sharing are addressed. Specifically, costs and depreciation sharing between two firms entering into a joint machinery ownership contract are examined.

Two, two-player models, a Nash equilibrium game theoretical model and an applied two-farm simulation model are used to determine impacts of machinery sharing on firms engaged in machinery sharing. The Nash equilibrium model determines theoretical optimal sharing rules for two generic firms. Using the Nash equilibrium model as the basis, the two-farm simulation model provides more specific insights into joint harvest machinery sharing. Both models include contractual components that are uniquely associated with machinery sharing. Contractual components include penalty

payment structure for untimely machinery delivery and the percentages of shared costs paid and depreciation claimed paid by each firm. Harvesting windows for each farm and yield reductions associated with untimely machinery delivery are accounted for within the models.

Machinery sharing can increase the NPV of after tax cash flows and potentially reduce risk. Sharing will, however, not occur if own marginal transaction costs and/or marginal penalty costs associated with untimely machinery delivery are too large. Further, if the marginal costs of sharing are small relative to own marginal net benefits, sharing will not occur.

There are potential tradeoffs between the percentage of shared costs paid and the percentage of shared depreciation claimed depending on each farms' specific tax deductions. Harvesting window overlaps help determine the viability of machinery sharing. Farms may be better off sharing larger, more efficient machinery than using smaller machinery even when harvest must be delayed. Percentages of shared costs, depreciation, and tax deductions have important tax implications that impact the after tax cash flows and should be considered when negotiating machinery sharing contracts.

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TABLE OF CONTENTS

CHAPTER Page

CHAPTER Page

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

TABLE Page

TABLE Page

CHAPTER I

INTRODUCTION

Agribusiness firms continually seek ways to reduce costs and improve machinery management to maintain profitability. Unfortunately, most ways of reducing machinery costs involve a decrease in net returns, tradeoffs exist. Consider the decision to purchase a new machine. Purchasing a lower quality machine may reduce initial costs, but additional repairs negatively affect productivity and costs, therefore, net returns. If the decision is made to purchase a higher quality machine, initial costs are higher, but fewer repairs and increased productivity may offset the increase in costs. Within most agribusiness firms, machinery costs represent a large portion of total capital outlays. Machinery costs, for example, are typically the largest annual non-land expense that agricultural producers face, accounting for up to 41 percent of annual farm production costs (Schwalbe 2006).

Machinery management options available to managers include purchasing the machinery independently, leasing, custom contracting, or sharing machinery ownership. This study focuses on sharing machinery. Machinery sharing is defined as the use of a single piece or set of machinery by two or more firms. Obviously, not all machines can be shared. However, because some machines are used sparingly and because of seasonality in production, businesses in agricultural production, forestry, and road

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The style and format of this dissertation follows that of the *American Journal of Agricultural Economics.*

construction may benefit from machinery sharing. Sharing may reduce total capital investment, reduce risk, and allow firms access to higher quality, larger capacity, and/or additional machines. Additional or larger capacity machinery may improve production timeliness which can increase returns when seasonality is important.

Producers in the U.S., in an effort to improve farm profitability, reduce costs, and manage risk, are beginning to adopt unique managed lease and joint machinery ownership programs (Schwalbe 2006). In the last two decades, equipment companies that provide alternative equipment options have seen increased growth (Schwalbe 2006; MH Equipment 2007; and Caterpillar 2007). A potential advantage of multi-firm utilization of machinery is that firms of all sizes may benefit from implementing machinery sharing. Through machinery sharing, small firms may have access to larger, more efficient machinery that would otherwise not be affordable. Productivity may also increase because of production timeliness through the use of newer, more efficient equipment. Similar to small firms, large firms may also be able to reduce capital investment costs and potentially capitalize on economies of size. Firms sharing machinery, however, may face decreased production if the shared machines are not available when needed.

Firms sharing machinery will experience an increase in transaction costs. For machinery sharing, little to no research has been conducted on the effects of machinery sharing contractual, negotiation, and transaction costs impacts on a firm’s bottom line. The limited research that has been published considers machinery sharing in the context of co-operatives and agricultural production outside the U.S. As such, this dissertation is the first comprehensive study of contractual issues associated with machinery sharing impacts on farm's net returns. To overcome this limited prior research, machinery dealers and producers from the Association of Agricultural Production Executives that are currently or that are considering machinery sharing were interviewed throughout the completion of this dissertation.

Objectives

The overall objective of this dissertation is to examine the impacts of machinery sharing on two firms that enter into a machinery sharing contract. To accomplish this overall objective, the dissertation addresses two sub-objectives. The first sub-objective is to determine the optimal machinery cost sharing rules on how initial investment and maintenance costs should be shared between two firms that are entering into a joint ownership contract. The second sub-objective is to determine how machinery sharing impacts the net present value of after tax cash flows for firms engaged in machinery sharing.

To satisfy these objectives, two models are developed, a Nash equilibrium theoretical and an applied two-farm simulation model. The single period Nash equilibrium model for two firms sharing machinery is developed to determine theoretical optimal sharing rules. Optimal machinery sharing rules are defined as the percentages of total shared machinery costs borne by each firm. Because few studies have considered the economics of machinery sharing, the Nash equilibrium model is one advancement in addressing this void in the literature. Harvesting windows and different penalty structures associated with untimely machinery delivery are considered. The Nash equilibrium model is general enough to accommodate most types of machinery sets.

The second sub-objective is achieved by using the theoretical model as the basis for an empirical simulation model of two farms sharing machinery. Because the functional forms used in the Nash equilibrium model are general, no specific results are obtained. The simulation model overcomes the generality of the Nash equilibrium model. More specifically, the two-farm simulation model is used to: 1) determine the impact of machinery sharing on a firm's net present value of after tax cash flows; 2) examine contractual issues, percentage of shared costs, penalty payment structure, and percentage of shared machinery depreciation; and 3) evaluate machinery sharing as a risk reduction management tool.

The two-farm simulation model is unique in that two farms are simultaneously simulated with both firm specific and joint components. Firm specific components include yields, prices, land attributes, non-shared machinery, and percentages of debt free land and non-shared machinery. Joint components include negotiated contractual items that affect both producers. As previously mentioned, contractual issues examined include the percentage of shared machinery costs, penalty payments for untimely machinery delivery, and the percentage of shared machinery depreciation claimed by each farm. Climate variability and harvesting windows are accounted for within the two-farm simulation model. A crop growth model, which uses farm specific weather data, is used to generate yields and maturity dates for each. Harvesting window sensitivity analysis is conducted by considering farm locations in diverse geographic locations. Various combinations of farms located in Texas, Colorado, and Montana are simulated. The two-farm simulation model is used to evaluate machinery sharing as a method to increase NPV of after tax cash flows and decrease risk compared to each farm independently buying the machinery.

Organization

This dissertation is organized in a traditional dissertation format consisting of seven separate chapters. This first chapter consists of an introduction with accompanying research objectives. The second chapter is a literature review. The review consists of general theory related to machinery sharing, as well as, literature specific to machinery sharing. Observations from discussions with agricultural producers currently engaged in machinery sharing are also included in this chapter. The theoretical model, developed in Chapter III, provides the foundation for the two-farm machinery sharing simulation model developed in Chapters IV and V. A discussion of the crop growth model and inputs used to determine crop yields and harvesting windows are presented in Chapter IV. The development of the empirical two-farm simulation model is completed in Chapter V. Results from the simulation models are presented in Chapter VI. Conclusions, a discussion of limitations of the research, and topics for further research complete the dissertation.

CHAPTER II

LITERATURE REVIEW AND INDUSTRY OPINION

Literature related to machinery sharing is separated into broad, and in most cases, already extensively developed interrelated areas of research. The key papers in contract theory, information-based models, investment theory, risk, and literature specific to machinery sharing are presented here. A brief section on simulation modeling including farm and crop growth is also included. This review does not pretend to address all the important issues or articles, rather selective issues in each area are presented.

Contract and Transaction Costs Theories

The foundation of contract and transaction costs theories began with Coase's (1937) essay where transaction costs are introduced to explain firm size. Coase (1937) explains that an entrepreneur begins to hire laborers when the cost of hiring is less than the cost of acquiring a good through the market. Firms emerge because transaction costs, costs above the price of the good or service, can be avoided through internalization of production (integration) (Coase 1937). From a network perspective of inter-organizational collaboration, there are potential gains to be realized from the pooling of resources (Powell 1990). Potential gains include access to new technologies, economies of size in joint production, risk sharing, and access to sources of know-how outside the firm through strategic alliances and partnerships. Supply chain analysis literature indicates that vertical interdependencies require understanding of resource allocation and information flows between firms engaged in sequential stages of production (Christopher 1998; Simchi-Levi, Kaminski, and Simchi-Levi 2000). Ties between firms in different levels of the netchain, for example, the interdependencies between machinery dealers and producers, are important to understanding inter-organizational relations (Lazzarini, Chaddad, and Cook 2001). Although Lazzarini, Chaddad, and Cook (2001) did not specifically consider the example of machinery sharing, interdependencies are important to firm governance structure and decision making.

Modern contract theory surfaced in the context of share-cropping in China (Cheung 1969). Cheung (1969) argues that as long as property rights are exclusive, specified, enforceable, and transferable, different contractual arrangements do not imply different efficiencies of resource allocation. Contract theory evolved further with the development of principal-agent models (Stiglitz 1974; Milgrom and Roberts 1992). Stiglitz (1974) uses an expected utility maximizing model of a laborer and landlord to explain why the agricultural sector has moved away from sharecropping to wage and rental systems. The inefficiency of the sharecropping system, changes in risk, development of capital markets, increasing capital intensity, and the increase in the rate of technological changes have contributed to the decline of sharecropping. Milgrom and Roberts (1992) identify the basic components of contract design as informativeness, incentive intensity, monitoring intensity, and equal compensation principles.

Building on previous foundational work (Coase 1937; Klein, Crawford, and Alchian 1978; Williamson 1979), Grossman and Hart (1986) present a theory of contracts where rights are divided into specific rights (rights stated in contract) and residual rights (all rights not stated in contract). They develop a two firm, two period, symmetric information Nash equilibrium bargaining model to explain when one firm will desire to acquire the assets of another (integration); the model is applied to the insurance industry. Inefficiencies are found to arise from the distribution of property rights; ownership structure determines the nature of the investment distortions. Even with *ex-ante* bargaining, inefficiencies can be explained by contract incompleteness. Because not all aspects of a contract are specified *ex-ante*, efficiency depends on the allocation of residual rights of control (Grossman and Hart 1986). In their two firm model with control by firm 1, firm 1 over invests relative to the first-best solution and firm 2 under invests. Similarly, with firm 2 in control, firm 2 over invests relative to the first-best solution and firm 1 under invests. In the case of no integration, it is very likely that both firms under invest.

More recently, stemming from Coase's (1937) essay, the theory of the firm has been redeveloped and redefined into four elemental theories consisting of rent-seeking, property rights, incentive system, and adaptation (Gibbons 2005). Gibbons (2005) uses utility maximizing principal-agent models to explain these elemental theories. Wu (2006) highlights specific types of distortions identified by literature in transaction costs, property rights, and incentives theory. Wu (2006) also points out that Gibbons (2005) provides a five-stage framework that incorporates the elemental theories into an integrative structure. He argues this structure is important for developing effective government policy and for identifying various inefficiencies and contract distortions created by contracting imperfections. Transaction cost theory focuses on *ex post* rent seeking while property rights theory attributes *ex ante* negotiations as the source of inefficiency (Wu 2006).

Asymmetric Information

One focus of principal-agent theory is to explain why firms deviate from profit-maximizing behavior, postulating that deviations can be traced to the inability of the principal to monitor actions of the agent. The root of the problem stems from incomplete information. Cooperative partners can misrepresent the skills, abilities, and resources that they bring into an alliance, which gives rise to adverse selection problems. Arrow (1963) shows uncertainty and asymmetric information in the medical industry may lead to market failure. Akerloff (1970) later develops a theoretical model of the used car market as an example of an adverse selection problem. Akerloff (1970) finds that with car type uncertainty (good or lemon), the lemons tend to drive out the good cars because it is difficult to distinguish the actual car type and both types sell at the same price. Cooperative partners may also have valuable skills, abilities, and/or resources that are not made available to their partners, which give rise to moral hazard problems. Theoretical asymmetric information literature is well developed (Akerlof 1970; Rothschild and Stiglitz 1976; Wilson 1977). For a general overview of the principal-agent framework see Bolton and Dewatripont (2005), where distinctions are made between hidden action (moral hazard) models and hidden knowledge models (adverse selection).

Investment Theory

Project investments are often evaluated on their net present value (NPV), which is the aggregation of the discounted periodic net after tax cash flows occurring throughout the project life. Investment and decision theory indicate that when NPV is positive, it is profitable to undertake a project (Just, Hueth, and Schmitz 2004). When cash flows are uncertain, NPV becomes probabilistic. In the probabilistic case, NPV is often expressed using its mean and variance to account for the uncertainty in cash flows (Bussey 1978). The mean-variance portfolio analysis is superior to considering only the discounted expected value of future net returns because future net returns are uncertain; the inclusion of variance accounts for risk (Markowitz 1952).

Contrary to the Marshallian criterion of shutting down operations if variable costs are cannot be covered, Dixit (1992) shows that if the investment satisfies certain conditions, the point of abandonment should be at a critical level of operating profit that is below the Marshallian criterion. The point made is that there is value in waiting to make a decision because investors are able to minimize downside risk while realizing the upside potential (Dixit 1992). This idea has given rise to the real options literature. In the case of machinery sharing, there may be value in establishing a machinery sharing contract such that the first machinery user has the option to delay machinery delivery to the second user. Of course exercising such an option would come at a cost. Any additional gains from postponing machinery delivery plus the cost of exercising the option must outweigh any penalties to be paid to the second user.

Risk

With uncertainty in outcomes, decisions are made according to a subjective probability theory where beliefs are focused on the occurrence of future events. The expected value is the weighted average of the outcomes (Simon and Blume 1994). The subjective expected utility theory hypothesis proposed by Savage (1954) states that the utility of a risky alternative is the decision maker's expected utility for that alternative where utilities are independent of the underlying state of nature and outcomes are assigned subjective probabilities independent of actions. Rabin and Thaler (2001) point out that the subjective expected utility theory hypothesis is flawed as a behavioral theory of choice. Subjected expected utility, however, is also argued to be the most appropriate theory for prescriptive assessment of risky choices (Hardaker et al. 2004).

Various risk efficiency criteria used to rank risk management strategies show a high degree of consistency in ranking among the highest ranked strategies (Gloy and Baker 2001). Gloy and Baker (2001) show that rankings produced by expected return, stochastic dominance, mean-variance, and Sharpe ratio criteria are likely to produce similar results. Hardaker et al. (2004) demonstrate stochastic efficiency with respect to a function orders utility efficient alternatives over a range of risk aversion levels measured in terms of certainty equivalents. Stochastic efficiency with respect to a function is more potentially discriminating at all levels of risk aversion than stochastic dominance with respect to a function (Hardaker et al. 2004).

Farmers' risk preferences affect the probability of adopting new technologies (Koundouri, Nauges, and Tsouvelekas 2003). Koundouri, Nauges, and Tsouvelekas

(2003) present a theoretical framework considering technology adoption in a randomly selected sample of farms located in Greece. Results show that farmers who maximize expected utility of profit invest in new technology as a means of hedging against input-related or cost-side production risk.

Machinery Sharing

Research on machinery sharing is limited. Several studies incorporating some form of machinery sharing have been examined in the context of farm cooperatives (de Toro and Hansson 2004b; Musabelliu and Skreli 1997) and agricultural production (Olszweski 1997; Werschnitzky 1972). Musabelliu and Skreli (1997), Olszweski (1997), and Werschnitzky (1972) address machinery sharing, but unfortunately only English short summaries are available. English translation of French, Russian, and German summaries are obtained from Texas A&M University Libraries on-line services.

Machinery utilization plan selections are important to a firm's cost reduction, risk management, and production. Olzsweski (1997) examines equipment sharing as a possible cost reduction technique. Through modernization and equipment sharing, farm managers are able to reduce capital expenditures by 39 to 78 percent (Olzsweski 1997). de Toro and Hansson (2004b) examine a Swedish machinery cooperative taking into account labor, specific machinery, timeliness costs, and weather variability. Their simulation model suggests machinery sharing contributes to a 15 percent reduction in total costs and a 50 percent reduction in investment requirements. de Toro and Hansson (2004b) only examine the effects of a machinery cooperative in one region. Sharing machinery between farms in different regions with different weather-determined harvesting windows was not examined. Scattered parcels of land from state farm break-ups in Albania have led farmers to examine alternative forms of cooperation including cooperative use of machinery (Musabelliu and Skreli 1997). Werschnitzky (1972) uses previously developed empirical investigations to describe the economic and social aims of interfarm co-operation for machinery sharing.

Factors to Consider

Previous literature has used various methodologies to characterize the relationship between combinations of machinery sets, labor, weather variability, and timeliness issues. Models using linear programming usually include probability values of workable field days as inputs (Edwards and Boehlje 1980; Witney and Eradat 1982; Jannot and Cairol 1994; Etyang et al. 1998; Siemens 1998; Ekman 2000). Models using discrete event simulation techniques are based on daily field operations for a given farm and include constraints on weather or soil workability, as well as, other choice variables (Buck, Vaughan, and Hughes 1988; Lal et al. 1991, 1992; Chen, Ahmad, and Willcutt 1992; Parmar, McClendon, and Potter 1996; de Toro and Hansson 2004a, 2004b).

Only a limited amount of time is available to complete critical operations. Timeliness, therefore, is an important factor to consider when selecting a machinery set. Edwards and Boehlje (1980) develop a simulation model to evaluate net machinery costs considering timeliness losses on corn-soybean farms. Costs associated with untimely operations are difficult to estimate. Cost estimates should consider factors such as acreage, size of machinery, and available labor hours by detailed cropping activity (Edwards and Boehlje 1980).

Perhaps the most important factor in machinery selection in production agriculture is uncertainty about the weather, thus time available for farm work. Hill et al. (2000) find that weather forecast information and forecast type are valued differently by producers in different regions. They conclude that weather forecasts have implications for producers and that forecasts need to be region specific. Because weather varies by year, a risk averse farmer would generally choose a machinery set that is adaptable and proven to perform over a range of weather conditions even though the machinery set is not optimal under a single state of nature (Danok, McCarl, and White 1980). In cases where harvesting capacity is a limiting factor, the number or size of machines may need to be increased to successfully harvest in periods of peak yield and/or demand. Additional capital investment required to increase harvesting capacity during peak yield times, however, may not be cost effective (Chen, Ahmad, and Willcutt 1992).

Chen, Ahmad, and Willcutt (1992) develop a simulation model of the seed cotton harvesting and hauling system. They show that machinery set selection and weather affecting initial harvest date significantly affect cotton lint picked and total revenue. Parmar, McClendon, and Williams (1994) also use a simulation model to show that net returns can be negatively affected by the number and scale of machinery units. Even when machinery sets with the highest capacity are employed, harvesting performance may be significantly reduced in years of extreme weather conditions (de Toro and Hansson 2004a). In addition, machinery selection may play a pivotal role in harvesting timeliness when seasonality affects the quality of goods produced (Mayande and Srinivas 2004).

Models of collaboration allow firms to arrange resources and capabilities in efficient ways to produce, minimize transaction costs, and overcome gaps in information. To address farm machinery sharing specifically, the literature suggests a variety of mathematical programming and simulation approaches as useful frameworks. Previous studies have given clear indications of key decision factors, although few have been developed specifically for shared machinery problems.

Crop Growth Simulation Modeling

"Crop models have many current and potential uses for improving research understanding, crop management decisions, policy planning and implementations, and adapting to current and future climate change" (Timsina and Humphreys 2006 p. 202). Crop growth simulation models were first developed to explain variation in crop growth, but uses in agricultural research have led towards strategic decision-making support, forecasting yields, and explorative scenario studies (Bouman et al. 1996). Such models have seen increased attention in the agronomy literature because they are less time-consuming and expensive than traditional field studies.

Many diverse crop models have been developed to predict growth, development and yields (de Wit, Brouwer, and Penning de Vries 1970; de Wit, Goudriaan, and van Laar 1978; van Keulen 1975; van Keulen, Penning de Vries, and Drees 1982; Stroosnijder 1982; Kropff and van Laar 1993; Bouman 1992, 1995; Rosenthal et al. 1989a, 1989b; Bannayan, Crout, and Hoogenboom 2003). Hoogenboom (2000) presents an overview of crop modeling. He discusses key inputs that are required to mathematically model interactions of science and the environment. Agrometeorological variables including precipitation, air temperature, and solar radiation are identified as key input variables for simulation models to estimate agricultural production.

Baier (1979) proposes a three group classification system for crop models that considers time scale, data sources, approach, purpose, and application. The three non-mutually exclusive proposed categories are mechanistic crop growth simulators, statistically based crop-weather models, and multiple regression yield models. Mechanistic crop growth simulation models are based on the physiological or causal effects between plants and environmental factors while statistical and multiple regression models are based on correlations between biological and physical processes.

de Wit (1982) proposes a four phase classification system (Bouman et al. 1996; Hoogenboom 2000) for crop models. Each phase incorporates additional biological processes, thereby increasing the complexity of the model. The four phases (with major input variables in the parentheses) are: 1) growth rates determined by weather conditions (temperature and solar radiation); 2) water-limited production (precipitation and/or irrigation + phase 1 variables); 3) nitrogen limited production (soil and plant nitrogen + phase 2 variables); and 4) nutrient limited production (phosphorous, potassium, and other minerals + phase 3 variables). Hoogenboom (1998) points out that balancing the level and amount of user-supplied input data is a delicate issue. Crop growth development has been modeled using the first three phases, but few models include one or more processes at Phase 4 (Hoogenboom 2000). Hansen et al. (2006) argues that advances in climate-based crop forecasting are likely to include crop models embedded within climate models to account for crop influences on regional climate.

DSSATv4, SORKAM, EPIC, CERES, SIRIUS, and CROPGRO are only a few of the many crop growth simulation models currently used. The Decision Support System for Agrotechnology Transfer (DSSATv4), which is used this dissertation, is a software program designed for seasonal analysis. DSSATv4 is one of the few models that can simulate crop growth and development with processes at all four phases given by de Wit (1982). The model uses a combination of crop soil and weather data bases, management programs, crop models, and application programs to integrate the effects of soil, crop phenotype, weather, and management options. DSSATv4 also provides for verification of crop model outputs; thus allowing users to compare simulated outcomes with observed results (International Consortium for Agricultural Systems Applications 2007). In addition, DSSATv4 includes application programs for seasonal and sequence analyses that assess the economic risks and environmental impacts associated with irrigation, fertilizer and nutrient management, climate change, soil carbon sequestration, climate variability, and precision management (International Consortium for Agricultural Systems Applications 2007). Similar to other seasonal analysis crop models, DSSATv4 evaluates a management policy for a single season from which physiological maturity date and crop yield are obtained.

Thornton, Dent, and Bacsi (1991) provide a description of crop growth models and applications using DSSATv4. The authors show that biophysical crop models are being used by many organizations for development and research. In particular, relevant applications of biophysical crop models at the field, farm, regional, and national are provided. At the farm level, research or development objectives may include biological and economic feasibility and stability or socio-economic objectives examining new technology adoption and reaction to change. Unfortunately, DSSATv4 does not estimate yield loss associated with untimely harvest after physiological maturity. Even though DSSATv4 does not include all the features needed in a two-farm simulation model, DSSATv4 is valuable in studying farm level crops.

Factors Affecting Crop Yield after Maturity

Wheat is not harvested at physiological maturity, but rather when the wheat grain is harvest ripe (Farrer et al. 2006). At physiological maturity wheat grain has a moisture content of 37 percent (Calderini, Abeledo, and Slafer 2000), but at that moisture level the grain is too soft to combine. After the grain has dried to an acceptable moisture level that is safe for harvesting and storage, the grain is ready to harvest. Farrer et al. (2006) provides a review of how harvesting delays beyond wheat grain ripeness result in yield reductions caused by shattering and lodging. The authors find that 20 percent yield losses are possible with only eight days between physiological maturity and harvest. Higher yield losses were attributed to hot, dry weather.

Shattering is when the spike-lets or grain kernels fall from the plant (Farrer et al. 2006). Yield losses can reach up to 17 percent from shattering if harvest is delayed (Clarke and DePauw 1983). Clarke (1981) shows that larger seed size is more susceptible to shattering.

Cereal grain yields are adversely affected by up to 50 percent from lodging (Stapper and Fischer 1990). Lodging, when the crop plant stands fall over or plant shoots are permanently displaced from an upright position (Pinthus 1973), is often caused by weather events such as wind, hail, or rain. Plant lodging reduces yields by making harvesting more difficult. Fischer and Quail (1990) concludes higher yields are achievable with genotypes that resist lodging. Berry et al. (2002) report that winter wheat suffers severe lodging every three to four years. A wheat simulation model developed by Berry et al. (2003) has successfully predicted the timing and amount of lodging risk using plant characteristics, soil, and weather data.

Tripathi, Sayre, and Kaul (2005) through experimental trials show that planting systems and cultivar selection can reduce lodging, as well as, increase grain yield by four percent. Tewolde, Fernandez, and Erickson (2006) evaluated 16 wheat cultivars for two growing seasons. They found that cultivars that headed later in the season had reduced yields of 35.3 kg ha^{-1} and 91.0 kg ha^{-1}. Cultivars that headed early outperformed cultivars that headed later because early-heading cultivars had a longer grain filling period in temperatures that were lower and more favorable (Tewolde, Fernandez, and Erickson 2006).

Pests, animals, and disease also contribute to grain yield reduction. Borman et al. (2002) using differential global positioning system technology, measure the impact of Canadian geese grazing on farm crops including wheat in Washington and Oregon. Paired-plot result comparisons show grain yields are reduced by up to 25 percent from grazing by geese. Hudec (2007) finds that delayed harvest of spring malting barley in

Slovakia results in increased fungal infestation and lower kernel germination. Biotic infestation, an indirect result of post-maturity moisture intensity, is one factor that determines the degree of down-grading in wheat (Clarke et al. 2005). In addition, Clarke et al. (2005) finds loss in post-mature wheat is similar across cultivars.

Farrer et al. (2006) shows the winter wheat can be reduced by up to 900 kg per hectare because of delayed harvest. In addition, yield losses are positively related to total precipitation and negatively related to minimum daily temperature while harvest date was not significant for reduction in test weights (Farrer et al. 2006). Because wheat yields decrease after the maturity date has been reached, another important aspect is determining the rate of yield reduction. Yield loss rates from delayed harvest have been reported of up to 0.5 percent per day (Bolland 1984), 0.3 to 0.9 percent per day (Abawi 1993), and from 5 to 18 percent for 30 days after physiological maturity (de Koning 1973). Abawi (1993) gives a yield loss function from shedding, quality loss from rain, and machine losses from gathering and separating wheat. The yield loss function due to delayed harvesting is $L_t = \begin{cases} 0.0004 \cdot n_t \cdot Y_t & if\ n_t < 10 \\ 0.004 \cdot n_t \cdot Y_t & otherwise \end{cases}$,

where L_t is the cumulative grain loss (t ha^{-1}), 0.0004 and 0.004 are the rate of yield loss, n_t is the number of days past maturity, and Y_t (t ha^{-1}) is the crop yield in year t (Abawi 1993).

Farm Economic Modeling

Farm modeling encompasses an enormous body of literature that has been well documented. Because of the amount of literature and previous documentation, the literature review here only discusses a few select references. The main focus is literature related to farm modeling that incorporates crop growth models.

Four volumes edited by Martin (1977a, 1977b, 1981, and 1992) provide an excellent survey of the agricultural economics literature including farm modeling from the 1940's to early 1990's. More recently, two volumes edited by Gardner and Rausser (2001a, 2001b) review and assess the state of knowledge in agricultural economics. Volume 1A deals primarily with agricultural production. In Chapter 2 of Volume 1A, Moschini and Hennessy (2001) review literature related to farm-level production decisions under risk and uncertainty. They conclude risk has long-run implications for business organization of agricultural production and the structure of resource ownership.

A selection of keynote papers and oral presentations on crop models and their applications from the international symposium titled "Systems Approaches for Agricultural Development" are highlighted in a book edited by Kropff et al. (1997). The editors provide a list of references that link biophysical processes captured in crop models to evaluate options of resource management at the field, farm, and regional scales. During the 2000 Annual Meetings of the American Society of Agronomy, a symposium titled "Crop Models in Research and Practice" was held. Proceedings from the symposium provide material for developing crop models and applications to farm modeling (International Consortium for Agricultural Systems Applications 2007). Previously discussed books, articles, and symposiums give researchers an overview of crop simulation models and how they can be applied to farm economic decision modeling.

Wright and Dent (1969) were among the first researchers to integrate crop and farm simulation models. The authors collaborated with an agronomist to perform simulations of pasture production for a sheep grazing system in Australia. A whole-farm approach is used to examine the practice of growing oats versus grazing. They find returns from grazing are $20.90 per acre. Returns are reduced as the percentage of acreage used for winter cropping of oats is increased.

Application of biophysical simulation models to production problems is discussed by Musser and Tew (1984). They argue that biophysical simulation should be included among the methods of empirical methodology for research. Dillon (1987) reviews the application of biophysical simulation models to agricultural economic research and he supports the use of biophysical simulation models to overcome data limitations. Results from Dillon, Mjelde, and McCarl's (1989) study on crop production decisions in the Blackland Region of Texas show that risk is important in production management decision making. Wheat production is more attractive to risk averse producers because wheat is exposed to less severe moisture conditions than spring crops such as corn and cotton. Several articles cited by Dillon (1987) as supporting evidence of the use of biophysical crop models in farm modeling are Mapp and Eidmann (1975, 1976), Boggess (1984), and Mjelde (1985).

At the farm level, Mapp and Eidman (1975) use a simulation model to estimate soil-water-crop relations to evaluate irrigation strategies in Oklahoma. In addition, Mapp and Eidman (1976) extend the use of biophysical simulation models to address potential implications for policy on the Ogallala aquifer. The authors calculate expected net returns for different water regulation alternatives to ascertain potential effects of policy. They find net present value of farm income is greatest under the graduated tax policy.

Buller and Bruning (1979) use a sequential simulation model to study the relationship between net farm income and land tract dispersion, rainfall, and management practices for a representative Northeast Kansas corn, soybean, and wheat farm. Results show that increasing land dispersion would decrease net farm income for farm sizes exceeding 275 acres. The authors assume that yield per acre per crop are identical. The effects of rainfall on soil workability are considered.

Lemieux, Richardson, and Nixon (1982) also used a whole-farm simulation model for a typical Texas High Plains cotton farm. FLIPSIM IV, a policy simulation model, was used to examine the effects of switching from the Federal Crop Insurance Program (FCI) to the Agricultural Stabilization and Conservation Service (ASCS) low yield disaster program. They found that risk averse producers would prefer the crop insurance coverage programs. An extension of the FLIPSIM IV program, Simetar© (Richardson, Schumann, and Feldman 2006), is available as a Microsoft ® Excel add-in software program. The model developed in the current study is created in Excel using Simetar©.

Boggess (1984) and Hoogenboom (2000) discuss the integrated and interdisciplinary processes of biophysical simulation. While Boggess (1984) relates behavioral theory to biophysical simulation, Hoogenboom (2000) takes a more general approach and focuses on the application and significance of weather and climate variability in strategic and risk management decision-making. Hoogenboom (2000) concludes that weather forecasts will play an important role in biophysical simulation models of the future.

Mjelde (1985) uses a biophysical simulation and economic optimization model to evaluate climate information on corn production management decisions at the field level. He finds that climate forecasts have value to corn producers. In particular he shows that corn yield declines with late harvesting using harvesting loss derivations from Johnson and Lamp (1966).

Parmar, McClendon, and Williams (1994) demonstrate how crop growth simulation models can be used in farm modeling. Peanut yield data generated from the crop growth model is incorporated into a machinery management model to determine the net returns above machinery costs for two different equipment sets. In this dissertation, machinery set selection effects on timeliness of harvesting and yields are accounted for within the model. A book chapter by Lal (1998) cites works that have previously developed models that range from simulating single operations to more sophisticated models simulating complete growing seasons. Lal (1998) also provides a list of studies that have successfully developed whole farm simulation models that include both plant physiological and growth processes with operational requirements. Stoorvogel et al. (2004) apply a methodology for examining tradeoffs between economic and environmental indicators using biophysical and econometric simulation models. The methodology is applied to a potato-pasture production system in Ecuador. The authors find that with a 50 percent decrease in farm potato prices, 99 percent of all fields will remain under the carbofuran EPA threshold of 40 ppb.

Finger and Schmid (2007) integrate biophysical simulations with an economic model to examine impacts of climate change on corn and winter wheat production in the Swiss Plateau. The authors use CropSyst to generate yield data to estimate a yield variation function. They find yields and yield variability are highly correlated with climate change and output prices.

This literature review does not provide a comprehensive review, but rather presents a few select pieces within each research area that are related to machinery sharing. The cited references serve as a guide and basis for understanding the structure and underpinnings of the models developed in the present study. The preceding review of literature also provides supporting evidence of the key factors to consider when developing the framework for a machinery sharing problem. Additionally, previous research indicates and supports the use of biophysical simulation models within farm economic models as a useful methodological approach. The coupling of biophysical and farm economic simulation models can be used to examine potential gains that can be realized from machinery sharing through cost reduction, risk sharing, and efficiencies.

Qualitative Data on Machinery Sharing

Because machinery sharing is not widely observed, literature and knowledge on the current status of machinery sharing is limited. To overcome this limited research, producers either considering machinery sharing or currently involved in sharing were interviewed in an informal group setting. These discussions with top agricultural producers occurred at the Association of Agricultural Production Executives (AAPEX) 2008 meetings held in San Juan, Puerto Rico. Fifteen producers that are already engaged in, or are considering sharing machinery were present at the group discussion. Several other AAPEX members were interviewed separately. The discussions centered around logistics, advantages, disadvantages, and concerns of sharing machinery.

Machinery sharing is already implemented into several large scale farming operations across the U.S. Equipment that is currently being shared ranges from wheat, corn, cotton, and soybean combine harvesters to manure spreaders. No commodity trucks were reported to be shared.

The most important issues to these producers when looking for potential partners for sharing equipment are compatibility, expectations, and trust. The majority of producers agreed that most agricultural producers are trustworthy. Overlaps in harvesting windows and transaction costs of sharing machinery are also considered important issues. Where machinery sharing is occurring, transactions costs and trust issues are often eliminated because the same producer manages and uses the same machinery on two geographically disperse farms.

Other producers engaged in machinery sharing addressed these important issues through contract negotiation. AAPEX members currently engaged in machinery sharing have reduced their liability and financial risk through forming limited liability companies. The limited liability company leases new equipment each year and both producers pay the company a percentage of the leasing costs based on machinery usage. Any repair costs not covered by warranty and that are caused by machinery operator error are paid by the producer who is currently using the machinery. Annual repair costs for combines under warranty range between $1,200 and $2,000. No additional insurance is purchased because the machinery is covered under an already existing umbrella policy purchased by the producers.

Other repair expenses such as belts, oil changes, and lubrication are shared between the producers based on machinery usage, while transportation costs are shared equally. Total annual transportation costs of renting a truck to haul a single combine between northeast Iowa and Colorado were reported to be $7,600. One producer noted that any inefficient harvesting by one producer was penalized by increased machinery usage and ultimately higher costs for that same producer. AAPEX members also indicated that they owned their own combine heads which reduced transportation costs. It should be noted, however, that transportation costs varied greatly from state to state because of U.S. Department of Transportation regulations on oversized loads. Trucks with oversized loads are only allowed on the road at specific times of the day and days of the week.

The qualitative understanding of machinery sharing practices, along with the published models, provides a baseline for the development of this dissertation. Deviations from information obtained in the discussions with AAPEX members are specifically addressed in the two-farm simulation model development.

CHAPTER III

THEORETICAL MODEL

Consider two economic agents considering buying new machinery (Figure 3.1). The agents must make a decision as to either buy and use the machinery independently or buy the machinery and share in its use. If the agents choose to buy independently, they each determine equipment size, receive their own returns, and pay all ownership and transaction costs. However, if the agents choose to share machinery ownership, they still receive all their own returns and pay all own variable and transaction costs, but each agent will only pay a percentage of the shared machinery and transaction costs. Further, if ownership is shared, the agents must determine provisions associated with the contract.

Contract provisions including how machinery costs, initial investment, and maintenance costs should be shared between two firms are addressed in this chapter. A single period Nash-equilibrium theoretical model for two firms sharing machinery is developed and used to determine the theoretical optimal sharing rules. As defined in Chapter I, optimal machinery sharing rules are the percentages of total shared machinery costs borne by each firm (agent). This chapter is concerned with setting up the machinery sharing problem and the cost sharing rules associated with the sharing component of the overall decision process.

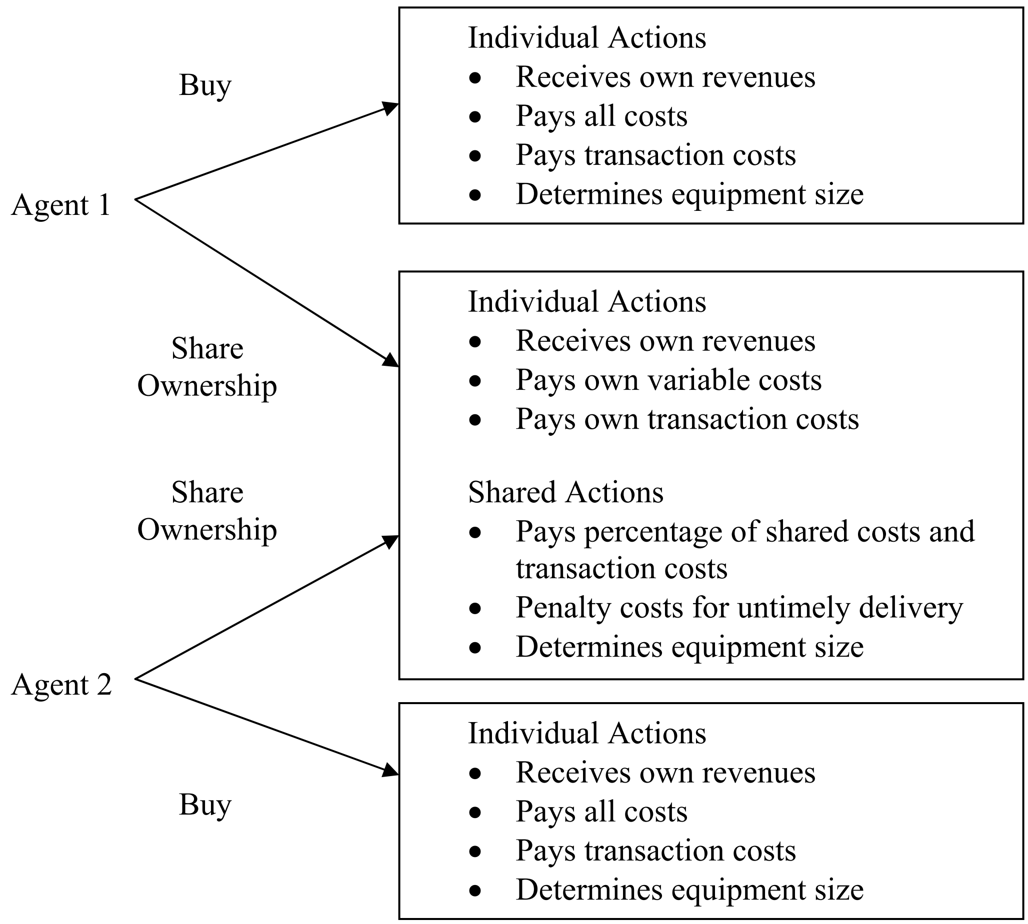

Figure 3.1 Machinery sharing decision tree for two economic agents with complete information

Nash Equilibrium Theoretical Game

To determine the optimal cost sharing rules, a Nash-equilibrium theoretical game for two risk neutral economic agents is constructed. Nash equilibrium is defined as "The strategy combination is a Nash-equilibrium if no player has incentive to deviate from his strategy given that the other players do not deviate" (Rasmusen 1989, 33). The theoretical model represents interactions of two producers who are sharing a new set of machinery. For ease in exposition, the machinery set to be shared is a harvesting set (combines) by two independent agriculture producers. Producer decision variables are the percentage of total shared costs paid by each producer and the machinery technology set to be purchased. Shared costs include purchase and financing costs net of salvage value, maintenance costs, transportation costs, and transaction costs.

Both producers, A and B, seek to maximize the expected present value of net returns, V^i, where *i* is either producer A or B. Both producers are assumed to be risk neutral. It is assumed that once determined, the percentage of shared costs is constant throughout the life of the contract. Further, it is assumed the firms enter into the machinery contract negotiations and base machinery sharing decisions on information and rules established *ex ante*, that is, before the actual sharing occurs. Under these assumptions, producer *i*'s expected present value of net returns, V^i, is

$$V^i = R^i - \gamma^i S^i + Pen^i - C^i \tag{3.1}$$

where R^i is defined as the expected present value of returns, γ^i is the percentage of costs shared, S^i is the expected present value of shared costs, Pen^i is the expected present value of a penalty payment, and C^i is the expected present value of non-shared firm specific costs including all own transaction costs. More specifically, the components of equation (3.1) are

$$R^i = \sum_{t=0}^{T} E\left[R_t^i (1+r)^{-t}\right], \tag{3.2}$$

$$S^i = \sum_{t=0}^{T} E\left[S_t^i (1+r)^{-t}\right], \tag{3.3}$$

$$Pen^i = \sum_{t=0}^{T} E\left[Pen_t^i (1+r)^{-t}\right], \text{ and} \tag{3.4}$$

$$C^i = \sum_{t=0}^{T} E\left[C_t^i (1+r)^{-t}\right]. \tag{3.5}$$

where E is the expectations operator taken over weather conditions, T is the total number of years in the planning horizon and t represents years, R_t^i are the returns associated with year t, r is the discount rate, S_t^i are the total shared costs in year t including shared transaction costs, Pen_t^i are the penalty payments or receipts in year t, and C_t^i are the non-shared firm specific costs in year t including non-shared transaction costs. For simplicity, it is assumed that all prices are nonstochastic.

With this framework, the next step is to provide the arguments in the above functions. It is assumed all shared costs must be paid by the two producers. With this assumption $\gamma^A = \alpha$ and $\gamma^B = (1-\alpha)$. It is assumed that once determined, α and the machinery technology set indicator, I, are fixed over the length of the contract. These simplifying assumptions are not unreasonable; at the beginning of the contract the parties agree to fix the percent of shared costs and the machinery set for the life of the contract.

The expected present value of returns, $R^i(g^i, z, a^i, I, r, v^i, w^i)$, is a function of output price, g^i, condition of equipment, z, acreage, a^i, machinery technology set, I, discount rate, r, variable inputs, v^i, and random weather, w^i. Machinery set selection affects returns because a larger capacity or more efficient machine allows for more efficient harvesting operations. The machinery set indicator, *I*, is assumed for mathematical ease to be a continuous variable that reflects changes in size and efficiency.

The contract specifies that both parties will share a percentage of the total costs of ownership. Shared costs include discounted cash flow payments of the machinery purchase and financing costs net of salvage value, $P(I,r)$, maintenance costs, $m(I,z,a,r)$, and yearly transportation costs associated with moving the machinery set between farms and transaction costs, $T(I,r)$. $P(I,r)$ is an increasing function of *I*; higher capacity and more efficient machinery sets have larger purchase prices. Present value of machinery maintenance costs are a function of chosen machinery technology, *I*, discount rate, *r*, total acreage ($a = a^A + a^B$), and the condition of the equipment, *z*. It is assumed shared maintenance costs allow each producer to receive the machinery in good operating condition.

There is a period of time or window of opportunity for optimal harvesting of the crops. Yields decrease when harvesting outside this window because weather and crop conditions begin to reduce crop yields and may eventually completely prevent harvest. Because of differences in location and variability in weather, harvesting windows for each producer may vary by year. If the two producers live in the same region where weather conditions are similar, sharing machinery is very likely to lead to demand for the combines to occur at the same time. As a result, one producer may face reduced yields because of untimeliness in harvesting. The model accounts for windows of opportunity by including an expected penalty function, $Pen(I,r,w^i,w^j)$, which is a function of machinery technology, the fixed discount rate, and random weather. Assuming producer A uses the equipment first, he must compensate producer B if machinery is not delivered at or before the contractual agreed time. This leads to the relationship $Pen = -Pen^A = Pen^B$; thus, the penalty is represented in the model by a single penalty function. By delaying the delivery of the machinery from producer A to producer B, producer B may face reduced yields because of harvesting delays. At the same time, producer A would face reduced returns if he delivered the machinery on time and did not complete harvesting operations.

Unshared firm specific costs, $C^i(h^i, I, a^i, r)$, are a function of input prices, h^i, machinery technology employed, acreage harvested, and the discount rate. Given that each producer independently operates shared machinery, any costs incurred that are not due to normal wear-and-tear become the responsibility of the producer who is operating the machine. For example, producer B should not be responsible for repair or maintenance costs resulting from careless machinery operation by producer A or for fuel used by producer A.

Given these definitions, producer A's problem is

$$\begin{aligned} \max_{\alpha,I} V^A = \max_{\alpha,I} \Big[& R^A(g^A, z, a^A, I, r, v^i, w^A) - \alpha[P(I,r) + m(I,z,a,r) + T(I,r)] \\ & - Pen\,(I, r, w^A, w^B) - C^A(h^A, I, a^A, r) \Big] . \end{aligned} \tag{3.6}$$

Producer B's problem is

$$\begin{aligned} \max_{\alpha,I} V^B = \max_{\alpha,I} \Big[& R^B(g^B, z, a^B, I, r, v^i, w^B) - (1-\alpha)[P(I,r) + m(I,z,a,r) + T(I,r)] \\ & + Pen\,(I, r, w^A, w^B) - C^B(h^B, I, a^B, r) \Big] . \end{aligned} \tag{3.7}$$

From producer A's maximization problem it is evident that producer A can increase net returns if α is equal to 0, *ceteris paribus*; consequently paying none of the shared costs. Similarly, producer B would have expected higher net returns if α equals 1, where producer A pays all the shared costs and producer B pays none. Given these two polar outcomes, there is obvious room for negotiation between the two firms. This negotiation sets up the game theory component of the model. The two producers must also decide on the machinery set, *I*, to be purchased. Larger and more efficient machinery sets increase returns and decrease the amount of expected penalty that will be paid. Shared costs, purchase costs, maintenance, and transportation costs, along with firm specific costs, however, increase as the machinery set is larger and more efficient. Again, trade-offs exist, as in general, each producers' return and cost functions are different with respect to machinery set, *I*.

Economic theory suggest the following concerning the signs of the partial derivatives with respect to the machinery set $\left(\frac{\partial R^i}{\partial I}, \frac{\partial P}{\partial I}, \frac{\partial m}{\partial I}, \frac{\partial T}{\partial I}, \frac{\partial C^i}{\partial I}\right)$. It is assumed that the signs of the aforementioned first partial derivatives are non-negative. Second partial derivatives are assumed to be negative for returns, $\left(\frac{\partial^2 R^i}{\partial I^2}\right)$ and penalty payment, $\left(\frac{\partial^2 Pen}{\partial I^2}\right)$, and positive for costs, $\left(\frac{\partial^2 C^i}{\partial I^2}\right)$. As the size of the technology set increases returns would be expected to increase because of increased efficiency and timeliness in harvesting. Returns, however, would increase at a decreasing rate. Similarly, as the machinery set increases, it is reasonable to assume that the purchase and financing costs, shared maintenance costs, and transportation costs also increase at an increasing rate.

Nash Equilibrium

Producer A's first order conditions (FOC) are

$$\frac{\partial V^A}{\partial \alpha} = -P(I,r) - m(I,z,a,r) - T(I,r) = 0 \text{, and} \tag{3.8}$$

$$\frac{\partial V^A}{\partial I} = \frac{\partial R^A}{\partial I} - \alpha\left[\frac{\partial P}{\partial I} + \frac{\partial m}{\partial I} + \frac{\partial T}{\partial I}\right] - \frac{\partial Pen}{\partial I} - \frac{\partial C^A}{\partial I} = 0. \tag{3.9}$$

Whereas, producer B's FOC are

$$\frac{\partial V^B}{\partial \alpha} = -P(I,r) - m(I,z,a,r) - T(I,r) = 0 \text{, and} \tag{3.10}$$

$$\frac{\partial V^B}{\partial I} = \frac{\partial R^B}{\partial I} - (1-\alpha)\left[\frac{\partial P}{\partial I} + \frac{\partial m}{\partial I} + \frac{\partial T}{\partial I}\right] + \frac{\partial Pen}{\partial I} - \frac{\partial C^B}{\partial I} = 0. \tag{3.11}$$

Nash equilibrium involves the simultaneous solving of the FOC to determine both decision variables, α and I.

The FOC conditions show two unique aspects of this problem. There are four FOC but only two decision variables, α and I. The problem is over-identified. Over-identification occurs because of the 1) sharing of the same machinery set and not determination of individual sets and 2) the realistic assumption that all costs are paid. The assumption of paying all the costs forces an exact relationship between the percentages of shared costs paid by the two producers. Equations (3.8) and (3.10) indicate there is no bounded solution. This arises because α enters both objective functions linearly. A linear function obviously has no extreme points without some constraint(s). A necessary constraint is that α is in the economic relevant range of 0 to 1. Fortunately, the two FOC, equations (3.9) and (3.11), can be used to solve for α, to provide insights into optimal sharing rules, one objective of this study. Unfortunately, an optimal *I* cannot be obtained using general equations.

Optimal Shared Cost Percentages

Solving equation (3.9) for α, provides producer A's reaction function for the optimal percentage for sharing costs:

$$\alpha = \frac{\frac{\partial R^A}{\partial I} - \frac{\partial Pen}{\partial I} - \frac{\partial C^A}{\partial I}}{\frac{\partial P}{\partial I} + \frac{\partial m}{\partial I} + \frac{\partial T}{\partial I}}. \tag{3.12}$$

If the machinery set selection is optimal, then the ratio of marginal net benefits of returns and costs not shared for producer A over marginal shared costs will be equal to the percentage of shared costs to be paid by producer A, equation (3.12). Consistency with economic theory can be shown. Economic theory suggests the optimal point of production for an individual firm is where marginal revenue equals marginal cost. If the marginal revenue equals marginal cost, the numerator in equation (3.12) equals zero at which point α equals zero. Consistent with previous observations, and economic theory, net returns are increased for producer A when producer A pays none of the shared costs, that is α equals zero.

Similarly, solving equation (3.11) for α provides producer B's reaction function:

$$\alpha = 1 - \frac{\frac{\partial R^B}{\partial I} + \frac{\partial Pen}{\partial I} - \frac{\partial C^B}{\partial I}}{\frac{\partial P}{\partial I} + \frac{\partial m}{\partial I} + \frac{\partial T}{\partial I}}. \tag{3.13}$$

Producer B's optimal decision results in the optimal percentage of shared costs being equal to one minus the ratio of marginal net benefits of non-shared returns and costs for producer B over marginal shared costs. Similar to producer A's reaction function, when marginal revenue is set equal to marginal costs, the numerator in the second part of equation (3.13) equals zero and α equals 1. When α equals 1, producer B's net returns increase because he pays none of the shared costs.

Setting equations (3.12) and (3.13) equal to each other and solving one obtains the Nash equilibrium for the percentage of shared costs:

$$\alpha = \frac{\frac{\partial R^A}{\partial I} - \frac{\partial Pen}{\partial I} - \frac{\partial C^A}{\partial I}}{\frac{\partial P}{\partial I} + \frac{\partial m}{\partial I} + \frac{\partial T}{\partial I}} = 1 - \frac{\frac{\partial R^B}{\partial I} + \frac{\partial Pen}{\partial I} - \frac{\partial C^B}{\partial I}}{\frac{\partial P}{\partial I} + \frac{\partial m}{\partial I} + \frac{\partial T}{\partial I}}. \tag{3.14}$$

The optimal or Nash equilibrium cost sharing percentage, α, is where the ratio of marginal net non-shared benefits over marginal shared costs of producer A equals 1 minus the marginal net non-shared benefits over marginal costs for producer B. The negative marginal net non-shared benefits over marginal costs for producer B indicates that cost sharing percentage cannot increase for both producers. A feasible economic equilibrium is not obtained if the equilibrium is outside the range of 0 to 1; machinery sharing will not occur. When the two curves do not cross in the economic feasible region, the outcome is a black hole or no economic equilibrium (Chang, Mjelde, and Ozuna 1998).

All marginal shared costs in the denominator of equation (3.14) are positive, thus the denominators are positive. As such, marginal shared costs alone cannot cause α to be negative. Further, marginal revenues are positive. Therefore, it is the magnitudes of own marginal costs, $\left(\frac{\partial C^i}{\partial I}\right)$, and the marginal penalty cost, $\left(\frac{\partial Pen}{\partial I}\right)$, that can cause α to be negative, thereby deterring machinery sharing. As an example of a black hole, consider producer A. For producer A, marginal revenue cannot be smaller than the sum of the marginal own costs and the marginal penalty. If marginal costs (own plus penalty) are larger, the optimal α becomes negative and no sharing occurs, a black hole. One potential cause of this particular black hole is own transaction costs. Recall *C*, includes own transaction costs. If own marginal transaction costs are large relative to the marginal returns, machinery sharing will not occur. A similar argument can be made for producer B.

Another example of a black hole is when own marginal costs are greater than marginal returns. Here, own marginal cost of operating the larger more efficient machinery outweighs any increase in revenue. In addition, machinery sharing does not occur when the marginal penalty costs are greater than marginal revenue minus marginal own costs. The penalty function based on harvesting windows is important in determining if machinery sharing will occur. A final example of when machinery sharing will not occur is when marginal shared costs are small (the denominator) relative to own marginal returns and costs (numerator). In this case, the denominator is small relative to the numerator giving an optimal cost sharing percentage greater than one.

If the two producers are homogenous in all aspects, the producers will equally pay shared costs. This can be shown by simplifying equation (3.14) to:

$$\alpha = D = 1 - D\,. \tag{3.15}$$

The solution to equation (3.15) is α = 0.5 or 50%; each homogenous producer pays one-half of the total shared costs. This special case is the only case when producers equally share costs without knowledge of the specific functions.

For heterogeneous producers, the percentage of total shared costs to be paid by each producer depends on the ratio of marginal own net benefits over marginal shared costs for each producer. The equilibrium will generally not occur at α = 0.5. The equilibrium point is dependent on the relative shapes of each producer's curve. If producer A realizes larger own marginal net benefits relative to marginal shared costs (larger ratio) than producer B, then producer A is willing to pay an additional percentage of the total shared costs to realize these additional benefits. Consequently, the percentage of shared costs would increase for producer A and decrease for producer B.

One extreme case for heterogeneous producers is when the equilibrium is at α = 1. Producer A is willing to pay all shared costs when own marginal returns minus the sum of own marginal costs plus marginal penalty exactly equals the sum of the marginal shared costs. As noted above, in this case producer B's will be such that the marginal revenue is equal to the sum of the marginal penalty plus marginal own costs. A similar argument can be made for the case α = 0, and producer B pays all shared costs.

Window of Opportunity

The preceding discussion on the marginal penalty function illustrates the importance of the window of opportunity in machinery sharing. Given our example of sharing harvesting machinery, three different scenarios exist when considering harvesting windows (Figure 3.2). In the following discussion, the first timeline represents producer A, who uses the machinery first, and the second timeline represents producer B. H_S represents the expected start of harvest and H_E the expected end of harvest. The three scenarios are:

1) no overlap in the harvesting operations for the two producers, timeline 2 to 3, (timeline 2 represents producer A and timeline 3 represents producer B in this scenario);
2) complete overlap in harvesting operations (timelines 2 to 1, but not timelines 1 to 2); and
3) partial overlap in harvesting operations (timelines 1 to 3).

The actual start of harvest for each year and producer is determined by weather conditions and location. Further, weather conditions and location will determine when producer A finishes harvesting and can deliver the machinery to producer B. If producer A is unable to deliver the machinery set to producer B by the time specified in the contract, then producer A must compensate producer B. Two important factors in determining this penalty are the windows of harvesting opportunity overlap and the form of the penalty function.

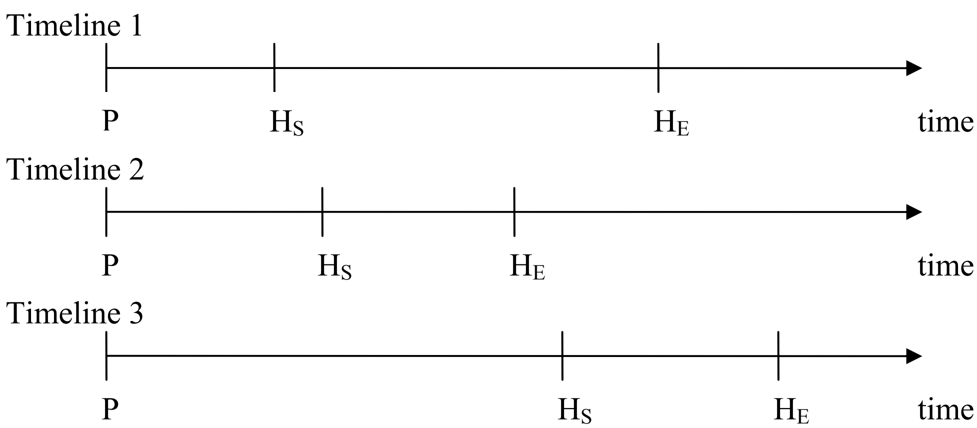

Figure 3.2 Three planting and harvesting timelines where P represents planting date, H_S is harvesting start date, H_E is harvesting end date, and time is the continuous planning horizon for one season

If there is no overlap in harvesting windows (scenario one), producer A will always complete harvesting before producer B needs the machinery. In this scenario, no penalty is necessary as timely delivery of the machinery always occurs. It is assumed that producer A does not deliver the machinery in a timely fashion only because his/her harvest is not yet finished. This is the simplest case, but the two producers will, in general, be separated by a large distance increasing transaction and transportation costs.

In the scenarios where there is either a partial (timeline 1 to 3) or complete (timeline 2 to 1) overlap in expected harvesting windows, the penalty function becomes an important component in machinery sharing. In the years where the machinery set is delivered before or at the specified date, producer A pays no penalty payment to producer B. However, in the years where weather is such that producer A does not finish harvest until after the specified calendar date; a penalty is paid to producer B.

Because the contract is determined *ex-ante* or before the weather occurs, development of the penalty is based on expected weather conditions. The expected penalty payment is driven by harvesting timeliness which is affected by the machinery set. A larger machinery set allows for a more efficient and timely harvest, and decreases the overlap. Transportation and maintenance costs, however, are a function of the size of the machinery set. Producers can not decrease the expected penalty to be paid without increasing these costs. In addition, expected returns are an increasing function of *I* but at a decreasing rate.

Penalty a Function of Machinery Set Only

Here, the penalty is only a function of the machinery set. If producer A delivers the machinery on or before the contractual date, no penalty is paid. On those years weather does not allow for timely delivery and producer A fails to deliver the machinery set by the agreed contractual date, producer A pays a fixed amount to producer B. This amount is a function of the machinery set chosen. As assumed in the model development, a larger more efficient machinery set is associated with smaller penalty payments, $\left(\frac{\partial \text{Pen}}{\partial \text{I}}\right) \leq 0$. Once the machinery set is chosen, this penalty function is easy to implement, but very inflexible. No incentives are provided to producer A to deliver the machinery set once the delivery date has been missed. Advantages of this penalty function are smaller transactions costs and information requirements.

Penalty a Function of Machinery Set and Delivery Date

To overcome the lack of incentives provided by a penalty function being only dependent on the machinery set, the penalty function could be based on the time that machinery is delivered beyond the specified date. Here, delivery time past the contract date, *k*, is included in the penalty function, $Pen\ (r, w^i, w^j, k(I))$. The expected marginal penalty in equation (3.14) becomes $\left(\frac{\partial \text{Pen}}{\partial \text{k}} \cdot \frac{\partial \text{k}}{\partial \text{I}}\right)$. The assumption made when developing the model was that the expected marginal penalty decreases with increases in machinery set. The sign of the marginal penalty value with respect to time, $\left(\frac{\partial Pen}{\partial k}\right)$, is positive; as more time lapses, the penalty paid by producer A to producer B increases to compensate producer B for reduced yields caused by untimely delivery. As the machinery set increases, delivery time is expected to be closer to the time specified in the contract because harvesting is more efficient and timely. Therefore, the sign of $\left(\frac{\partial k}{\partial I}\right)$ is negative. Including delivery time from the contract date addresses the lack of incentives for producer A to deliver the machinery once the delivery date has been missed. Information requirements and transactions costs, however, are higher when considering timely delivery than they were in the first case.

Penalty a Function of Machinery Set, Delivery Date, and Returns

Producers are more interested in how returns are affected by delayed machinery delivery than the actual date of delivery. Rewriting the penalty as a function of returns one obtains $Pen(R^A(g^A, z, a^A, r, w^A, k(I)),\ \ R^B(g^B, z, a^B, r, w^B, k(I)))$. The expected marginal penalty in equation (3.14) becomes

$$\frac{\partial Pen}{\partial I} = \left(\frac{\partial Pen}{\partial R^A} \cdot \frac{\partial R^A}{\partial k} \cdot \frac{\partial k}{\partial I} + \frac{\partial Pen}{\partial R^B} \cdot \frac{\partial R^B}{\partial k} \cdot \frac{\partial k}{\partial I} \right). \tag{3.16}$$

Recall, the assumption is that the marginal penalty with respect to machinery set is non-positive, $\left(\frac{\partial Pen}{\partial I} \leq 0 \right)$. For this assumption to hold regardless of magnitudes, the following must hold. From the above discussion it was shown $\left(\frac{\partial \mathrm{k}}{\partial \mathrm{I}} \leq 0 \right)$. Producer A's marginal returns with respect to the delivery date is nonnegative; because of penalty costs, a producer will only delay delivery of the machinery if the delay increases his/her returns, $\left(\frac{\partial \mathrm{R}^{\mathrm{A}}}{\partial \mathrm{k}} \right) \geq 0$. Therefore, for the first three terms in the marginal penalty function to be negative, the marginal penalty with respect to producers A's returns must be non-negative, $\left(\frac{\partial Pen}{\partial R^A} \geq 0 \right)$. For last three terms to be negative, the marginal penalty with respect to producer B's returns must be non-positive, $\left(\frac{\partial Pen}{\partial R^B} \leq 0 \right)$. This occurs because delaying producer B's harvest would never increase returns because the crop has already matured, therefore $\left(\frac{\partial \mathrm{R}^{\mathrm{B}}}{\partial \mathrm{k}} \right) \leq 0$.

With this penalty function, producers are concerned with how returns change based on untimely machinery delivery and how the penalty changes based on changes in returns generated from untimely machinery delivery. These changes are represented by $\left(\frac{\partial Pen}{\partial R^A}\cdot\frac{\partial R^A}{\partial k}\right)$ for producer A and $\left(\frac{\partial Pen}{\partial R^B}\cdot\frac{\partial R^B}{\partial k}\right)$ for producer B. It should be noted that this penalty function is not profit sharing because producer B is only compensated for additional returns gained by producer A after the delivery time has expired and not producer A's total returns. Consider producer B. If producer B's returns are not affected by untimely delivery of the machinery, then no penalty should be paid based on this component. Under this assumption, $\left(\frac{\partial R^B}{\partial k}\right)=0$, producer B's component (last three terms in equation (3.16)) goes to zero. A similar argument can be made for producer A. Intuitively pleasing, is the result if neither producers' returns are impacted by untimely delivery, the penalty function becomes irrelevant in determining the optimal cost sharing percentages. Relative to the previous two penalty functions, larger information requirements and transaction costs are associated with the penalty being a function of returns, along with machinery set and delivery date.

Discussion and Conclusions

Ad hoc information suggests that machinery sharing may be a viable strategy for agribusiness managers to improve firm's performance by reducing total capital investment, risk management, and providing firms access to higher quality, capacity and/or additional machines. Few studies to date have considered the economics of machinery sharing. This model is a step towards addressing this void in the literature. Rather than look at the question of share or do not share machinery, this chapter looked at the question from the standpoint that the decision to share had already been made. Contractual issues associated with sharing machinery between two producers are discussed using a theoretical game theory model.

The Nash equilibrium indicates the optimal percentage of shared costs is determined by the ratio of marginal own net benefits over the marginal shared costs. Several factors can cause there to be no equilibrium (black hole), where no machinery sharing will occur. One potential cause of black holes is transaction costs. Machinery sharing is not optimal when own marginal transaction costs are large, driving marginal net benefits to be negative. Own transaction costs are idiosyncratic, affected by a firms' internal organization, strategies, resources, objectives, and all unique firm attributes. More efficient firms that are able to utilize their own unique capabilities and resources to reduce own transaction costs are more likely to share machinery. Another potential cause of black holes is when marginal shared costs are small relative to own marginal net returns. If at the margin there is little cost savings, machinery sharing is less likely to occur.

The model also illustrates the importance of windows of opportunity in the use of shared machinery. If one producer does not deliver the machinery to the other producer in a timely fashion, a penalty may be paid between the producers. The penalty function can take on different forms ranging from very simple to more complex forms. As the complexity is increased, transaction costs and informational requirements increase leading to the potential for less machinery sharing. If transaction costs are too high and explicit functional forms and/or information is too cumbersome to obtain, a simpler rule based on acreage in production may be warranted.

Unique to this general model set up was the linear nature of the percentage of shared costs and the over identification of the model because of a single machinery set and the assumption of all costs being paid. Given net return maximization, the percentage of shared costs enters the model linearly. From society's viewpoint, any percentage of shared costs may be Pareto Optimal. Further model development is necessary including considering other ways to include sharing of costs. Including risk attitudes by maximizing utility instead of net returns will force the percentage to enter the model nonlinearly. General functional forms cannot be used in this case, specific forms will have to be assumed. Given the lumpy aspects of machinery purchases, quadratic programming or simulation modeling should be considered when using specific functional forms. Another important non-continuous aspect ignored in the model is taxes. Producers may be able to share tax deductions by sharing machinery.

CHAPTER IV

YIELD AND HARVEST WINDOW SIMULATIONS

Two important components in the machinery sharing simulation model are wheat yields and harvest windows. A biophysical wheat growth simulation model is used to obtain yields and maturity dates. As noted in the literature review, the use of growth simulation models to generate crop yields is becoming an increasingly common procedure (Lawless and Semenov 2005; Basso et al. 2007; Savin et al. 1995; Pecetti and Hollington 1997). Decision Support System for Agrotechnology Transfer (DSSATv4 2004*)* is used to simulate wheat yields and to obtain maturity dates for four farm locations. Simulated and county historical wheat yields are compared to calibrate DSSATv4. The effects of outlier observations for yields on the performance of the model are examined.

Four farm locations are simulated: 1) Dumas in Moore County, Texas; 2) Pampa in Gray County, Texas; 3) Akron in Washington County, Colorado; and 4) Big Sandy in Chouteau County, Montana. One of the main considerations in determining the locations is harvesting windows. Locations for the farms are selected such that harvesting windows have partial, complete, and very little overlap among the farms. Another consideration is availability of other data necessary for both the crop growth simulation and the machinery sharing simulation models. Generally in this dissertation, the town names are used to refer to the farm locations.

Fifty-one crop growing seasons are simulated for each location to obtain a distribution of wheat yields and maturity dates. Harvesting windows are determined from the simulated maturity dates. Wheat yields decrease after the maturity date has been reached. Unfortunately, DSSATv4 only provides crop yield at maturity date. Discussion of harvesting windows and yield reductions after maturity date are presented in Chapter V.

Crop Simulation Requirements

DSSATv4 is a process-oriented, management level model designed to simulate soil water and nitrogen balances for wheat plant growth (DSSATv4 2004). Data requirements for the crop simulation model are divided into four categories: variety-specific genetic characteristics, soil, weather, and other inputs including other management decisions.

Variety

The dominant class of wheat grown in the region of each location is modeled. U.S. winter wheat is the dominant cultivar used in the Texas and Colorado locations, while spring wheat is the cultivar used in Montana. Winter wheat production is estimated at 140.6 million bushels in Texas (U.S. Department of Agriculture 2007a) and soft winter wheat varieties accounted for 7.9 percent of total planted wheat acreage in 2000 (Texas Agricultural Statistics Service 2007). Although soft red winter wheat (SRWW) cultivars are often recommended as the type of wheat to grow in Texas (Reid and Swart 2006), hard winter wheat is the dominant class of wheat produced, accounting for 85.7 percent of the planted wheat acreage in Texas (Texas Agricultural Statistics

Service 2007). SRWW is recommended over hard red winter wheat (HRWW) cultivars because of rust resistance, straw strength, and 15 bushel per acre yield advantages over HRWW. The DSSATv4 cultivar, Winter-US, is modeled for the Texas and Colorado farm locations, which is a HRWW. In Colorado, HRWW is the most suitable variety for weather conditions under dryland production (Johnson and Haley 2006). Hard winter (red and white) wheat is the dominant class of wheat produced in Colorado, accounting for more than 95 percent of the total wheat grown (Colorado Wheat 2007). Over 97 percent of the hard red spring wheat grown in Montana is on dryland acreage with spring wheat acreage comprising approximately 47 percent of total wheat acreage in 2007 (Lanning et al. 2008). The DSSATv4 cultivar, Spring-High Latitude, is modeled for the Montana farm location.

Soil

Representative soil characteristics from Natural Resources Conservation Service online county soil surveys for each of the locations are used (U.S. Department of Agriculture 2007b). Soil properties including bulk density, drained upper and lower water limits, saturation water content, organic matter content, and volumetric soil water content are required inputs. The soil type with the highest prevalence rate within each county is selected. For Moore County (Dumas location), Sherm silty clay loam is the predominant soil type comprising 45.6% of the county. Pullman clay loam, a silty clay loam, comprising 24.9% of the county is the predominant soil type in Gray County (Pampa). Weld silt loam is the predominant soil type in Washington County (Akron) with a 16.9% prevalence rate. Telstad-Joplin Loams are the predominant soil type in

Table 4.1 Description of Soil Conditions and Parameters

	Akron	Dumas	Pampa	Big Sandy
Soil Classification	Weld Silt Loam	Silty Clay Loam	Silty Clay Loam	Telstad-Joplin
Color	Brown	Black	Black	Brown
Drainage	Well	Moderately Well	Moderately Well	Well
% Slope	3	3	3	1
Runoff Potential	Moderately Low	Moderately High	Moderately High	Lowest
Fertility Factor	0.1	0.1	0.1	0.1
Latitude	40.1	35.5	35.5	48.1
Longitude	-103.1	-101.6	-100.6	-110.0
Elevation (m)	1384.8	1114.0	985.1	844.3
Initial Conditions				
Water % Available	70.0	80.0	80.0	80.0
Nitrogen (kg/ha)	5.0	5.0	5.0	5.0

Source: Adopted from the National Climatic Data Center (U.S. Department of Commerce 2008) and from the Natural Resources Conservation Service online county soil surveys (U.S. Department of Agriculture 2007b).

Chouteau County (Big Sandy) with a 7.4% prevalence rate. Characteristics of each soil type and initial soil conditions following a fallow year used in the crop simulation model are presented in Tables 4.1 and 4.2. All other soil parameters specified in the model are set to DSSATv4 default values.

Weather

Daily weather data for 52 years, 1955 to 2006, are obtained from the National Climatic Data Center (U.S. Department of Commerce 2008). Weather data requirements include daily precipitation, maximum daily temperature, minimum daily temperature, and daily solar radiation. Solar radiation is not available for these years; therefore, the solar radiation generator data DSSATv4 is used. Daily weather data are used to simulate

Table 4.2. Soil Parameters Specified within the DSSAT[1] Model

Depth (cm)	Organic Carbon (%)	Lower Limit (cm3)	Drained Upper Limit (cm3)	Saturation (%)	Bulk Density (g/cm3)	Saturated Hydraulic Conductivity (cm/h)	Root Growth Factor (0 to 1)
				Akron			
5	1.00	0.02	0.18	0.18	1.15	0.92	1.00
15	1.00	0.02	0.18	0.18	1.15	0.92	1.00
30	1.00	0.02	0.18	0.18	1.15	0.92	0.60
60	0.50	0.02	0.17	0.17	1.25	0.92	0.25
90	0.50	0.02	0.17	0.17	1.25	0.92	0.15
120	0.20	0.02	0.16	0.16	1.25	0.92	0.05
150	0.20	0.01	0.15	0.15	1.25	0.92	0.00
180	0.20	0.00	0.15	0.15	1.25	0.92	0.00
				Dumas			
5	1.00	0.14	0.30	0.31	1.25	0.92	1.00
15	1.00	0.14	0.30	0.31	1.25	0.92	1.00
30	0.10	0.14	0.27	0.27	1.35	0.92	0.60
60	0.10	0.12	0.25	0.25	1.35	0.92	0.25
90	0.10	0.12	0.25	0.25	1.35	0.92	0.15
120	0.10	0.12	0.25	0.25	1.35	0.92	0.05
150	0.10	0.04	0.17	0.14	1.35	0.92	0.00
180	0.10	0.00	0.10	0.11	1.35	0.92	0.00
				Pampa			
5	1.00	0.14	0.30	0.31	1.25	0.92	1.00
15	1.00	0.14	0.30	0.31	1.25	0.92	1.00
30	0.10	0.14	0.27	0.27	1.35	0.92	0.60
60	0.10	0.12	0.25	0.25	1.35	0.92	0.25
90	0.10	0.12	0.25	0.25	1.35	0.92	0.15
120	0.10	0.12	0.25	0.25	1.35	0.92	0.05
150	0.10	0.04	0.17	0.14	1.35	0.92	0.00
180	0.10	0.00	0.10	0.11	1.35	0.92	0.00

Table 4.2 Continued

Depth (cm)	Organic Carbon (%)	Lower Limit (cm3)	Drained Upper Limit (cm3)	Saturation (%)	Bulk Density (g/cm3)	Saturated Hydraulic Conductivity (cm/h)	Root Growth Factor (0 to 1)
				Big Sandy			
5	3.00	0.30	0.50	0.60	1.35	14.00	1.00
15	3.00	0.30	0.50	0.60	1.35	14.00	1.00
30	2.00	0.30	0.48	0.55	1.45	4.00	0.60
60	1.00	0.30	0.48	0.55	1.50	4.00	0.25
90	1.00	0.30	0.48	0.55	1.50	4.00	0.15
120	1.00	0.30	0.47	0.55	1.75	1.40	0.05
150	0.50	0.30	0.47	0.55	1.75	1.40	0.00
180	0.50	0.30	0.47	0.55	1.75	1.40	0.00

[1]DSSAT, Decision Support System for Agrotechnology Transfer, is the crop simulation model computer software (DSSATv4 2004).

crop growth and development for a given year to capture the effects of climate variability on crop growth.

Because winter wheat is planted in the fall and harvested the following year, 52 years of weather data are needed to simulate the 51 cropping years. Only 52 years of weather is used because beyond that time weather data for some of the stations have many missing observations. A principle weather station in the county of each farm location is chosen and surrounding weather stations are used to fill in missing data. The principle weather stations for the four farm locations are the Dumas, Pampa, Big Sandy, and Akron 4 E weather stations. Surrounding weather stations used to fill in missing observations are Channing 11NE, Sunray 4 SW, Alanreed, Havre, and Akron. Weather Underground, an online weather source, is also used to fill in missing weather data (Weather Underground 2007).

Table 4.3 Management Parameters for Each Farm Location

	Akron	Dumas	Pampa	Big Sandy
Previous Crop	Fallow	Fallow	Fallow	Fallow
Cultivar	Winter Wheat	Winter Wheat	Winter Wheat	Spring Wheat
Planting Date	15-Sep	1-Sep	1-Sep	10-Apr
Planting Method	Dry Seed	Dry Seed	Dry Seed	Dry Seed
Row Spacing (cm)	16	16	16	16
Plant Population at Seeding (plants/m2)	162	162	162	200
Plant Population at Emergence (plants/m2)	162	162	162	200
Planting Depth	5.5	5.5	5.5	5.5
Fertilizer on the Seed 5cm Deep (N,kg/ha)	30	100	70	200
Tillage Drill Depth (cm)	6	6	6	6

Other Inputs

Other input data such as management decisions on nitrogen rate, seeding density, and tillage are determined from state extension publications and set to recommended levels for the four locations. Planting dates are set within historical ranges (U.S. Department of Agriculture 1972). Management decisions are summarized in Table 4.3.

County Historical and Simulated Yields

Simulated wheat yields are compared to county historical wheat yields to calibrate DSSATv4. Because simulated yields are calibrated to county historical yields, yield loss due to disease, spillage, and pests are implicitly accounted for in the crop growth simulation model. County yield data are used because they are the most consistent available data for the four farm locations. Not all counties, however, have reported historical yields for the years 1956 to 2006. County yields represent the average of all management practices and soil types in the county. In addition, trends are expected in the historical wheat yields, because of advances in genetics and technology. Washington County (Akron) shows a statistically significant trend for historical yield data from 1956 to 2003 (p-value $\leq$ 0.09) associated with the coefficient for year in Table 4.4). Trend in Moore County (Dumas) is weakly statistically significant (p-value $\leq$ 0.18). Gray (Pampa) and Chouteau (Big Sandy) counties show no significant trend when using available historical data from 1956 to 2006. All available county historical data and final simulated yields are presented in Figures 4.1 through 4.4.

Trends in simulated yields are only weakly statistically significant for Washington County (Akron) for years 1956 to 2003 (p-value $\leq$ 0.17) and years 1990 to 2003 (p-value $\leq$ 0.19). The trend in simulated yields for Washington County is most likely explained by changes in the weather data, including differences in how weather data is collected, measurement errors, data handling inconsistencies, and/or a trend in the weather.

Because of advances in genetics, technology and accuracy of statistical reporting, and evidence of trends in county historical yields, this study will compare historical and simulated yields from 1990 to 2006. No or statistically weak trends for county historical and simulated yields are present when considering yield data from 1990 to 2006 for Moore, Gray, and Chouteau counties (see Table 4.4). A strong statistical trend, however, is present in county historical yield data for Washington County (p-value $\leq$ 0.00).

Simulated yield values mimic the historical yield patterns for most years in Dumas except for one year, 1999 (Figure 4.1). During 1999, Dumas historical yield is 49.5 bu/acre and the corresponding simulated yield is 20.72 bu/acre. Historical and

Table 4.4 Trends[1] for Historical and Simulated Wheat Yields

	Moore	Gray	Washington	Chouteau
		Historical[2]		
Years with Data	1973-2006	1973-2006	1956-2003	1956-2006
Constant	-412.21	-202.93	692.87	337.50
Standard Error	313.34	259.37	375.22	290.79
p-Value	0.20	0.44	0.07	0.25
Year	0.22	0.11	-0.33	-0.16
Standard Error	0.16	0.13	0.19	0.15
p-Value	0.18	0.40	0.09	0.29
R-Squared	0.06	0.02	0.09	0.03
		Simulated[3]		
Constant	194.20	61.61	607.35	-77.55
Standard Error	257.59	165.48	402.25	324.08
p-Value	0.46	0.71	0.14	0.81
Year	-0.08	-0.02	-2.87	0.05
Standard Error	0.13	0.08	0.20	0.16
p-Value	0.52	0.83	0.17	0.76
R-Squared	0.01	0.00	0.06	0.00
		Historical[2]		
Years with Data	1990-2006	1990-2006	1990-2003	1990-2006
Constant	1100.91	184.46	3731.71	1229.85
Standard Error	993.37	848.79	1041.34	837.83
p-Value	0.29	0.83	0.00	0.16
Year	-0.54	-0.08	-1.85	-0.60
Standard Error	0.50	0.42	0.52	0.42
p-Value	0.30	0.85	0.00	0.17
R-Squared	0.07	0.00	0.46	0.12
		Simulated[3]		
Constant	-551.81	-273.26	1573.85	727.04
Standard Error	579.95	415.47	1114.08	864.64
p-Value	0.36	0.52	0.18	0.41
Year	0.29	0.15	-0.77	-0.35
Standard Error	0.29	0.21	0.56	0.43
p-Value	0.33	0.48	0.19	0.43
R-Squared	0.06	0.03	0.11	0.04

[1]Trends are tested using the equation $Yield_t = \alpha + \beta Year_t + \varepsilon_t$ where $Yield_t$ are historical county or simulated yields.

[2]Historical values are calculated using all available data for a specified range of years.

[3]Simulated values are calculated using only years with corresponding historical data.

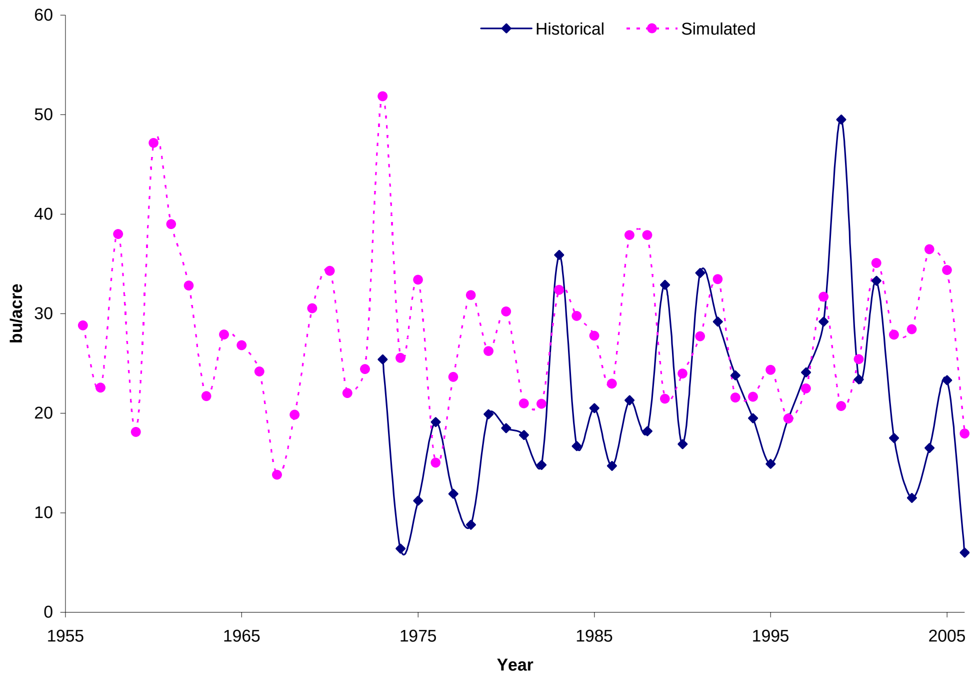

Figure 4.1 Dumas winter wheat historical county and simulated yields

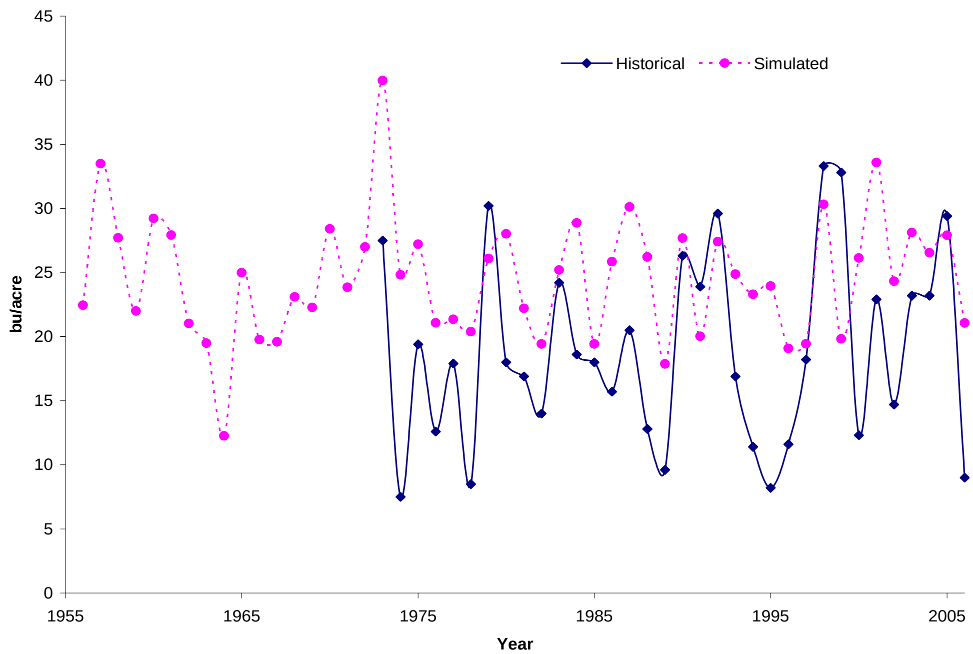

Figure 4.2 Pampa winter wheat historical county and simulated yields

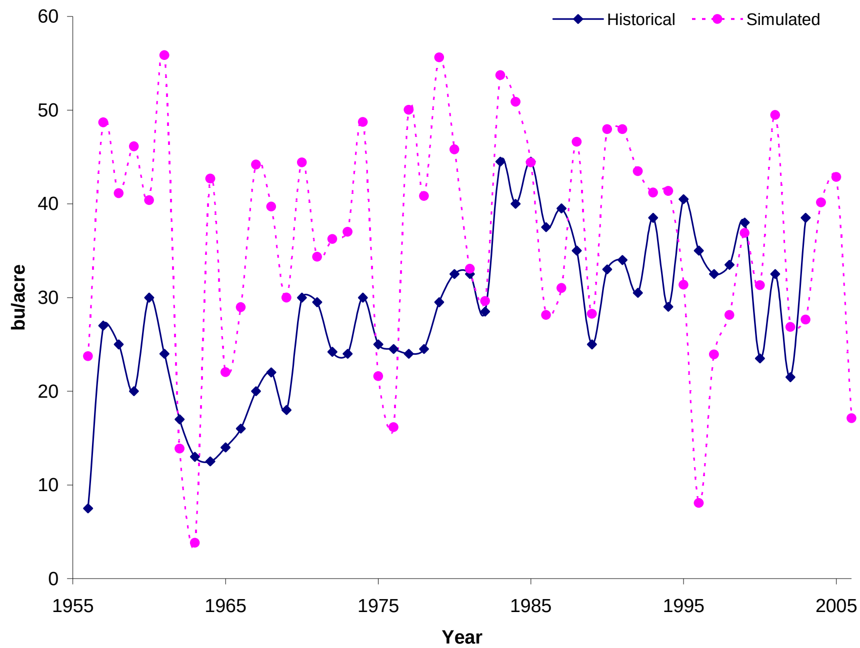

Figure 4.3 Akron winter wheat historical county and simulated yields

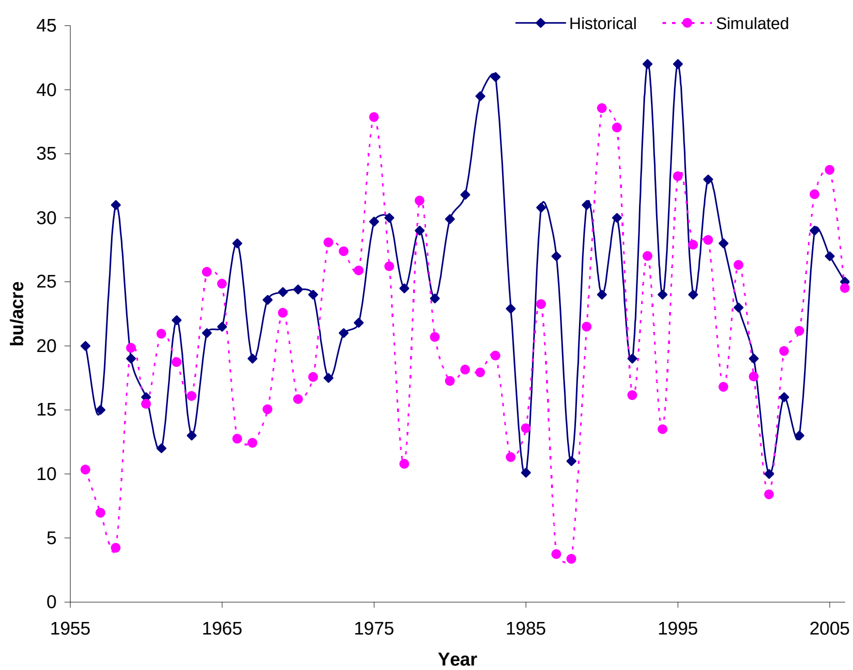

Figure 4.4 Big Sandy spring wheat historical county and simulated yields

simulated yield patterns are similar in Pampa except for three years (1994, 1995, and 1996) where county historical yields are lower than simulated yields (Figure 4.2). Lowest simulated yields in Akron correspond to three years (1963, 1976, and 1996) of low historical wheat yields; however, simulated yields for two years (1996 and 1997) are extremely low compared to county historical yields (Figure 4.3). Big Sandy historical and simulated wheat yields are highly correlated except from 1980 to 1983 where historical yields are high and simulated yields are low (Figure 4.4).

Calibrating DSSATv4 was done by altering initial soil moisture and daily temperatures as suggested by the model developers. Final initial soil moisture levels used are given in Table 4.1. Because of extremely low temperatures in Akron, simulated wheat yields were initially zero for four years (1984, 1989, 1990, and 1991). As recommended by one of the developers of DSSATv4, the minimum temperature was raised to deter plant winter-kill (Hoogenboom 2008). Wheat that is exposed to extreme cold temperatures for prolonged periods of time and lack of snow cover are the primary reasons for winter kill (Fausey et al. 1999). The model accounts for winter-kill associated with low temperatures, but does not account for snow cover. Complete winter-kill was eliminated when minimum and maximum temperatures were raised up to 20 degrees for 12 days in December 1983, 3 days in January 1984, 8 days in February 1989, 9 days in December 1989, and 5 days in December 1990.

County historical mean yields are 23.07, 20.41, 32.89, and 25.18 bu/acre, when using available data from years 1990 to 2006 for Moore, Gray, Washington, and Chouteau Counties (Table 4.5). Simulated mean yields for the years 1990 to 2006 are

Table 4.5. Summary Statistics of Historical and Simulated Wheat Yields Using Available Data

	Dumas	Pampa	Akron	Big Sandy
		Historical		
Mean	20.77	18.79	28.15	24.19
Variance	9.13	7.32	8.50	7.73
Minimum	6.00	38.95	30.20	31.96
Median	19.30	7.50	7.50	10.00
Maximum	49.50	18.00	29.25	24.00
Skewness	0.99	33.30	44.50	42.00
Kurtosis	1.72	0.33	-0.21	0.32
Years	1956-2006	1956-2006	1956-2006	1956-2006
		Simulated		
Mean	27.73	24.55	36.15	20.36
Variance	7.66	4.76	12.19	8.68
Minimum	13.80	12.24	3.82	3.38
Median	26.82	24.82	39.71	19.59
Maximum	51.83	39.96	55.86	38.55
Skewness	0.83	0.47	-0.61	0.12
Kurtosis	1.07	1.44	-0.06	-0.36
Years	1956-2006	1956-2006	1956-2006	1956-2006
		Historical		
Mean	23.07	20.41	32.89	25.18
Variance	10.10	8.32	5.49	8.75
Minimum	6.00	8.20	21.50	10.00
Median	19.30	7.50	7.50	10.00
Maximum	49.50	18.00	29.25	24.00
Skewness	0.99	33.30	44.50	42.00
Kurtosis	1.72	0.33	-0.21	0.32
Years	1990-2006	1990-2006	1990-2006	1990-2006
		Simulated		
Mean	26.63	24.92	34.46	24.80
Variance	5.86	4.14	11.58	8.65
Minimum	17.95	19.08	8.08	8.40
Median	25.42	24.88	36.88	26.31
Maximum	36.47	33.58	49.48	38.55
Skewness	0.32	0.23	-0.70	-0.15
Kurtosis	-1.18	-0.45	0.03	-0.82
Years	1990-2006	1990-2006	1990-2006	1990-2006

Table 4.5 Continued

	Dumas	Pampa	Akron	Big Sandy
Mean Test Using Available Data from 1990 to 2006				
2 Sample t Test	-1.26	-2.00	-0.49	0.13
p-Value	0.22	0.06	0.63	0.90
Variance Test Using Available Data from 1990 to 2006				
F-test	2.97	4.04	4.45	1.02
p-Value	0.02	0.00	0.00	0.48

[1]Distribution comparison tests are based on all available historical data and corresponding simulated data for specified range of years.

26.63, 24.92, 34.46, and 24.80 bu/acre for Dumas, Pampa, Akron, and Big Sandy. Mean values of both historical and simulated wheat yields from 1990 to 2006 are statistically equal for all locations at the 95 percent confidence level (Table 4.5). Except for Big Sandy, the variances are not statistically equal at the 95 percent confidence level (Table 4.5). The hypothesis tests, two-sample Student-t test of Univariate Means and *F*-test of Univariate Variances, used in Simetar© to test means and variances, are individual tests. A description and interpretation of the tests is provided in Richardson (2006).

Bartlett-Adjusted Test

As another verification test of the calibrated crop simulation model, a newly developed test statistic called the Bartlett-adjusted likelihood ratio-based statistic test, (T_B), (Abdulsalam et al. 2008) is used to jointly test means and variances. This statistical test uses the measurement error model framework to verify simulation models. A common procedure to verify is to regress simulated yield on historical values. The joint null hypothesis of a zero intercept and unit slope is tested using an *F*-test with an overall hypothesis of H_0: $\beta_0 = 0$, $\beta_1 = 1$ (White et al. 2007). *F*-test results are given in Table 4.5. This method is invalid because of correlation between the error term and dependent variable which corresponds to inconsistent estimates of the intercept and slope parameters. Abdulsalam et al. (2008) cite additional authors who critique the use of this *F*-test and offer an alternative, the Bartlett-adjusted test statistic (T_B).

The null hypothesis remains the same for this adjusted statistic, which is approximately distributed as a chi-square distribution with two degrees of freedom (Abdulsalam 1996; Abdulsalam et al. 2008). Equations used to calculate T_B are (Abdulsalam et al. 2008):

$$S = \begin{pmatrix} S_{xx} & S_{xy} \\ S_{yx} & S_{yy} \end{pmatrix} = \sum_{t=1}^{n} \left(Z_t - \bar{Z}\right)\left(Z_t - \bar{Z}\right)', \tag{4.1}$$

$$\bar{Z} = n^{-1} \sum_{t=1}^{n} Z_t = \begin{pmatrix} \bar{X} \\ \bar{Y} \end{pmatrix}, \tag{4.2}$$

$$\hat{\beta}_1 = \frac{\left(S_{yy} - S_{xx}\right) + \sqrt{\left(S_{yy} - S_{xx}\right)^2 + 4S_{xy}^2}}{2S_{xy}}, \tag{4.3}$$

$$\phi = \left(\frac{n-4}{n-2}\right)\left[\left(\frac{Sxx}{2n\hat{\sigma}^2}\right) - 1\right], \tag{4.4}$$

$$1 - \hat{a}_n = 1 - \frac{n-2}{4(n-1)\phi + n}, \tag{4.5}$$

$$\hat{\sigma}^2 = \frac{\hat{a}^T S \hat{a}}{2n(1 + \hat{\beta}_1^2)}, \tag{4.6}$$

and $$T_B = (1 - \hat{a}_n)(n-2)\log\left\{.5\left(\frac{\hat{a}^T \hat{a}}{\hat{a}^T S \hat{a}}\right)\left[a^T S a + n(\bar{Y} - \bar{X}\right]^2\right\}, \tag{4.7}$$

where *S* is the corrected sum of squares and cross product matrix defined by test statistic $\bar{Z}$, Z_t is a linear measurement error model, $\bar{X}$ is the simulated mean, $\bar{Y}$ is the historical mean, n is the number of observations, $\hat{\beta}_1$ is the maximum likelihood estimator of the slope parameter, $a = (1,-1)^T$, $\hat{a} = (\hat{\beta}_1,-1)^T$, $1-\hat{a}_n$ is the Bartlett adjustment factor, and ϕ and $\hat{\sigma}^2$ are used to calculate $1-\hat{a}_n$.

Bartlett-adjusted test statistic results for all locations are given in Table 4.6. When historical county and simulated years from 1990 to 2006 are considered separately, the Bartlett-adjusted test indicates that only Pampa and Akron are statistically different from the null hypothesis. However, when all locations are tested jointly using data from years 1990 to 2006, the Bartlett-adjusted test indicates all locations are not statistically different from the null hypothesis.

As noted earlier, simulated yields mimic county historical yield patterns for all locations except for a few years. To test the importance of these years on the Bartlett statistic for Akron and Pampa, the simulated yields for some years are replaced with their means. A closer inspection of Figure 4.2 shows historical county yields for three years in Pampa (1994, 1995, and 1996) are very low compared to simulated yields. Similarly, Figure 4.3 shows simulated yields for two years in Akron (1996, 1997) are extremely low when compared to historical county yields. Minimum temperatures were extremely low in 1996 and 1997 during part of the winter in Akron, which resulted in DSSATv4 giving simulated yields that are much lower than historical county yields for these two years. Low historical county yields in northern Texas from 1994 to 1996 may be attributed to erratic weather patterns, a dry spring in 1995 and severe Greenbug infestation (Texas Agricultural Extension Service 1995). Greenbug, *Schizaphis graminum* Rondani, is an aphid and pest that feeds on grain crops. Because pest and

Table 4.6 Bartlett Test Statistics for Each Farm Location

	Dumas	Pampa	Akron	Big Sandy	All
			1956-2006		
Bartlett Test Statistic	2.63	20.21	23.71	6.70	26.08
p-Value	0.27	0.00	0.00	0.04	0.00
			1990-2006		
Bartlett Test Statistic	2.14	8.19	11.24	4.87	1.97
p-Value	0.34	0.02	0.00	0.09	0.37
			Data Adjusted[1] 1990-2006		
Bartlett Test Statistic	2.14	3.19	5.83	0.06	2.12
p-Value	0.34	0.20	0.05	0.97	0.35

[1]Two years in Colorado and three years in Pampa, TX were adjusted to the mean values.

disease treatments are not included in the simulation model, simulated yields from 1994 to 1996 do not account for the reduction in yields due to Greenbug infestations. Historical county yields, therefore, are expected to be lower than simulated yields.

When historical yields for these years for Pampa and simulated yields for Akron are adjusted to the mean values, Bartlett-adjusted test statistics fails to reject the null hypothesis at the 95 percent confidence level for all locations (Table 4.6). This indicates these few years contribute to the null hypothesis being rejected earlier. Given that historical county and simulated yield means and variances are not statistically different from each other for all locations as given by the Bartlett-adjusted test statistic, the wheat growth model provides reliable simulated wheat yields.

Maturity Date Distributions

In addition to wheat yields, wheat grain maturity date is also obtained for each year from DSSATv4. The distributions of simulated wheat grain maturity dates are

Table 4.7 Descriptive Statistics for Simulated Maturity Dates in Gregorian Date

	Dumas	Pampa	Akron	Big Sandy
Mean	148	144	181	195
Standard Deviation	8	9	6	6
Maximum	165	159	193	210
Minimum	130	125	167	180

Note: Gregorian Date is a continuous count of days within one year.

given in Figure 4.5, while the summary statistics on the first day of maturity are presented in Table 4.7.

The maturity date is distinct from the beginning harvesting date. The two dates are related in that the maturity date determines the beginning harvesting date and the beginning harvesting date is one component that determines the harvesting window. Wheat is not ready to be harvested at the simulated maturity date because of high grain kernel moisture levels; harvesting begins after the maturity date. The length of the actual harvesting window depends on the beginning harvesting date, as well as, the speed of the harvesting equipment (assuming the machinery is at the place of harvest and ready to operate), weather, and wheat acreage. Almost complete overlap of wheat maturity dates for Pampa and Dumas would indicate that beginning harvest dates almost completely overlap; therefore, harvesting windows will almost completely overlap for these two locations.

In cases where simulated wheat maturity dates have partial or no overlap, harvesting windows may still overlap. For example, the Texas farm locations have almost no wheat maturity date overlap with the Akron farm location, but harvesting windows will overlap because of the amount of time necessary to complete harvesting.

If machinery is shared, additional time is necessary to account for transportation of machinery from one farm to the other. When maturity dates partially overlap as in the case of Akron and Big Sandy, harvesting windows will overlap. Additional discussion of the harvesting windows is provided in Chapter V of the dissertation where it is incorporated into the farm simulation model.

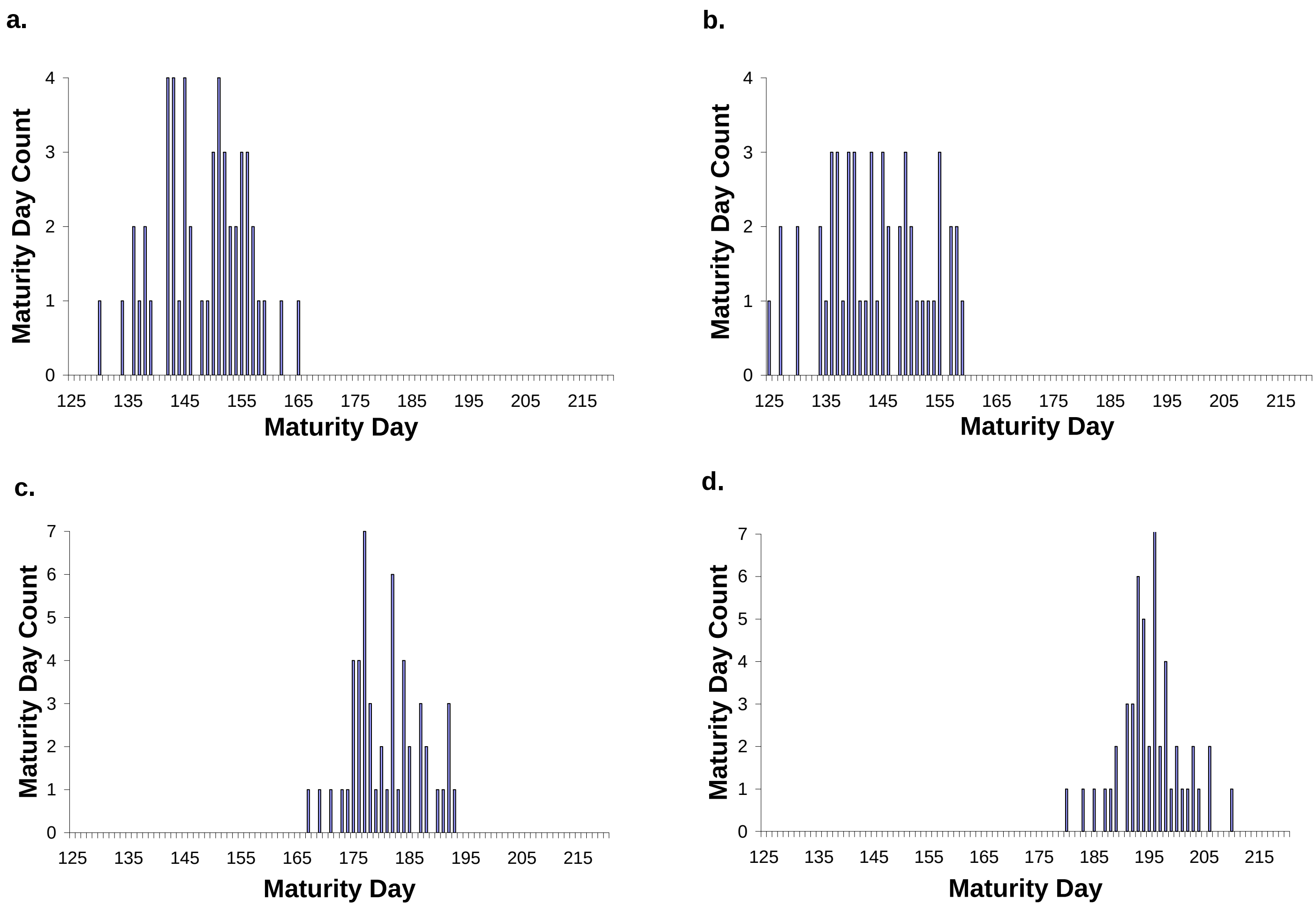

Figure 4.5 Maturity date distributions in Gregorian Date for a) Dumas, b) Pampa, c) Akron, and d) Big Sandy

CHAPTER V

MACHINERY SHARING SIMULATION MODEL

A discrete, stochastic, multi-year simulation model, which calculates costs, returns, taxes, and net present value (NPV) of after tax cash flows, is developed for the four wheat farm locations. The four wheat farm locations described in Chapter IV, Dumas, Pampa, Akron, and Big Sandy, are modeled with stochastic prices, crop yields, and harvesting windows. Costs and returns normally included in a farm simulation model are present, but because of machinery sharing the model has several unique aspects.

Two farms are simultaneously simulated. The machinery shared is two combine harvesters, referred to throughout this chapter as shared machinery or harvesting machinery. One potential cost of sharing machinery is the possibility that the harvest machinery will not be available at the optimal time for both farms. There is a period of time or window of opportunity for optimal harvesting of crops. If the two producers live in the same region where weather conditions are similar, sharing machinery is likely to lead to demand for harvesting machinery at the same time. As a result, one producer may face reduced yields because of a delay in harvesting. If the farms are geographically diverse, the harvest windows for the two farms may either partially overlap or have no overlap. Because of variability in weather, harvesting windows for each farm vary not only by farm but also by crop year. Transportation costs increase, however, as producers are more geographically dispersed. Contractual arrangements, such as the percentage of shared costs (which among other issues has tax implications) and penalties associated with delays in harvest are also included. The contract is assumed to allow 25 consecutive days of harvesting plus travel time without penalty.

All four farms are 10,000 acre wheat farms using a wheat-fallow rotation. In any given year 5,000 acres, therefore, are in production. All farms are the same size to eliminate size of farm impacts and to allow isolation of machinery sharing effects. In addition, each farm has a homestead consisting of five non-farmable acres where a house and buildings reside. It is assumed that the house, buildings, and five acres are owned debt free. The model is developed such that the financial and contractual structure of the farms including land values, percentage of owned land, and percentage of owned non-shared machinery, can easily be varied. A description of each farm with the accompanying machinery required for each farm is presented in Table 5.1.

It is assumed that the farms engaging in machinery sharing have formed a limited liability company (LLC) which encompasses only the shared machinery. Given this assumption, depreciation and other costs from sharing machinery can be transferred from one farm to another. These costs are independent of the percentage of own shared costs borne by each farm. Flexibility in allocating depreciation and costs potentially has important tax implications which may influence the decision to share machinery.

The machinery sharing model is simulated for 1000 iterations using Simetar© (Richardson, Schumann, and Feldman 2006). Each iteration represents five crop years. Stochastic crop yields and maturity dates are jointly drawn from distributions obtained from the wheat growth simulation model discussed in Chapter IV. Prices are

Table 5.1 Description of All Farm Locations and Required Machinery

Acreage (acres)	10,000
Homestead (acres)	5
Rotation	wheat-fallow
Ownership	Sole
Shared Machinery	
Combine 1	+
Combine 2	+
Non-Shared Machinery	
Tractor 255 hp 1	+
Tractor 255 hp 2	+
Tractor 255 hp 3	+
Semi/Trailer 1	+
Semi/Trailer 2	+
3/4 ton Pickup New	+
3/4 ton Pickup Used	+
Grain Drill 1	+
Grain Drill 2	+
Grain Cart 1	+
Grain Cart 2	+
Heavy Duty Disk	+
Self-propelled Sprayer	+

Note: + indicates required machinery

also stochastic and are determined from an empirical distribution of state wheat prices. Yields and prices are assumed to be independent.

Farm Combinations

A total of five combinations of two farms' sharing machinery are considered: 1) Pampa and Pampa; 2) Pampa and Dumas; 3) Pampa and Akron; 4) Pampa and Big Sandy; and 5) Akron and Big Sandy. The combinations are chosen so that harvesting windows completely overlap (combination 1 and 2), partially overlap (combination 3 and 5), and have very little overlap (combination 4). In the Pampa and Pampa combination, the two farms are identical.

Net Present Value of After Tax Cash Flows

Simulated NPV's of after tax cash flows for each farm location are adapted from equations 3.6 and 3.7 of the Nash equilibrium theoretical model in Chapter III. The adapted equation is

$$NPV^i = \sum_{t=1}^{5}\left[\left(R_t^i + GP_t^i - C_t^{NS,i} - Tax_t^i + Pen_t^i - \alpha^i[C_t^{S,i}]\right)(1+r)^{-t}\right], \tag{5.1}$$

where i is either the first farm (Producer A) or the second farm (Producer B), R_t^i is revenue generated in year t excluding government payments, GP_t^i are government payments, $C_t^{NS,i}$ are non-shared variable and fixed costs, Tax_t^i is federal income and self employment taxes, Pen_t^i is the penalty cost for untimely machinery delivery paid by producer i, α^i is the percentage of shared costs paid by producer i, $C_t^{S,i}$ are shared machinery variable and fixed costs, and r is the discount rate. For the first farm, $\alpha^A = \alpha$, and $\alpha^B = (1-\alpha)$ for the second farm, where α is the percentage of shared costs paid by Producer A. If a penalty in year t is incurred, Pen_t^i enters the model as a cost (negative) for Producer A and as a benefit (positive) for Producer B. A six percent discount rate is assumed (Federal Reserve Statistical Release 2005).

Revenues

Revenues include receipts generated from wheat production and crop insurance. Annual revenue on a per acre basis is determined from the equation

$$R_t^i = \max\begin{pmatrix} P_t^i(Z_t^i - L_t^i) \\ CI_t^i \;\middle|\; CI_t^i \geq P_t^i(Z_t^i - L_t^i) + GP_t^i \end{pmatrix}, \tag{5.2}$$

where P_t^i is the randomly drawn stochastic wheat price for year *t*, Z_t^i is total wheat production, L_t^i is the corresponding total yield loss, CI_t^i is crop insurance payments, and GP_t^i is government payments. Wheat is not harvested in years where yield and price are so low that net returns generated from wheat production and government payments are less than crop insurance payments. Revenues are still generated in such years because of crop insurance payments but operating harvesting costs are zero.

Prices

The randomly generated stochastic price is determined from an empirical distribution of correlated state wheat prices from 1990 to 2007 (U.S. Department of Agriculture 2007c). Generated stochastic prices are comprised of two components. The deterministic component is the mean or systematic variability of the random variable that is explainable. The stochastic component, determined from the standard errors of the empirical distribution, is the unexplainable portion of the random variable (Richardson 2006). When trends are present in the price data set, the deterministic component is the trend, and the stochastic component is the standard deviation of the residuals about the estimated trend line. The trend equation is

$$T_t = \gamma + \beta Year_t + \varepsilon_t \qquad (5.3)$$

where γ, and *β* are the coefficients to be estimated, $Year_t$ is the farm model simulation year (historical price data are years 1 through 18 and simulated years are 19, 20, 21, 22, and 23), and ε_t is the disturbance term. Only Montana state price data showed a price trend that is statistically significant at the α = 0.05 percent level. The Montana trend

Table 5.2 Summary Statistics of Wheat Prices in Dollars per Bushel by State from 1990 to 2007

	Texas	Colorado	Montana
Mean	3.39	3.45	3.82
Standard Deviation	1.01	0.99	1.08
Minimum	2.28	2.23	2.80
Median	3.12	3.23	3.61
Maximum	6.30	6.35	7.60

Source: Summary statistics calculated from state wheat prices from 1990 to 2007 (U.S. Department of Agriculture 2007c).

equation has an R^2 of 0.25 and is calculated using 2.87 (0.47) as the intercept and 0.10 (0.04) as the slope where values in parentheses are standard errors.

Because prices are determined using state price data, Dumas and Pampa wheat prices are the same price. Summary statistics of historical state wheat prices are given in Table 5.2.

Government Payments

Following the loan deficiency payment program from the 2002 Farm Bill for wheat, government policy guarantees farmers a target price of \$3.92 per bushel for years 2004 to 2007 (U.S. Department of Agriculture 2004). Wheat farmers are allowed to achieve this price using a combination of direct payments, loans, and counter-cyclical payments. In this model, farmers are guaranteed the target price of \$3.92 per bushel of harvested wheat through an end of the year direct payment. Government payments per acre are determined from the equation

$$GP_t^i = \max \begin{cases} (3.92 - P_t^i)(Z_t^i - L_t^i) & if \;\; P_t^i < 3.92 \\ 0 & if \;\; P_t^i \geq 3.92 \end{cases} \tag{5.4}$$

when the stochastic price, P_t^i, is less than the target price, 3.92, the difference between the target and the stochastic prices is multiplied by the quantity of wheat produced, Z_t^i, minus any yield loss, L_t^i, to determine government payments. If the stochastically drawn price of wheat is greater than the target price, then no government payments are made.

Crop Insurance Payments

The decision to harvest or not harvest is based on whichever action generates the highest net revenue. If a producer decides to harvest, crop insurance payments equal zero. If the producer does not harvest, crop insurance payments per acre are

$$CI_t^i = (3.00)(0.65)\overline{Y}^i, \tag{5.5}$$

where 3.00 is the crop insurance price guarantee, 0.65 is the crop insurance yield coverage percentage, and $\overline{Y}^i$ is the simulated mean yield. All farm locations are insured at a 65 percent coverage level of simulated mean yields. The mean yield is obtained from simulated yield data from 1990 to 2006 (Table 4.5). All 5,000 planted acres are assumed to be insured. The premium costs for Dumas, Pampa, Akron, and Big Sandy are \$3.75, \$3.50, \$4.00 and \$3.50 per acre.

Yields

Total wheat production, Z_t^i, is the product of the stochastically drawn wheat yield in bushels per acre multiplied by the number of planted acres. To obtain a large number of consistent yields between the farms, DSSATv4 (2004) is used to generate wheat yields, see Chapter IV. In the model, a randomly drawn simulated yield is obtained for each of the five years associated with an iteration. One year of the 51 simulated years

Table 5.3 Simulated Wheat Yield Correlation Matrix between Farm Locations

	Dumas	Big Sandy	Akron	Pampa
Dumas	1	-0.11	0.26	0.63
Big Sandy		1	-0.16	-0.16
Akron			1	0.31
Pampa				1

(1956 to 2006) is drawn with replacement for each of the five years. The year (not yield) drawn is the same for each farm. Each selected year gives a corresponding yield and maturity date. Because the same year is drawn for each farm, years are 100 percent correlated. Factors not modeled that affect yields are accounted for within the model. Correlation coefficients between simulated yields are reported in Table 5.3.

Harvesting Window Calculations

The maturity date is used as the basis for determining harvest starting day. Harvesting window for the first farm in Gregorian days is

$$HWS_t^A = MDay_t^A + 17\,, \tag{5.6}$$

$$HWE_t^A = HWS_t^A + HDays_t^A\,, \tag{5.7}$$

and

$$HW_t^A = HWE_t^A - HWS_t^A\,, \tag{5.8}$$

where HWS_t^A is the harvesting window start date in year *t*, $MDay_t^A$ is the simulated maturity date, 17 days is the wheat dry-down period, HWE_t^A is the harvesting window end date, $HDays_t^A$ is the harvesting time in days, and HW_t^A is the harvesting window in days. Given that grain kernel moisture must be at an acceptable level to allow for safe storage, harvest is assumed to begin two and a half weeks (17 days) following the simulated maturity date. This assumption is based on data reported in Monson et al. (2007). They report differences between physiological maturity and harvest starting time, based on kernel moisture, range between two and three weeks.

The size of the combines used in this dissertation requires 25 workable days to harvest 5,000 acres of wheat. Actual harvesting time depends on being able to harvest each day past the starting date. This assumption is similar to previous studies that have used criterion based on a combination of soil moisture level, precipitation, and/or the number of precipitation events to determine suitable days for field machinery operations and soil workability (Whitson et al. 1981; Babeir, Colvin, and Marley 1986; Dillon, Mjelde, and McCarl 1989; Rotz and Harrigan 2005; Dyer and Baier 1979; Rounsevell 1993). A day is deemed unworkable if daily precipitation is greater than or equal to 0.1 inches. Rainfall greater than or equal to 0.1 inches for any day during the harvesting window is assumed to result in the lengthening of the harvest time and harvest window by one day. This assumption is made because if rainfall occurs in the morning, then harvesting is halted for the remainder of that day to allow for the wheat stalks to dry. If rainfall occurs in the evening, then harvesting is also delayed a full day to allow the wheat stalks to dry.

It is assumed that the contract guarantees the first farmer 25 consecutive days from the harvesting window start date plus travel time to deliver the machinery without penalty. Because the 25 contracted harvest days may not all be workable field days, the first farmer faces a decision 25 days after the harvesting window start date. His/her decision is to either stop harvesting and leave the remainder of the crop in the field to ensure timely machinery delivery or complete harvesting and potentially delay machinery delivery to the second farm. The harvesting window for the first farm is completed when all wheat is harvested or 25 days after the harvest start date so machinery can be delivered to the second farm by the contracted machinery delivery date. $HDay_t^A$ is chosen by the first producer such that net returns generated from harvesting additional days are greater than the incurred penalty payment from untimely machinery delivery. The decision rule used by the first producer is presented in the penalty function section below (see equation 5.22).

The second farm begins harvest at the maximum of the drawn maturity date plus 17 days or at the first farm's ending harvest date plus travel time,

$$HWS_t^B = \max\begin{pmatrix} MDay_t^B + 17 \\ HWE_t^A + Travel_t \end{pmatrix}, \tag{5.9}$$

where $Travel_t$ is the travel time between the first farm and the second farm. The end of the harvesting window for the second farm occurs when the last acre is harvested. If the first farm does not harvest and collects the crop insurance payment, then there is timely machinery delivery to the second farm and harvesting begins 17 days after maturity. Field work days for the second farm are calculated similar to the first farm.

Travel time between farm locations is a function of the distance and speed of travel. The following values are assumed for travel time, average speed is 50 miles per hour (mph) with an average travel day of 10 hours. Average speed and travel day includes fuel, food, rest stops, and machinery unloading. To illustrate travel time calculations, consider the Pampa and Akron farms sharing machinery. The distance

Table 5.4 Travel Time Between Farm Locations in Days

	Dumas	Pampa	Big Sandy
Akron	2.0	2.0	3.0
Dumas		1.0	3.0
Pampa		0.0	4.0

between Pampa and Akron is 456 miles. Travel time from Pampa to Akron is

$$Travel_t = 456(miles)\left(\frac{1 \quad hour}{50 \quad miles}\frac{1 \quad day}{10 \quad hour}\right) = 1.9\, Days = 2\; Days. \qquad (5.10)$$

Travel days are rounded to the next highest day. Time to travel between each farm location is shown in Table 5.4.

Yield Reductions Related to Harvesting Time

As noted earlier, DSSATv4 is calibrated to county historical yields. Because county historical yields are the average yield over all management decisions and weather, yield losses are already accounted for in the reported county historical yield. It is assumed simulated wheat yields already account for yield loss from the date of maturity until the end of harvest in a normal year. This loss includes the 17 day dry-down period plus 25 consecutive harvesting days starting at the end of the dry-down period because simulated yields are calibrated to county historical yields. Delays in harvesting and lengthening of the harvest window because of weather and/or untimely machinery delivery, however, are assumed not to be included in the simulated yields. The reported yield loss rate given by Bolland (1984), 0.5 percent per day, is used to determine additional yield loss from weather delays and untimely machinery delivery.

Delays in harvesting result in a 0.5 percent yield loss per acre for each additional day. Yield loss is

$$L_t^i = \sum_{D_t^i=1}^{n^i} Y_t^i (0.005) D_t^i HR, \qquad (5.11)$$

where D_t^i is the number of additional days, n^i is the total number of delayed harvest days (including workable and non-workable days), Y_t^i is the stochastic simulated yield, 0.005 is the one-half percent daily yield loss, and HR is the harvest rate in acres per day. Additional days for the first farm are the number of harvesting day delays from rainfall; whereas, additional days for the second farm are the number of days beyond the contracted machinery delivery date (25 days since maturity plus travel time) plus the number of harvesting day delays from rainfall. The harvest rate, determined from the machinery capacity, is 200 acres per day.

Costs

Wheat production costs are divided into two categories, shared and non-shared costs. Both shared and non-shared costs, $C_t^{j,i}$, are comprised of variable, $VC_t^{j,i}$, and fixed costs, $FC_t^{j,i}$,

$$C_t^{j,i} = VC_t^{j,i} + FC_t^{j,i}, \qquad (5.12)$$

where *j* is shared or non-shared costs. Other non-production costs also included in the model are penalties and federal income and self employment taxes. Because one objective is to examine after tax cash flow, both variable and fixed costs must be included.

Non-Shared Costs

All ownership and operating costs unrelated to shared machinery are considered non-shared costs. Fixed costs include factor payments for land including fallow acreage, real estate taxes, non-shared machinery depreciation, and machinery taxes, housing, and insurance. Variable costs include seed, fertilizer, herbicide, crop insurance, operating interest, machinery interest, repairs, labor, and fuel and lube. Non-machinery operating costs are consistent with the crop simulation model inputs. Harvesting machinery operating costs, which include labor, repair and maintenance, and fuel and lube costs, are assessed to the producer operating the machinery.

Additional costs are determined using information provided by Outlaw et al. (2007) and state costs projections (Texas AgriLife Extension 2007; University of Idaho 2003; Colorado State University Cooperative Extension 2006). Representative costs for all farm locations and assuming the percentage of shared machinery costs is 50 percent are shown in Tables 5.5 through 5.8. Total costs including interest and depreciation are smallest for Akron at $93.16 per acre, followed by Big Sandy at $97.47 per acre, Pampa at $102.31 per acre, and Dumas at $102.58 per acre. Variation in non-shared variable costs between farm locations is attributed to differences in fertilizer and operating interest costs.

Shared Costs

Harvesting machinery ownership costs are the only costs potentially shared by producers. If machinery is shared, then harvesting ownership costs are the percentage of shared machinery costs. When machinery is not shared, each producer bears all

Table 5.5 Costs Estimate for Dumas, TX Sharing Machinery

	Quantity per Acre	Units	Price per Unit	Cost per Acre	Total Cost
Operating Costs					
Seed	1.00	bu	4.22	4.22	21100.00
Fertilizer	70.00	lbs	0.23	16.10	80500.00
Herbicide	1.00	acre	6.37	6.37	31850.00
Crop Insurance	1.00	acre	3.75	3.75	18750.00
Non-Shared Machinery					
Fuel and Lube				16.44	82200.00
Repair and Maintenance				6.77	33850.00
Labor				7.18	35900.00
Harvesting Machinery Costs[1]					
Fuel and Lube				5.32	26600.00
Repair and Maintenance				3.16	15800.00
Labor				3.18	15900.00
Operation Interest@7.0%				3.81	19028.63
Total Operating Costs				76.30	381478.63
Ownership Costs					
Land Payments[2]					
Principal				3.13	31250.00
Interest				2.97	29735.72
Real Estate Taxes				1.80	9000.00
Non Shared Machinery					
Depreciation				7.96	39815.54
Taxes, Housing, Insurance				2.32	11600.00
Harvesting Machinery Costs[1]					
Depreciation				7.10	35491.69
Taxes, Housing, Insurance				1.00	5000.00
Total Ownership Costs				26.28	161892.95
Total Costs				102.58	543371.57

[1]Shared machinery operating and ownership costs are calculated assuming the percentage of costs shared is 50 percent.

[2]Includes allocation of fallow acres and are the average costs over the five years. Actual year costs are used in the simulation model.

Table 5.6 Costs Estimate for Pampa, TX Sharing Machinery

	Quantity per Acre	Units	Price per Unit	Cost per Acre	Total Cost
Operating Costs					
Seed	1.00	bu	4.22	4.22	21100.00
Fertilizer	70.00	lbs	0.23	16.10	80500.00
Herbicide	1.00	acre	6.37	6.37	31850.00
Crop Insurance	1.00	acre	3.50	3.50	17500.00
Non-Shared Machinery					
Fuel and Lube				16.44	82200.00
Repair and Maintenance				6.77	33850.00
Labor				7.18	35900.00
Harvesting Machinery Costs[1]					
Fuel and Lube				5.32	26600.00
Repair and Maintenance				3.16	15800.00
Labor				3.18	15900.00
Operation Interest@7.0%				3.79	18963.00
Total Operating Costs				76.03	380163.00
Ownership Costs					
Factor Payments[2]					
Principal				3.13	31250.00
Interest				2.97	29735.72
Real Estate Taxes				1.80	9000.00
Non Shared Machinery					
Depreciation				7.96	39815.54
Taxes, Housing, Insurance				2.32	11600.00
Harvesting Machinery Costs[1]					
Depreciation				7.10	35491.69
Taxes, Housing, Insurance				1.00	5000.00
Total Ownership Costs				26.28	161892.95
Total Costs				102.31	542055.95

[1]Shared machinery operating and ownership costs are calculated assuming the percentage of costs shared is 50 percent.
[2]Includes allocation of fallow acres and are the average costs over the five years. Actual year costs are used in the simulation model.

Table 5.7 Costs Estimate for Akron, CO Sharing Machinery

	Quantity per Acre	Units	Price per Unit	Cost per Acre	Total Cost
Operating Costs					
Seed	1.00	bu	4.22	4.22	21100.00
Fertilizer	30.00	lbs	0.23	6.90	34500.00
Herbicide	1.00	acre	6.37	6.37	31850.00
Crop Insurance	1.00	acre	4.00	4.00	20000.00
Non-Shared Machinery					
Fuel and Lube				16.44	82200.00
Repair and Maintenance				6.77	33850.00
Labor				7.18	35900.00
Harvesting Machinery Costs[1]					
Fuel and Lube				5.32	26600.00
Repair and Maintenance				3.16	15800.00
Labor				3.18	15900.00
Operation Interest@7.0%				3.34	16679.25
Total Operating Costs				66.88	334379.25
Ownership Costs					
Factor Payments[2]					
Principal				3.13	31250.00
Interest				2.97	29735.72
Real Estate Taxes				1.80	9000.00
Non Shared Machinery					
Depreciation				7.96	39815.54
Taxes, Housing, Insurance				2.32	11600.00
Harvesting Machinery Costs[1]					
Depreciation				7.10	35491.69
Taxes, Housing, Insurance				1.00	5000.00
Total Ownership Costs				26.28	161892.95
Total Costs				93.16	496272.20

[1]Shared machinery operating and ownership costs are calculated assuming the percentage of costs shared is 50 percent.

[2]Includes allocation of fallow acres and are the average costs over the five years. Actual year costs are used in the simulation model.

Table 5.8 Costs Estimate for Big Sandy, MT Sharing Machinery

	Quantity per Acre	Units	Price per Unit	Cost per Acre	Total Cost
Operating Costs					
Seed	1.00	bu	4.22	4.22	21100.00
Fertilizer	50.00	lbs	0.23	11.50	57500.00
Herbicide	1.00	acre	6.37	6.37	31850.00
Crop Insurance	1.00	acre	3.50	3.50	17500.00
Non-Shared Machinery					
Fuel and Lube				16.44	82200.00
Repair and Maintenance				6.77	33850.00
Labor				7.18	35900.00
Harvesting Machinery Costs[1]					
Fuel and Lube				5.32	26600.00
Repair and Maintenance				3.16	15800.00
Labor				3.18	15900.00
Operation Interest@7.0%				3.55	17755.50
Total Operating Costs				71.19	355955.50
Ownership Costs					
Land Payments[2]					
Principal				3.13	31250.00
Interest				2.97	29735.72
Real Estate Taxes				1.80	9000.00
Non Shared Machinery					
Depreciation				7.96	39815.54
Taxes, Housing, Insurance				2.32	11600.00
Harvesting Machinery Costs[1]					
Depreciation				7.10	35491.69
Taxes, Housing, Insurance				1.00	5000.00
Total Ownership Costs				26.28	161892.95
Total Costs				97.47	517848.45

[1]Shared machinery operating and ownership costs are calculated assuming the percentage of costs shared is 50 percent.
[2]Includes allocation of fallow acres and are the average costs over the five years. Actual year costs are used in the simulation model.

Table 5.9 Machinery Operating and Ownership Costs for Non-Shared and Harvesting Machinery

	Non-Shared	Harvesting Non-Sharing	Harvesting Sharing	Total Sharing[1]	Total Non-Sharing[2]
Depreciation	7.96	12.53	14.20	14.23	20.49
Interest	9.39	9.04	4.52	13.91	18.43
Taxes, housing, and insurance	2.32	4.00	2	4.32	6.32
Repairs	6.77	2.96	6.32	8.25	9.73
Labor	7.18	3.18	3.18	8.77	10.36
Fuel/Lube	16.44	5.32	5.32	19.10	21.76

[1]Total Sharing is the summation of non-shared and shared harvesting costs assuming the percentage of shared costs is 50%.
[2]Total Non-Sharing is the summation of all non-shared and all harvesting costs.

harvesting machinery ownership costs. Harvesting machinery ownership costs include depreciation, principal, interest, taxes, housing, and insurance for the two combines. Total machinery operating and ownership costs per acre when sharing and not sharing machinery are given in Table 5.9. Although the machinery is the same in the shared and non-shared cases, costs are higher in the shared case because of the additional use of the combines and travel costs.

Travel costs are shared by the percentage of shared costs paid. To illustrate how travel costs are calculated, consider Pampa and Akron sharing machinery. Total travel costs are

$$TravelC = (2)(miles)\frac{\$}{mile} = (2)(456 \quad miles)\frac{\$2.30}{mile} = \$2097.60 \tag{5.13}$$

where 2 is the number of trips (roundtrip), *miles* is the one-way distance between the two farms, and \$2.30 is the trucking rate per loaded mile.

The percentage of owned debt-free land and non-shared machinery is also considered. The percentage of land and machinery that is debt free is important in determining yearly interest payments and may impact the decision to share machinery. A farmer who owns his/her machinery and land debt free, for example, would have smaller tax deductions and may be more willing to share machinery if he/she is able to use a larger portion of the depreciation. The other extreme would be a farmer who has high land and machinery debt giving large tax deductions. In this case, the farmer may consider machinery sharing to solely reduce machinery costs because additional tax deductions have little impact. In this model, it is assumed that each farm refinanced the loan amount for both land and non-shared machinery at the beginning of the five simulated years. Shared machinery is assumed to be purchased in year one and sold at the end of the fifth year. Sensitivity analysis is conducted by varying the percentage of ownership for both land and non-shared machinery.

Machinery Costs

The Machinery Cost Analysis software program (Smathers, Patterson, and Shroeder 2002) is used to develop machinery operating and ownership costs for machinery and equipment utilization on the 10,000 acre farms. Purchase price, years to trade, and salvage values of machinery are given in Table 5.10. Because harvesting machinery is used twice as much when sharing machinery, salvage values for harvesting machinery when sharing are assumed to be 35 percent of the non-sharing salvage value (Stewart 2008).

Table 5.10 Description of Machinery Set

	Purchase Price	Years to Trade	Salvage Value Non-Sharing	Salvage Value Sharing
Combine New 1	$240,000.00	5	$83,388.76	$62,541.57
Combine New 2	$240,000.00	5	$83,388.76	$62,541.57
Semi/Trailer 1	$50,000.00	25	$4,748.59	$4,748.59
Semi/Trailer 2	$50,000.00	25	$4,748.59	$4,748.59
Tractor 255 hp 1	$115,000.00	15	$22,388.46	$22,388.46
Tractor 255 hp 2	$115,000.00	15	$22,388.46	$22,388.46
Tractor 255 hp 3	$115,000.00	15	$22,388.46	$22,388.46
3/4 ton Pickup New	$38,000.00	10	$14,369.96	$14,369.96
3/4 ton Pickup Used	$10,000.00	6	$3,781.57	$3,781.57
Grain Drill 1	$43,000.00	12	$5,955.78	$5,955.78
Grain Drill 2	$43,000.00	12	$5,955.78	$5,955.78
Grain Cart 1	$15,000.00	15	$1,440.10	$1,440.10
Grain Cart 2	$15,000.00	15	$1,440.10	$1,440.10
Heavy Duty Disk	$20,000.00	15	$1,920.13	$1,920.13
Self-propelled Sprayer	$85,000.00	15	$8,704.58	$8,704.58

All farm locations follow a wheat-fallow minimum till rotation and in the fall after fallowing, fields are disked prior to planting winter wheat. In the case of spring wheat production, fields are not disked until the spring of the planting year. To reduce soil erosion, there is no tillage following wheat harvest. Because wheat stubble is left in the field until just before planting, there is reduced weed growth and soil erosion, and increased soil moisture (Klein 2006).

Depreciation costs are determined using straight-line depreciation net of salvage value. Operating interest rate is seven percent. Labor to operate machinery costs $12.15 per hour, whereas non-machine labor costs $7.20 per hour.

Machinery Usage Calculations

The methodology used to determine machinery usage given in Table 5.11 is illustrated below. Annual usage of machinery is determined using engineering equations provided by the American Society of Agricultural and Biological Engineers. The latest equations and typical value ranges were last updated in February of 2006 (American Society of Agricultural and Biological Engineers 2006a, 2006b). Area capacity for farm operations is determined using

$$AC = \frac{swE_f}{8.25}, \tag{5.14}$$

where AC is area capacity in acres per hour, s is field speed in miles per hour, w is implement working width in feet, E_f is field efficiency, and 8.25 is a constant with units used to convert to acres per hour. Typical values provided in American Society of Agricultural and Biological Engineers (2006b) for field speed, implement working width, and field efficiency are used to determine area capacity. Field efficiency accounts for time lost because of operator capability, habits, and field characteristics. Turning, idle travel, material handling, cleaning clogged equipment, machinery adjustment, lubrication, and refueling, account for the majority of time loss (American Society of Agricultural and Biological Engineers 2006a). An example of area capacity calculations for a 255 horsepower tractor pulling a heavy duty disk is

$$AC = \frac{swE_f}{8.25} = \frac{(4.5 \quad miles/hour)(53 \quad feet)(0.85)}{8.25} = 24.57 \text{ acres per hour}, \tag{5.15}$$

where s is the field speed in miles per hour, w is the implement working width in feet, and E_f is the field efficiency.

Table 5.11 Machinery Usage by Farm Location for Non-sharing of Harvesting Machinery

	Akron	Dumas	Pampa	Big Sandy
Shared Machinery		Hours		
Combine New 1	273	273	273	273
Combine New 2	273	273	273	273
Non-Shared Machinery				
Tractor 255 hp 1	300	300	300	300
Tractor 255 hp 2	300	300	300	300
Tractor 255 hp 3	203	203	203	203
Grain Drill 2	164	164	164	164
Grain Cart 1	136	136	136	136
Grain Cart 2	136	136	136	136
Heavy Duty Disk	407	407	407	407
Self-propelled Sprayer	108	108	108	108
Non-Shared Machinery		Miles		
Semi/Trailer 1	5000	5000	5000	5000
Semi/Trailer 2	5000	5000	5000	5000
3/4 ton Pickup New	12000	12000	12000	12000
3/4 ton Pickup Used	12000	12000	12000	12000

Total annual usage of each implement and power unit is found using effective field capacity and total acreage. Annual usage of a 255 horsepower tractor pulling a heavy duty disk, for example, is

$$Annual\ Usage = \frac{Acreage}{AC} = \frac{5{,}000\ \ acres}{24.57\ \ acres/hour} = 203 \text{ hours.} \tag{5.16}$$

Recall, the harvested acreage is 5,000 acres per farm. Calculations are similar for determining area capacity and annual usage of equipment for other operations and farms. Annual usage of equipment for each farm is given in Table 5.11.

To determine the time required to complete each farm operation, T_i, the following assumptions are made. First, a workday is assumed to be 10 hours long with

80 percent field scheduling efficiency, E_s. Managers' ability to make use of personal and employee workable working hours is defined scheduling efficiency. Farm acreage, *A*, must also be known. Continuing the previous example of the time required to prepare the seed bed by disking, the required time to complete this operation is

$$T_i = \frac{acres}{(10 \quad hrs/day)(E_s)(AC \quad acres/hour)}$$

$$= \frac{5{,}000 \quad acres}{(10 \quad hrs/day)(0.8)(24.57 \quad acres/hour)}$$

$$= 25.43 \text{ days}, \tag{5.17}$$

when only one disk is used and half of the acreage is fallowed.

Annual usage of ¾ ton new and used pick-up trucks is assumed to be 12,000 miles for each farm. Machinery usage for shared machinery is calculated using similar procedures. Total hours of machinery usage for shared machinery are the sum of usage occurring between machinery sharing farm locations.

Federal Self-Employment and Income Taxes

Both annual self-employment and income taxes are calculated. Annual self-employment taxes are composed of two separate taxes, a Social Security tax, and a Medicare tax. The social security tax is the minimum of 12.4 percent on the first $102,000 of taxable income or 92.35 percent multiplied on all taxable income. Medicare tax is 2.9 percent on all taxable income. Self-employment taxes are

$$SST = \min\left\{0.124(102{,}000) \quad or \quad 0.9235(taxable \quad income)\right\} \tag{5.18}$$

and $$MT = 0.029\left\{(taxable \quad income)\right\}, \tag{5.19}$$

where *SST* is the social security tax, *MT* is the medicare tax, 0.9235 is a percentage multiplied by the taxable income to determine self-employment taxes under the regular method, and taxable income is the total self-employment taxable income (RIA Federal Tax Handbook 2008). Taxable income is the revenue generated from wheat sales, government payments, crop insurance payments, and penalties (positive for farm 1 and negative for farm 1) minus cash operating expenses and depreciation. Total self-employment taxes are the sum of self-employment income (social security tax) and Medicare taxes. To reduce taxation impacts from differences in state laws, all state income taxes are assumed to be zero. This assumption has no effect on the Texas farms because Texas does not have a state income tax. There is some effect, however, on the Montana and Colorado farms because these states have state income taxes.

Federal income taxes are calculated using adjusted gross income. Adjusted gross income is self employment taxable income minus one-half of self-employment taxes, any business carryover loss from the previous year, standard deductions, and personal exemptions. The federal tax liability is found by applying 2007's Schedule Y-1 to adjusted gross income. In addition to depreciation, operating expenses, interest, and property taxes, additional annual income tax deductible items include a standard deduction of $10,900 (married and filing jointly) and a personal exemption of $14,000 (husband, wife, and two children).

Base Contractual Penalty

The base penalty is similar to the theoretical penalty payment as a function of machinery set and delivery date discussed in Chapter III. Both penalties overcome the lack of incentive for the first farm to deliver the shared machinery set once the contracted delivery date has been missed. As noted earlier, the contract is assumed to allow 25 consecutive days of harvest plus travel time without penalty. When the harvesting machinery is not delivered to the second farm location at the specified date, a penalty cost of

$$Pen_t^A = -\left(P_t^B L_t^B\right), \tag{5.20}$$

is assessed to farm A and

$$Pen_t^B = -Pen_t^A \tag{5.21}$$

is paid to farm B. In this equation, P_t^B is the price of wheat received by farm B, and L_t^B is farm B's cumulative yield loss in bushels incurred because of delayed harvest from untimely machinery delivery only. If L_t^B is zero, then the penalty assessed to farm A is zero.

Producer A must decide between completing the harvest and paying the penalty or terminating the harvest early and paying zero penalty at the end of the 25 contracted harvest days. The second producer receives the penalty amount to compensate for loss in yield from delayed harvesting. The penalty increases each day beyond the contracted delivery date that Producer A delays delivery because of Producer B's increased yield loss. As discussed in the theoretical model, Producer A is comparing marginal revenue generated from harvesting each additional day beyond the contracted date to own marginal costs and marginal penalty cost. Producer A continues harvesting until marginal revenue from harvesting is less than or equal to marginal costs (own and penalty).

The decision rule used by Producer A to continue harvesting or deliver the machinery to Producer B is determined by the equation

$$DEC_t^A = P_t^A K_t^A - HC_t^A - P_t^B L_t^B, \qquad (5.22)$$

where P_t^A is the price received by farm A, K_t^A is the total wheat left in the field to be harvested, HC_t^A are Producer A's harvesting costs for the acreage remaining to be harvested, and P_t^B and L_t^B are as defined earlier. If DEC_t^A is greater than zero, it is more profitable for Producer A to complete harvesting, pay the penalty, and delay machinery delivery. When DEC_t^A is less than zero, the penalty is greater than additional revenues minus harvesting costs and Producer A is better off delivering the machinery on the specified contract date. The penalty acts as an incentive for timely delivery of the machinery. Note that Producer B's yield loss used in equation 5.22 is only yield loss attributed to untimely machinery delivery and not total yield losses. Producer A is only required to compensate for yield loss resulting from retaining the machinery beyond the contracted delivery date.

Table 5.12 Averaged Annual Percent Change in Inflation Rates

Annual Inflation Rate for Taxes	5.42%
Annual Inflation Rate for Wages	3.09%
Annual Inflation Rate for Fuel	9.47%
Annual Interest Rate for Savings	4.88%
Annual Inflation Rate for Variable and Fixed Costs	2.47%
Annual Inflation Rate for Land Value	6.66%

Source: Averages determined from the Food and Agricultural Policy Research Institute 2006, 2008) and the National Agricultural Statistics Service (U.S. Department of Agriculture 2008).

Inflation

Annual inflation rates for taxes, wages, variable and fixed costs, fuel, operating interest, savings, land value and machinery are included (Table 5.12). Rates are determined by averaging percent change in values from the Food and Agricultural Policy Research Institute baselines (Food and Agricultural Policy Research Institute 2006, 2008) and the National Agricultural Statistics Service (U.S. Department of Agriculture 2008). In year 1, all rates equal zero, making 2006 the base. Annual rates are assumed to be the same for years simulated. Changes in annual inflation rates for variable and fixed costs of production are equal to the annual inflation change for the Consumer Price Index.

CHAPTER VI

RESULTS

Besides simulating NPV of after tax cash flows, as discussed in Chapter V, the present value of revenues, costs, federal self-employment and income taxes, and penalty payments are simulated for five years using a six percent discount rate. Although not presented in this chapter, NPV of ending net worth is also calculated. Cumulative distribution graphs of present value of revenues, costs, federal self-employment and income taxes, penalty payments, and NPV of ending net worth are given in Appendix A. Only differences in the NPV of after tax cash flows are presented in this chapter. Differences are calculated as shared NPV after tax cash flows minus non-shared NPV after tax cash flows over 1000 iterations, where each iteration represents five years. For simplicity, NPV of after tax cash flows is sometimes referred to as simply NPV.

Four contractual issues are examined. First, in addition to the base case penalty, three additional potential penalty functions are examined. Second, the percentage of shared costs is varied from zero to 100 percent for each farm (recall farm 2's percentage is one minus farm 1's percentage). Third, the effect of machinery size is simulated. Fourth, sensitivity analysis on the percentage of shared machinery depreciation is examined. Sensitivity analysis on the simulated parameters is also conducted by varying the percentage of debt free land and non-shared machinery, discount rate, yield reduction from untimely machinery delivery, yields, and prices.

Table 6.1 Differences in Expected Values and Standard Deviations of NPV of After Tax Cash Flows for the Base Penalty Payment for Each Farm Combination Assuming Different Percentages of Shared Costs Paid (in Hundred Thousand Dollars)

	Pampa & Pampa		Pampa & Dumas		Pampa & Akron		Pampa & Big Sandy		Akron & Big Sandy	
	Pampa	Pampa	Pampa	Dumas	Pampa	Akron	Pampa	Big Sandy	Akron	Big Sandy
					Farm One Pays 100%					
Mean	-1.266	2.993	-1.292	2.948	-1.284	4.047	-1.406	4.558	-1.444	3.954
Standard Deviation	-0.037	-0.418	-0.038	-0.451	-0.032	-0.066	-0.019	-0.330	-0.052	-0.386
					Farm One Pays 75%					
Mean	0.338	1.426	0.316	1.483	0.341	2.714	0.259	3.120	-0.070	2.510
Standard Deviation	-0.101	-0.356	-0.102	-0.388	-0.098	-0.068	-0.088	-0.281	-0.060	-0.334
					Farm One Pays 50%					
Mean	1.917	-0.168	1.899	-0.007	1.941	1.377	1.897	1.665	1.298	1.047
Standard Deviation	-0.175	-0.304	-0.176	-0.317	-0.175	-0.068	-0.167	-0.221	-0.064	-0.271
					Farm One Pays 25%					
Mean	3.463	-1.779	3.448	-1.522	3.506	0.036	3.497	0.190	2.661	-0.438
Standard Deviation	-0.255	-0.265	-0.256	-0.244	-0.256	-0.066	-0.252	-0.151	-0.065	-0.201
					Farm One Pays 0%					
Mean	4.972	-3.401	4.961	-3.060	5.033	-1.310	5.058	-1.306	4.020	-1.944
Standard Deviation	-0.329	-0.236	-0.331	-0.174	-0.332	-0.060	-0.331	-0.077	-0.063	-0.129

Base Farm Scenarios

The base farm scenarios are as developed in the previous chapter. In these scenarios, farm 1's penalty payment to farm 2 is 100 percent of the yield losses associated with untimely machinery delivery; farm 1 bears all the risk associated with untimely machinery delivery. As expected, when the percentage of shared costs borne by the first farm is 100 percent, differences in mean NPV of after tax cash flows are negative for the first farm and positive for the second farm for every farm combination (Table 6.1). This indicates that the first farm would never share harvesting machinery if it bears all shared costs and all the risk. Obviously, the second farm is willing to share harvesting machinery if it pays none of the shared costs and assumes none of the risk.

Besides the 100 percent payment scenario, the only other scenario where farm 1's mean difference is negative is when the percentage of shared costs borne by farm 1 is 75 percent for the Akron and Big Sandy combination. Akron has a negative mean difference in NPV because of the higher average price Big Sandy receives (almost $0.37/bu larger than Akron's price). Given that Akron has to compensate Big Sandy for yield loss beyond the contractual date at the price that Big Sandy receives, untimely machinery delivery is costly to Akron. This penalty payment combined with paying the majority of shared costs causes the difference in mean NPV to be negative.

Differences in mean NPV of after tax cash flows for farm 2 are positive when farm 1 pays either 75 percent or 100 percent of the shared costs. When shared costs are split evenly or when farm 2 pays a larger percentage of the costs, the overlap in harvesting window helps determine if the change in NPV is positive or negative. Similar to farm 1, if farm 2 pays 100 percent of the costs, its changes in NPV of after tax of cash flows are always negative. When the harvesting windows highly overlap, Pampa – Pampa (100 percent overlap) and Pampa – Dumas, even at 50 percent sharing of costs farm 2's change in NPV of after tax cash flows is negative. Negative changes in NPV occur because farm 1 is not required to compensate for yield losses before the end of the 25 days stipulated in the contract. Recall, the contract in the base farms provides the first farm 25 days from the start of harvest to complete harvest without any penalty. Farm 2, therefore, may have up to 25 days of uncompensated yield loss.

When the harvest windows only partially overlap, Pampa – Akron and Pampa – Big Sandy, farm 2 can pay 75 percent of the costs and still have a positive change in mean NPV of after tax cash flows. The Akron – Big Sandy combination has a negative cash flow change for Big Sandy when Big Sandy pays 75 percent of the shared costs. These changes in NPV are similar to those discussed when the first farm pays the majority of shared costs.

There are interactions between the percentage of shared costs, harvesting windows, and farm specific characteristics. In general, differences in NPV of after tax cash flows are larger when harvesting windows have little overlap because yield losses from untimely machinery delivery are reduced. Harvesting windows, however, do not fully explain the differences in NPV of after tax cash flows. Farm specific factors including price, yield, and weather also contribute to differences in NPV of after tax cash flows.

Positive standard deviation differences indicate an increase in risk and negative differences indicate a reduction in risk. Differences in standard deviations of NPV of after tax cash flows for all farms in every farm combination are negative. Reduction in risk is partially caused by shared machinery costs being spread over two farms instead of only one farm. As the percentage of shared costs paid for a farm is reduced, the differences in standard deviations become more negative (less risky) for all farms in every combination except for Akron in both the Pampa – Akron and Akron – Big Sandy combinations. With the exception of Akron, risk decreases as the percentage of shared costs decrease because the farm is liable for fewer costs.

Annual Percent Change of After Tax Cash Flows

Average annual percent changes of after tax cash flows for the base case are given in Table 6.2. Changes are calculated by dividing the five year differences in expected values of NPV of after tax cash flows (Table 6.1) by the absolute value of the mean NPV of after tax cash flow when non-sharing harvesting machinery and then dividing by 5. Absolute values are used because some mean NPV of after tax cash flows are negative. The reader is cautioned in using the percentages because of this issue.

A wide range of annual percentage changes are noted. As the percentage of shared costs paid increases, the average annual percentage change in after tax cash flows decreases for all farms and all combinations. For the Dumas farm, some of the annual percent changes are large in absolute value, ranging up to 486 percent in the Pampa – Dumas combination. The reason the percentages are large is the absolute value of the mean NPV of after tax cash flows when non-sharing harvesting machinery is small.

Table 6.2 Average Annual Percent Change in Expected NPV of After Tax Cash Flows and Percent Change in the Five Year Standard Deviation for the Base Penalty Case

	Pampa & Pampa		Pampa & Dumas		Pampa & Akron		Pampa & Big Sandy		Akron & Big Sandy	
	Pampa	Pampa	Pampa	Dumas	Pampa	Akron	Pampa	Big Sandy	Akron	Big Sandy
	Farm 1 Pays 100%									
Mean	-9.53	22.53	-9.72	467.96	-9.67	9.55	-10.58	141.00	-3.41	122.31
Standard Deviation	-1.42	-16.30	-1.48	-14.53	-1.25	-1.96	-0.76	-8.72	-1.56	-10.19
	Farm 1 Pays 75%									
Mean	2.54	10.74	2.38	235.42	2.57	6.41	1.95	96.52	-0.17	77.65
Standard Deviation	-3.93	-13.89	-3.99	-12.49	-3.83	-2.03	-3.41	-7.41	-1.79	-8.81
	Farm 1 Pays 50%									
Mean	14.43	-1.26	14.29	-1.17	14.61	3.25	14.28	51.49	3.06	32.38
Standard Deviation	-6.82	-11.86	-6.87	-10.19	-6.80	-2.03	-6.49	-5.82	-1.90	-7.16
	Farm 1 Pays 25%									
Mean	26.06	-13.39	25.95	-241.62	26.39	0.08	26.32	5.86	6.28	-13.55
Standard Deviation	-9.92	-10.33	-9.97	-7.85	-9.97	-1.98	-9.80	-3.99	-1.94	-5.30
	Farm 1 Pays 0%									
Mean	37.43	-25.60	37.34	-485.72	37.88	-3.09	38.07	-9.83	9.49	-60.14
Standard Deviation	-12.82	-9.19	-12.88	-5.59	-12.93	-1.80	-12.89	-2.99	-1.89	-3.39

With a small denominator, even small increases in NPV of cash flows can lead to large percentage changes. The only other farm showing such large percentage changes is the Big Sandy farm, which occur at the extreme cost sharing percentages.

As other examples, consider the Pampa – Pampa, Pampa – Dumas, and Pampa – Akron, and Pampa – Big Sandy combinations when farm 1 pays 75 percent of the shared costs. Farm 1 has approximately a two percent annual average increase in NPV cash flows. The second farm has a 10 percent increase in the Pampa – Pampa combination, a 235 percent increase in the Pampa – Dumas combination, a six percent increase in the Pampa – Akron combination, and a 96 percent increase in the Pampa – Big Sandy combination. When farm 1 pays 50 percent of the shared costs in the Akron – Big Sandy combination, Akron has a three percent increase and Big Sandy has a 32 percent increase in average annual after tax cash flows.

Alternative Penalty Functions

When wheat is mature and ready to harvest but machinery delivery is delayed, harvesting obviously cannot begin. For each day of delayed harvest there is a reduction in yields. The penalty functions considered allow for the risk associated with untimely machinery delivery to be incurred all by farm 1 (Base Farms – scenario previously discussed), all by farm 2 (No Penalty), and to be shared equally between the two farms (Penalty Payment 50 Percent). A fourth penalty (Lump Sum Penalty) is also considered. Penalties are consistent with theoretical penalty functions described in Chapter III.

No Penalty Payment

In terms of who bears the risk associated with untimely machinery delivery, the other extreme from the base scenario is when farm 2 bears all the risk. In this case, farm 1 does not pay a penalty for untimely delivery. As expected, when no penalty is paid by farm 1, farm 1 is always better off and farm 2 is always worse off than in the base case (Table 6.3 versus Table 6.1). Signs of the differences in NPV of after tax cash flows are the same in the base penalty and no penalty cases. As the harvesting window overlap decreases, there is less yield loss from untimely machinery delivery and the penalty becomes less important to machinery sharing. For example, in Pampa – Big Sandy, there is almost no overlap of harvesting windows; as such, differences between the base and no penalty cases are almost nonexistent. Standard deviation differences are not identical to the base case, but inferences are similar.

Penalty Payment 50 Percent

In this case, the penalty payment, therefore, risk of untimely delivery is shared equally between farms 1 and 2. Farm 1 pays one-half of the yield losses that occur beyond the contracted date which allows farms engaging in sharing machinery to equally share harvesting window risk. Because of the reduced penalty, farm 1 chooses to complete harvest and delay machinery delivery to farm 2 more often than in the base case. For instance, in the Pampa – Pampa combination, the first farm chooses to complete harvest 84 percent of the simulated years in the base case, but finishes harvesting in 92 percent of the simulated years when the penalty payment is shared equally. Harvesting is not completed three percent of the simulated years in both

Table 6.3 Differences in Expected Values and Standard Deviations of NPV of After Tax Cash Flows for No Penalty Payment for Each Farm Combination Assuming Different Percentages of Shared Costs Paid (in Hundred Thousand Dollars)

	Pampa & Pampa		Pampa & Dumas		Pampa & Akron		Pampa & Big Sandy		Akron & Big Sandy	
	Pampa	Pampa	Pampa	Dumas	Pampa	Akron	Pampa	Big Sandy	Akron	Big Sandy
					Farm 1 Pays 100%					
Mean	-1.168	2.872	-1.181	2.839	-1.255	4.028	-1.405	4.558	-1.386	3.886
Standard Deviation	-0.037	-0.422	-0.036	-0.455	-0.031	-0.072	-0.019	-0.330	-0.046	-0.398
					Farm 1 Pays 75%					
Mean	0.433	1.302	0.424	1.372	0.370	2.695	0.259	3.120	-0.013	2.440
Standard Deviation	-0.103	-0.361	-0.102	-0.391	-0.097	-0.074	-0.087	-0.281	-0.054	-0.345
					Farm 1 Pays 50%					
Mean	2.010	-0.295	2.004	-0.118	1.969	1.358	1.898	1.664	1.355	0.975
Standard Deviation	-0.178	-0.310	-0.177	-0.320	-0.173	-0.075	-0.166	-0.220	-0.057	-0.281
					Farm 1 Pays 25%					
Mean	3.552	-1.907	3.549	-1.633	3.532	0.017	3.498	0.189	2.718	-0.511
Standard Deviation	-0.257	-0.272	-0.257	-0.247	-0.255	-0.073	-0.251	-0.151	-0.058	-0.211
					Farm 1 Pays 0%					
Mean	5.058	-3.529	5.058	-3.171	5.058	-1.329	5.058	-1.307	4.077	-2.020
Standard Deviation	-0.331	-0.243	-0.331	-0.178	-0.331	-0.067	-0.331	-0.076	-0.056	-0.138

scenarios because crop insurance payments are larger than the value of harvested wheat plus government payments. Results and inferences for this case are similar to those of no penalty payment, as such the results are not presented.

Lump Sum Penalty Payment

Here, it is assumed a lump sum penalty of $2,500 is paid by farm 1 to farm 2 if the contracted machinery delivery date is not met regardless of the number of days beyond the contracted date. Relative to the base case, in some farm combinations, farm 1 is better off and farm 2 is worse off. For example, in the Pampa – Pampa combination, farm 1 is better off and farm 2 is worse off than the base case at all percentages of shared costs because the lump sum amount is less than the value of farm 2's yield losses. Similar to the base case, farm 1 chooses to complete harvest 84 percent of the simulated years when a lump sum penalty is used. When a larger lump sum penalty of $10,000 is paid, farm 1 chooses to complete harvest less often at 76 percent of the years. If the lump sum penalty is smaller at $500 dollars, farm 1 still chooses to complete harvest 84 percent of the years. Inference from the differences in NPV of after tax cash flows and standard deviations with a lump sum penalty of $2,500 are similar to the base case. Because changes in the differences in NPV of after tax cash flows are only in magnitude, specific results of the lump sum penalty payment are not presented.

Two-Farm Cash Flows – Nash Equilibrium

Two obvious inferences arise from the results. First, the best option for each farm is to share machinery and pay zero percent of the shared costs. Second, farm 1 desires the no penalty contract, whereas, farm 2 is better off with the full penalty (base case) for untimely machinery delivery. These two inferences indicate there is room for contract negotiation. Further, they suggest a closer inspection of the total differences of NPV after tax cash flows for farm 1 and farm 2 is warranted. The two-farm NPV after tax cash flow is the sum of the differences for both farms. Positive values indicate improvement in the total two-farm welfare from sharing machinery, whereas, negative values indicate the farms taken together would be better off not sharing machinery.

As expected, the maximization of NPV of after tax cash flows occurs for each farm at the extreme case where the other farm pays 100 percent of the shared costs. The Nash equilibrium, however, is found by maximizing the joint or combined expected NPV of after tax cash flows for the two farms. The percentage of shared costs that results in the two-farm cash flows maximum is also the Nash equilibrium (Table 6.4).

Two-Farm Cash Flows with Compensation

Two-farm cash flows are positive for all percentages of shared costs and farm combinations when using either the base penalty or no penalty (Table 6.4). As the overlap in harvest windows decreases, two-farm cash flows increase with the largest two-farm welfare being associated with the Pampa – Big Sandy combination. In the Pampa – Pampa combination, the largest two-farm cash flows for both the base penalty and no penalty cases is where farm 1 pays 75 percent of the shared costs. In the base penalty case, the farms are better off by $176,400 from sharing machinery. In the Pampa – Dumas combination, two-farm cash flows are largest at $192,600 when farm 1 pays 25 percent of the shared costs with the base penalty. Both the Pampa – Akron and Pampa – Big Sandy combinations, however, have the largest overall two-farm cash

Table 6.4 Two-Farm Expected NPV of After Tax Cash Flows Differences for the Base Penalty and No Penalty Payments for Each Farm Combination Assuming Different Percentages of Shared Costs Paid (in Hundred Thousand Dollars)

	Pampa & Pampa	Pampa & Dumas	Pampa & Akron	Pampa & Big Sandy	Akron & Big Sandy
			Farm 1 Pays 100%		
Base Penalty	1.727	1.656	2.763	3.152	2.510
No Penalty	1.704	1.657	2.774	3.152	2.499
			Farm 1 Pays 75%		
Base Penalty	1.764	1.799	3.055	3.379	2.440
No Penalty	1.735	1.796	3.065	3.379	2.427
			Farm 1 Pays 50%		
Base Penalty	1.749	1.892	3.318	3.562	2.345
No Penalty	1.715	1.886	3.327	3.562	2.330
			Farm 1 Pays 25%		
Base Penalty	1.683	1.926	3.541	3.687	2.223
No Penalty	1.644	1.916	3.549	3.687	2.207
			Farm 1 Pays 0%		
Base Penalty	1.571	1.901	3.722	3.751	2.076
No Penalty	1.529	1.887	3.729	3.751	2.057

flows when farm 1 pays zero percent of the shared costs in the no penalty case. Two-farm cash flows are largest in the Akron – Big Sandy combination at $251,000 when farm 1 pays 100 percent of the shared costs with the base penalty. Similar results are obtained for the no penalty case.

Interestingly, when the harvest windows highly overlap (Pampa – Pampa and Pampa – Dumas) or partially overlap (Akron – Big Sandy), the base penalty case provides the largest two-farm cash flows at all percentages of shared costs except when farm 1 pays 100 percent of the shared costs in the Pampa – Dumas combination. When the harvest windows partially overlap (Pampa – Akron and Akron – Big Sandy), results are ambiguous. The no penalty case provides the largest two-farm cash flows in the Pampa – Akron combination and the base penalty provides the largest two-farm cash flows in the Akron – Big Sandy combination. In the case where the harvest window decreases to almost no overlap (Pampa – Big Sandy), both the base penalty and no penalty two-farm cash flows are nearly identical.

Largest two-farm cash flows with the base penalty and no penalty for all combinations coincide with economic theory from society's vantage point, in that optimal sharing occurs when the absolute value of marginal differences of NPV of after tax cash flows for both farms are equal. From the theoretical results, optimal sharing is where marginal differences from farm 1 equal one minus the negative of the marginal differences from farm 2 (see Chapter III). Marginal differences are calculated by subtracting differences in NPV of after tax cash flows associated with two percentages of shared costs. For example, in the Pampa – Pampa combination for the base penalty case, differences in NPV of after tax cash flows for farm 1 when going from 50 to 75 percent of the shared costs are $191,700 and $33,800 (Table 6.1). The marginal difference for farm 1 when going from 50 to 75 percent of the shared costs is -$157,900 ($33,800 – $191,700). The marginal difference for farm 2 at these same percentages of shared costs is $159,400 ($142,600 – -$16,800). This example also happens to be the case where marginal differences are closest in value for the different percentages given. Thus, optimal sharing (defined as providing the largest total or combined change in NPV of after tax cash flows) occurs in the Pampa – Pampa combination when farm 1 pays 75 percent of the shared costs. Optimal sharing results in the simulation model coincide with economic theory and the theoretical optimal sharing rules from the Nash equilibrium for all farm combinations. Results are consistent even though theoretical results are derived using small infinitesimal changes, but empirical results are associated with large percentage changes.

Among the penalties examined, the differences in two-farm cash flow values are small. The range of differences in two-farm cash flows is small because farm 1 is compensating for farm 2's yield loss associated with untimely machinery delivery when using a penalty or gaining additional net revenue from completing harvest when there is no penalty. Differences in the two-farm cash flows are because of yield losses occurring beyond the contracted delivery date and the inclusion of taxes. The penalties result in almost a zero sum transfer; two-farm cash flows are distribution neutral between the two farms.

Even though the highest two-farm cash flow values mentioned above result in highest overall farms' welfare, individual farms are not always better off. For instance, in the Pampa – Dumas combination two-farm cash flow is largest when farm 1 pays 25 percent of the shared costs. Dumas, however, is not better off sharing machinery (Table 6.1). For Dumas to agree to share machinery with Pampa paying 25 percent of the shared costs, Pampa must compensate Dumas at least $152,200. Farmers will not agree to share machinery and knowingly lose money without compensation.

Two-Farm Cash Flows without Compensation

To avoid additional compensation beyond the penalty payment issues, cases where both farms are not better off from machinery sharing are eliminated. Here, only two-farm cash flows are considered where the individual differences in NPV of after tax cash flows are positive for both farms (see Table 6.1). In the Pampa – Pampa and Pampa – Dumas combinations with the base penalty, the only scenario where both farms are better off from sharing machinery is when farm 1 pays 75 percent of the shared costs. In the Pampa – Akron and Pampa – Big Sandy combinations, both farms are better off sharing machinery when the percentage of shared costs paid by farm 1 is either 25, 50, or 75 percent; the highest two-farm welfare occurs when farm 1 pays 25 percent of the shared costs in the both the base and no penalty cases. With the base penalty, the only scenario where both farms are better off sharing machinery in the Akron – Big Sandy combination is when the farms equally share costs. In the no penalty case, two-farm welfare is maximized when farm 1 pays 75 percent of the costs. The highest two-farm cash flow for the Akron – Big Sandy combination is the base penalty case.

Small Harvesting Machinery Set

As previously discussed, both small and large farms may benefit from sharing machinery. Small firms may have access to larger, more efficient machinery that would otherwise not be affordable and large firms may be able to reduce capital investment costs and potentially capitalize on economies of size. Firms sharing machinery, however, may face decreased production if the shared machines are not available at the point of production when needed.

In the previous scenarios, the harvesting machinery requires 25 workable harvesting days to complete harvest regardless of sharing or non-sharing the equipment. In this section, a smaller harvesting machinery set is assumed when non-sharing harvesting machinery. This smaller harvesting machinery set requires 35 workable harvesting days to complete harvest. When a smaller harvesting machinery set is used, time to complete harvesting, operating costs, and repair costs increase. Fuel and lube costs increase to \$7.34 per acre, labor increases to \$4.40 per acre, repairs increase to \$5.82 per acre, interest increases by four cents to \$9.08 per acre, and depreciation decreases to \$8.62 per acre. Purchase price, however, for the smaller harvesting machinery decreases from \$240,000 to \$120,000 per combine. Yield loss for each farm increases when non-sharing harvesting machinery because the smaller machinery set requires 10 additional workable harvesting days to complete harvest.

Differences in NPV of after tax cash flows and two-farm cash flows for the Pampa – Akron combination with a smaller harvesting machinery set are given in Table 6.5. Differences in Table 6.5 are calculated as shared NPV with the larger machinery set

Table 6.5 Differences in Expected Values, Standard Deviations, and Two-Farm NPV of After Tax Cash Flows for the Base Penalty Payment, a Small Non-Shared Machinery Set, and Assuming Different Percentages of Shared Costs Paid (in Hundred Thousand Dollars)

	Pampa	Akron	Pampa & Akron
	Differences in Cash Flows	Differences in Cash Flows	Two-Farm Cash Flows
	Farm 1 Pays 100%		
Mean	0.164	5.148	5.312
Standard Deviation	-0.063	-0.023	-0.074
	Farm 1 Pays 75%		
Mean	1.789	3.815	5.604
Standard Deviation	-0.129	-0.025	-0.132
	Farm 1 Pays 50%		
Mean	3.389	2.478	5.867
Standard Deviation	-0.206	-0.025	-0.196
	Farm 1 Pays 25%		
Mean	4.953	1.137	6.090
Standard Deviation	-0.287	-0.023	-0.263
	Farm 1 Pays 0%		
Mean	6.481	-0.209	6.272
Standard Deviation	-0.363	-0.017	-0.321

(25 workable days required to complete harvest) minus non-shared NPV with the smaller machinery set (35 workable days required to complete harvest). For all percentages of shared costs, differences in NPV of after tax cash flows are positive for the Pampa farm. Pampa is better off sharing the larger harvesting machinery because harvesting is timelier and costs may be smaller when sharing machinery. When Pampa (farm 1) pays none of the shared costs, Akron is better off using the smaller machinery set and not sharing. Because there are 25 days of uncompensated yield loss as assumed in the contract when sharing machinery, it is costly for Akron to delay harvest.

Results indicate that when Pampa pays 25 percent or more of the shared costs, Akron is better off delaying harvest and harvesting at a faster rate using the larger harvesting machinery set than harvesting when wheat is ready to harvest with the smaller machinery set. Risk is reduced in all cases by machinery sharing. Two-farm cash flow differences inference is similar to that discussed under the base penalty case. This one example clearly shows the use of machinery sharing to obtain the use of larger machinery is a viable option producers may want to consider.

Alternative Depreciation Sharing

Tax deductions including depreciation help determine taxable income used in calculating after tax cash flows. Because firms sharing machinery are assumed to have formed a limited liability company, depreciation of shared machinery can be allocated unequally. The impact of the percentage of shared machinery depreciation deducted by each farm in the Pampa – Akron combination on differences in NPV of after tax cash flows is given in Table 6.6. Pampa and Akron are the base case farms previously discussed; however, the percentage of depreciation deducted by each farm is varied. Recall, shared machinery is 100 percent financed.

For both farms, the higher the percentage of depreciation deducted the larger the differences in NPV of after tax cash flows. This occurs because the higher the percentage of depreciation deducted the lower the amount of federal income taxes paid. Lower taxes paid, *ceteris paribus*, the higher the net after tax cash flows. At all percentages of shared depreciation, differences in NPV of after tax cash flows are positive for both farms when the percentage of shared costs paid by the Pampa farm is either 50 or 75 percent. Risk, however, is reduced for both farms at all percentages of shared depreciation when Pampa pays 50 percent or less of the shared costs.

As defined previously, two-farm NPV of after tax cash flow is “the sum of the differences for both farms.” Two-farm cash flows are largest for all percentages of shared costs when Pampa deducts zero percent of the shared machinery depreciation (Table 6.7). This occurs because Akron generally has a higher taxable income because of higher yields. The largest two-farm cash flows occur when Akron pays all the costs and uses all the depreciation. Again, higher taxable income is the reason for this result. The costs do not change, but who pays the costs does change. Recall, the two-farm cash flows are distribution neutral. The impact of taxes and depreciation is illustrated using the scenario where both farms pay 50% of the shared costs. In this scenario, when Pampa moves from using 100% of the depreciation deduction to zero percent, Pampa NPV after tax cash flows decrease by $37,100 ($208,400 – $171,300 from Table 6.6). At the same time, Akron’s net after tax cash flows increase by $112,900 ($192,600 – $79,700 from Table 6.6).

The standard deviations of the two-farm differences are given in Table 6.7. The combination of Akron paying all costs and taking all depreciation deductions also results in the largest reduction in risk for the two-farm cash flows. In addition, risk for two-farm cash flows is reduced at all percentages of shared costs and all percentages of depreciation over non-sharing harvesting machinery.

Table 6.6 Differences in Expected Values and Standard Deviations of NPV of After Tax Cash Flows for Different Percentages of Shared Depreciation Deducted by Pampa in the Pampa and Akron Combination Assuming Different Percentages of Shared Costs Paid (in Hundred Thousand Dollars)

Farm 1 Depreciation Deduction	0%		50%		100%	
	Pampa	Akron	Pampa	Akron	Pampa	Akron
	Farm 1 Pays 100%					
Mean	-1.434	4.610	-1.284	4.047	-1.189	3.455
Standard Deviation	-0.153	-0.023	-0.032	-0.066	0.064	-0.095
	Farm 1 Pays 75%					
Mean	0.155	3.269	0.341	2.714	0.457	2.127
Standard Deviation	-0.225	-0.021	-0.098	-0.068	0.009	-0.099
	Farm 1 Pays 50%					
Mean	1.713	1.926	1.941	1.377	2.084	0.797
Standard Deviation	-0.305	-0.018	-0.175	-0.068	-0.058	-0.103
	Farm 1 Pays 25%					
Mean	3.240	0.579	3.506	0.036	3.682	-0.534
Standard Deviation	-0.387	-0.014	-0.256	-0.066	-0.133	-0.105
	Farm 1 Pays 0%					
Mean	4.732	-0.772	5.033	-1.310	5.248	-1.869
Standard Deviation	-0.458	-0.005	-0.332	-0.060	-0.204	-0.104

Table 6.7 Two-Farm Expected Values and Standard Deviations of NPV of After Tax Cash Flows for Different Percentages of Shared Depreciation Paid by Pampa in the Pampa and Akron Combination Assuming Different Percentages of Shared Costs Paid (in Hundred Thousand Dollars)

Farm 1 Depreciation Deduction	0%	50%	100%
	Farm 1 Pays 100%		
Mean	3.176	2.763	2.266
Standard Deviation	-0.145	-0.083	-0.025
	Farm 1 Pays 75%		
Mean	3.423	3.055	2.584
Standard Deviation	-0.202	-0.141	-0.078
	Farm 1 Pays 50%		
Mean	3.640	3.318	2.881
Standard Deviation	-0.266	-0.205	-0.140
	Farm 1 Pays 25%		
Mean	3.819	3.541	3.147
Standard Deviation	-0.331	-0.272	-0.206
	Farm 1 Pays 0%		
Mean	3.960	3.722	3.379
Standard Deviation	-0.382	-0.330	-0.265

Percentage of Debt Free Land and Non-Shared Machinery

In the previous scenarios, both farms have 75 percent of their land and non-shared machinery debt free. In the following scenarios, this assumption is changed. As discussed previously, the percentage of land and machinery that is debt free is important in determining yearly interest payments and may impact the decision to share machinery. A farmer who owns his/her machinery and land debt free, for example, would have smaller tax deductions relative to a farmer who has higher debt. Differences in NPV of after tax cash flows for varying percentages of shared depreciation and shared costs for the Pampa – Akron combination are given in Table 6.8 at different debt levels. Pampa and Akron farms are the base case farms with the exception of the percentages of debt free land and shared depreciation.

When the percentage of shared machinery depreciation claimed increases for either farm, mean differences in NPV of after tax cash flows increase at all percentages of shared costs (Table 6.7). Similarly, when the percentage of debt free land and non-shared machinery decreases, mean differences in NPV of after tax cash flows generally increase at all percentages of shared costs and percentages of depreciation (Table 6.8).

Depreciation becomes more valuable as the percentage of debt free land and machinery increases because of larger taxable income from reduced interest payments. Differences of differences in NPV of after tax cash flows are larger as the percentage of debt free land and non-shared machinery increases. Alternatively, when the debt free percentage is small, there are larger tax deductions and the depreciation is not always used. To illustrate what the differences of differences means, consider the following example. Consider the case where Akron is zero percent debt free and Pampa pays 100 percent of the shared costs (Table 6.8). Mean differences in NPV of after tax cash flows for Akron are $492,000 and $408,000 when Pampa deducts zero percent and 100 percent of the shared depreciation. When Akron is 100 percent debt free and Pampa pays 100 percent of the shared costs, however, differences in NPV of after tax cash flows are $458,300 and $336,400 when Pampa deducts zero and 100 percent of the shared depreciation. The difference in NPV differences for Akron when it is 100 percent debt free is $121,900 ($458,300 – $336,400), which is larger than the case where Akron is zero percent debt free, $84,000 ($492,00 – $408,000). Differences of differences in

NPV of after tax cash flows for both Pampa and Akron at all percentages of shared costs are larger when the percentage of debt free land and non-shared machinery increases. This indicates there is an interaction between depreciation and the debt free percentage that impacts the NPV of after tax cash flows.

Another example is the case where Pampa is zero percent debt free and paying zero percent of the shared costs. Differences in NPV of after tax cash flows for Pampa are \$545,100 and \$551,200 when Pampa deducts zero and 100 percent of the shared depreciation (Table 6.8). The difference of the differences is \$6,100 (\$545,100 – \$551,200). When Pampa is 100 percent debt free and Pampa pays zero percent of the shared costs, however, differences in NPV of after tax cash flows are \$417,500 and \$495,900 when Pampa deducts zero and 100 percent of the shared depreciation. The difference of the differences is \$78,400 (\$495,900 – \$417,500), which is larger than the case where Pampa is zero percent debt free (\$6,100). Differences of differences in NPV of after tax cash flows for Pampa are \$53,000 when Pampa pays 100 percent of the shared costs instead of zero percent. Differences of differences decrease as the percentage of shared costs paid increase and increase as the percentage of shared depreciation increases. These two inferences indicate that there may be trade-offs between the percentages of shared costs paid and shared depreciation claimed when considering different levels of debt free land and non-shared machinery.

Table 6.8 Differences in Expected Values and Standard Deviations of NPV of After Tax Cash Flows for Different Percentages of Shared Depreciation and Debt Free Land and Non-Shared Machinery for the Pampa and Akron Combination Assuming Different Percentages of Shared Costs Paid (in Hundred Thousand Dollars)

% Debt Free (Farms 1-2)	100 – 0%		100 – 0%		100 – 0%		0 – 100%		0 – 100%		0 – 100%	
Farm 1 % Depreciation	0%		50%		100%		0%		50%		100%	
	Pampa	Akron	Pampa	Akron	Pampa	Akron	Pampa	Akron	Pampa	Akron	Pampa	Akron
Farm 1 Pays 100%												
Mean	-1.616	4.920	-1.307	4.524	-1.086	4.080	-1.285	4.583	-1.265	3.976	-1.251	3.364
Standard Deviation	-0.161	-0.202	-0.034	-0.337	0.097	-0.456	-0.046	-0.007	-0.017	-0.030	0.004	-0.051
Farm 1 Pays 75%												
Mean	-0.130	3.480	0.212	3.099	0.472	2.675	0.402	3.254	0.426	2.652	0.442	2.044
Standard Deviation	-0.232	-0.142	-0.115	-0.283	0.017	-0.409	-0.059	-0.011	-0.027	-0.036	-0.002	-0.058
Farm 1 Pays 50%												
Mean	1.327	2.023	1.697	1.660	1.993	1.252	2.087	1.923	2.114	1.327	2.134	0.723
Standard Deviation	-0.288	-0.075	-0.182	-0.222	-0.054	-0.356	-0.074	-0.014	-0.038	-0.041	-0.010	-0.065
Farm 1 Pays 25%												
Mean	2.759	0.547	3.157	0.204	3.486	-0.186	3.771	0.591	3.801	0.002	3.825	-0.602
Standard Deviation	-0.328	-0.005	-0.234	-0.159	-0.114	-0.299	-0.091	-0.017	-0.052	-0.047	-0.020	-0.071
Farm 1 Pays 0%												
Mean	4.175	-0.944	4.601	-1.267	4.959	-1.639	5.451	-0.744	5.486	-1.328	5.512	-1.928
Standard Deviation	-0.356	0.064	-0.274	-0.093	-0.164	-0.241	-0.111	-0.018	-0.068	-0.050	-0.033	-0.075

Table 6.9 Two-Farm Expected Values and Standard Deviations of NPV of After Tax Cash Flows for Different Percentages of Shared Depreciation and Debt Free Land and Non-Shared Machinery for the Pampa and Akron Combination Assuming Different Percentages of Shared Costs Paid (in Hundred Thousand Dollars)

% Debt Free (Farm 1 – Farm 2)	100 – 0%	100 – 0%	100 – 0%	0 – 100%	0 – 100%	0 - 100%
Farm 1 % Depreciation	0%	50%	100%	0%	50%	100%
			Farm 1 Pays 100%			
Mean	3.304	3.217	2.995	3.298	2.711	2.113
Standard Deviation	-0.309	-0.334	-0.338	-0.046	-0.040	-0.039
			Farm 1 Pays 75%			
Mean	3.350	3.311	3.147	3.656	3.078	2.486
Standard Deviation	-0.308	-0.350	-0.361	-0.063	-0.055	-0.053
			Farm 1 Pays 50%			
Mean	3.350	3.357	3.245	4.010	3.442	2.857
Standard Deviation	-0.289	-0.348	-0.370	-0.081	-0.072	-0.067
			Farm 1 Pays 25%			
Mean	3.306	3.361	3.300	4.361	3.803	3.223
Standard Deviation	-0.253	-0.329	-0.366	-0.100	-0.091	-0.083
			Farm 1 Pays 0%			
Mean	3.231	3.334	3.320	4.708	4.157	3.584
Standard Deviation	-0.209	-0.299	-0.355	-0.121	-0.109	-0.099

Interestingly, as in the previous scenarios, risk is not always reduced for both farms in all of the Pampa – Akron combinations. In three cases, Pampa has increased risk from sharing machinery, whereas, risk is reduced in all cases for Akron. Even though Pampa has increased risk from sharing machinery in some combinations, two-farm standard deviations are negative for all cases of the Pampa – Akron combination (Table 6.9). This result indicates that overall risk in NPV of after tax cash flows is reduced for all cases of the Pampa – Akron combination.

Total yearly shared machinery ownership costs ($117,067 including principal and interest) are higher than the tax deductible depreciation ($83,492) from shared machinery. As the percentage of debt free land and non-shared machinery increases, however, depreciation may become more valuable because of smaller tax deductions. The potential tradeoff between the percentage of shared costs paid and the percentage of depreciation used at different percentages of debt free land and non-shared machinery is shown by examining one Pampa – Akron combination. Here, Pampa is zero percent debt free and Akron is 100 percent debt free. In this case, depreciation may be more important to Akron than Pampa because Akron has smaller tax deductions. From Table 6.8, it is evident that Akron is not willing to pay a higher percentage of the shared costs to deduct a higher percentage of shared depreciation. The scenarios in this table, however, are lumpy because of the large changes in percentages used. As an alternative, consider the case where Akron pays 55 percent of the shared costs and deducts 75 percent of the shared machinery depreciation. In this case, differences in NPV of after tax cash flows are larger for both farms at $244,000 for Pampa and $136,000 for Akron than equal sharing of costs and shared depreciation ($211,400 for Pampa and $132,700 for Akron). This one example illustrates farms need to consider tax consequences in determining percentages of shared costs and depreciation. Proper contractual arrangements can increase individual and two-farm cash flows. Not all arrangements involve tradeoffs between the two farms when smaller percentage changes are considered.

Sensitivity Analysis

Additionally, sensitivity analysis on the NPV of after tax cash flows is conducted by varying the discount rate, yield reduction from untimely machinery delivery, yields, and prices. Inferences on the NPV of after tax cash flows are the same as the base penalty scenario when the discount rate varies from three to nine percent. In addition, inferences are similar to the base case when yield reduction from untimely harvesting varies from zero to 1 percent yield loss per day. Recall, factors to increase or decrease yield and price are included in the model. When the factor for yield varies from zero to 10 percent and the factor for price varies from zero to 20 percent, inferences are similar to the base case. Inferences, therefore, are robust relative to the assumptions made concerning these components of the model.

CHAPTER VII

DISCUSSION AND CONCLUSIONS

Businesses with seasonality in production, including agricultural production, may benefit from machinery sharing. Machinery sharing, the use of a set of machinery by two or more firms, may provide a way to reduce costs and boost revenues to increase profitability. Consider two farms sharing a combine. A single combine is used to harvest acreage on two farms instead of one. Purchasing costs for the two farms are reduced when sharing the combine compared with purchasing two separate combines. Variable costs for operating the combine, however, increase because of increased use of the combine. Harvesting timeliness, dependent on the climate variability and geographical location of the farms, is an important determinant of each farms' revenues. Optimal harvesting times, along with specified contractual arrangements, will determine whether machinery sharing is a viable management tool for each particular farm.

Previous research on machinery sharing is limited. Only a few studies have considered machinery sharing in the context of European farm co-operatives and agricultural production. Many studies, however, have looked at individual components related to machinery sharing including machinery set selection, labor requirements, climate variability, harvesting windows, and yield reduction. None, however, have considered machinery sharing in the U.S., while accounting for these components, along with harvesting windows, yield loss from untimely machinery delivery, and contractual issues. This dissertation is the first comprehensive study of many of these issues.

The overall objective of this dissertation is to determine the impacts of machinery sharing on two firms engaged in machinery sharing. Two models, a Nash equilibrium game theoretical model and an applied two-farm simulation model, are used to attain this objective. A single period Nash equilibrium theoretical model for two firms sharing machinery determines the theoretical optimal sharing rules. This single shot game theory model, based on continuous differentiable functions, uses calculus to maximize the objective function. Optimal machinery sharing rules are defined as the percentage of total shared machinery costs borne by each firm. Sharing does not occur when the equilibrium is not within the economic feasible region. The Nash equilibrium model also illustrates the importance of harvesting windows.

Because of the generality of the functional forms considered in the theoretical model, an empirical simulation model of two farms sharing machinery is developed to provide more specific inferences. The basis for the simulation model is the Nash equilibrium model. Components of both models include the normal components, such as costs, yields, and prices, found in most if not all farm models. Unique to both models are components associated with sharing machinery, such as harvesting windows for each farm, yield reduction associated with untimely delivery of the machinery, and machinery sharing contractual arrangements. The farm simulation model is a discrete-time multi-year model. Net present values of after tax cash flows for each farm are determined and sensitivity analysis is conducted by varying the contract terms, specifically, the percentage of shared machinery costs paid by each farm. In additional to the percentage of shared machinery costs, other contractual issues examined are penalty payment structures for untimely machinery delivery and percentage of shared machinery depreciation. The simulation model is unique in that two farms are simultaneously simulated. Machinery sharing as a method to increase cash flows and reduce risk compared to sole ownership is evaluated using the two-farm simulation model. Contractual issues' effects on cash flows are also examined.

Four geographically diverse farms are developed. Machinery sharing between two of the farms occurs by simultaneously simulating two of the farms. Farm combinations are chosen such that harvesting windows range from highly overlapping to having virtually no overlap. Both federal self-employment and income taxes are included in the two-farm simulation model.

Contributions

This dissertation contributes to the understanding of machinery sharing effects on both farms entering into a machinery sharing contract. To the author's knowledge, no study has examined contractual arrangement issues in the context of machinery sharing. Further, a methodological contribution, modeling biophysical crop characteristics and two-farms simultaneously in an economic simulation model, is also garnered. Inferences from the simulation model are robust relative to the assumptions made on model components. Further, as expected, inferences from both the theoretical model and applied simulation model are consistent, even though the two models differ in their methodological approach.

Inferences from both models help explain why machinery sharing is observed but not widely practiced in today's farming operations. The simulation model suggests that machinery sharing can increase NPV of after tax cash flows over non-sharing machinery. Further, simulation results show machinery sharing may reduce risk associated with cash flows. These results are dependent on farm specific characteristics and contractual arrangements. These results suggest those producers sharing machinery have overcome contractual problems and most likely are experiencing increased cash flows.

Machinery sharing, however, occurs only when there is a feasible economic equilibrium. Equilibriums outside the feasible region (black holes) can be caused by high marginal transaction costs and/or small marginal shared costs relative to own marginal net returns. Large transaction costs may be caused by firm inefficiencies. There can be expected risk reductions and increases in NPV of after tax cash flows when sharing machinery. Even though overall NPV of after tax cash flows are improved when sharing machinery, in many of the scenarios presented one farm is gaining at the expense of the other farm. For example, in the Pampa – Dumas combination and base penalty case where Pampa pays 25 percent of the shared costs, Pampa gains $344,800 and Dumas loses $152,200 over non-sharing harvesting machinery.

Another reason machinery sharing is not widely practiced is because of small potential increase in cash flows. Gains from machinery sharing, for example, may be small in comparison to annual farm revenue. Consider the Pampa – Akron combination in the base penalty case where farm 1 pays 25 percent of the shared costs. In this combination, Pampa gains approximately $70,000 per year, whereas, Akron gains approximately $700 per year. Akron's gain is small compared to the value of the whole farm with million dollar annual revenues.

The third reason that machinery sharing may not be widely practiced is because of additional transactions costs, such as finding a farmer to share machinery and trust issues. Such non-market psychological transaction costs are not modeled. Two farms owned or operated by the same entity, however, that are able to utilize their own unique capabilities and resources to reduce own transaction costs may be able to overcome these non-market issues and be more likely to share machinery. Some producers interviewed at the Association of Agricultural Production Executives 2008 meetings, for example, share machinery on two geographically diverse farms that are operated by the same firm.

Machinery sharing is a potential risk management tool for agribusiness firms. Generally, NPV of after tax cash flow risk is reduced when sharing machinery. Findings also suggest there are interactions among percentages of shared costs paid, yield losses associated with sharing machinery, and the penalty paid to compensate for yield losses.

Percentage of Shared Costs

A potential reasonable assumption to reduce transaction costs and facilitate machinery sharing is for two identical size farms to equally share costs associated with machinery sharing. When two firms are homogenous, the Nash equilibrium theoretical model suggests that firms will equally pay shared costs. In reality, farms sharing machinery are not homogenous. In the two-farm simulation model, all farms harvest 5,000 acres per year; however, because of different soil types, the effects of climate variability, and yield losses from delayed harvesting, the farms are not homogenous.

This becomes very apparent in the Pampa – Pampa farm combination. Theoretical conclusions and empirical results coincide in that the Nash equilibrium generally does not occur where the percentage of shared costs are 50 percent. In the Pampa – Pampa combination, for example, optimal sharing occurs when farm 1 pays 75 percent of the shared costs. The first farm to harvest (farm 1) must pay a larger portion of the costs to compensate the second farm (farm 2) for the 25 days of uncompensated yield loss associated with the first farm completing harvest.

As suggested by the theoretical model conclusions (Chapter III) and shown in the empirical model results (Chapter VI), firms can increase net returns and NPV of after tax cash flows by paying a smaller percentage of the shared costs for all penalty payment scenarios. Taking all the results together indicates there is room for negotiation when determining the percentage of shared costs each farm pays. In addition, risk is generally reduced when sharing versus non-sharing harvesting machinery (Table 6.1).

Penalty Paid for Untimely Machinery Delivery

Similar to the percentage of shared costs, the penalty structure is a contractual issue negotiated *ex-ante*. The penalty is paid by farm 1 to farm 2 when machinery is not delivered to farm 2 by the contracted date. Several penalty payments for untimely machinery delivery with different levels of harvesting risk borne by each farm are considered. Inferences from the different penalty payments are robust.

As expected, the first farm to use the harvesting machinery prefers to shift all harvesting risk to the second farm (No Penalty). Similarly, the second farm prefers to bear zero harvesting risk (Base Case). In the base case, farm 1 bears all risk from delaying machinery delivery because farm 1 compensates farm 2 for yield loss incurred beyond the contracted date. When there is no penalty for untimely machinery delivery, farm 2 bears all harvesting risk associated with untimely machinery delivery. In this case, farm 1 has no incentive to deliver the machinery by the contracted date. Variations of the penalty payment, such as a 50 percent penalty payment, allow for equal sharing of the harvesting risk. In the case of the lump sum penalty, the incentive for farm 1 to deliver the machinery by the contracted date depends on the penalty payment amount. If the lump sum penalty is large enough, farm 1 will choose to deliver the machinery by the contracted date. Obviously, the structure of the penalty payment preferred by each farm is dependent on the order of machinery usage and the penalty payment amount.

Inferences from the penalty payments for individual farms do not vary between penalty payments. In general, risk is reduced for all penalties. Even though inferences are similar, an inspection of two-farm cash flows indicates the largest two-farm cash flows depend on the penalty payment and harvesting windows. In general, the base penalty provides the largest two-farm cash flows when harvesting windows highly overlap. No penalty provides the largest two-farm cash flows when there is almost no overlap in harvesting windows. When there is a partial overlap in harvesting windows, results are ambiguous.

Harvesting Windows

When harvesting windows highly overlap, both farms are individually better off (positive differences) sharing machinery only when farm 1 pays more than half of the shared costs. Farm 1 must pay a larger percentage of the costs because farm 2 is incurring uncompensated yield losses as s/he waits for the harvesting equipment. There appears to be more room for negotiation when harvesting windows partially or do not overlap. For instance, both farms are better off in the Pampa – Akron and Pampa – Big Sandy combinations when the percentage of shared costs paid by farm 1 ranges from 25 to 75 percent. Even though both farms are better off when sharing machinery within this range of percentage of shared costs, one farm gains at the expense of the other farm as the percentages change.

Machinery Set Size

Firms sharing machinery may have access to larger, more efficient machinery that would otherwise be unaffordable. To examine this postulate, sensitivity analysis on the size of machinery when sharing machinery is conducted. The Pampa – Akron combination is reformulated such that when non-sharing machinery, smaller combines requiring 35 workable harvesting days to complete harvest are modeled. A larger harvesting machinery set, as already assumed in the model when sharing machinery, is affordable and requires 25 workable harvesting days to complete harvest.

The larger more efficient machinery set is associated with a smaller penalty payment because of smaller yield losses from timelier harvests. Pampa, regardless of the percentage of shared costs paid, is always better off with machine sharing and using the larger machine. Generally, Akron is better off delaying harvest and harvesting at a faster rate using the larger harvesting machinery set than harvesting on time at a slower rate using the smaller harvesting machinery set. Only when Akron pays all the costs, is Akron better off with the smaller combine. Using machinery sharing to obtain the use of larger machinery, even at the expense of delaying harvest, is a viable option producers may want to consider.

Percentage of Depreciation Claimed

As expected, when a farm deducts a larger percentage of depreciation, *ceteris paribus*, machinery sharing becomes more profitable to that farm. The reason is less federal income taxes are paid, therefore net after tax cash flows are larger. There are interactions between depreciation and the level of debt free land and non-shared machinery that impacts the NPV of after tax cash flows. Depreciation becomes more valuable as the percentage of debt free land and machinery increases because of smaller tax deductions from interest payments. Farms with a larger taxable income can benefit more from using a larger percentage of tax deductible depreciation. Alternatively, when the debt free percentage is small, there are larger tax deductions associated with interest payments. When such large tax deductions are available, depreciation may not always be used even when considering carryover losses.

There are potential tradeoffs between the percentage of shared costs paid and the percentage of shared depreciation claimed when different percentages of debt free land and non-shared machinery are considered. The tradeoffs exist because NPV of after tax cash flows are larger when a larger percentage of depreciation is deducted and smaller when a larger percentage of shared costs is paid. A farm with a high percentage of debt free land may be willing to pay more of the shared machinery costs in return to be able to deduct a higher percentage of the shared depreciation. For farm managers considering machinery sharing, the percentages of debt free land and non-shared machinery, shared costs, and depreciation are important items to consider when negotiating the machinery sharing contracts. Proper contractual arrangements can increase both individual and two-farm cash flows.

Limitations and Further Research

Besides the usual data and modeling assumptions limitations which are present in all studies, the results of this study have additional qualifications. Results depend on the crop growth model used to generate yields and maturity dates. Because of low simulated yields in some years, weather data are adjusted to reduce the effects of winter-kill caused by extended sub-zero temperature periods. Furthermore, yield reduction rates post maturity are not included in the crop growth model. A rate from published research articles is incorporated into the model.

Two financial structures, sole-proprietorship when non-sharing and sole proprietorship with a limited liability company when sharing harvesting machinery, are assumed in the two-farm simulation model. A farm's financial structure has potential important tax consequences because tax regulations vary by the structural arrangement. Because the percentage of debt free land and non-shared machinery along with depreciation percentage claimed have important tax implications, thereby, affecting the NPV of after tax cash flows, other forms of financial structure may change the inferences presented in this dissertation.

Depreciation is calculated using the straight-line depreciation method. Other methods of calculating deprecation may also be important to machinery sharing. For example, the double-declining balance depreciation method allows for greater tax deductions in the first years of ownership, however, deducted depreciation above the value of the machinery must eventually be reconciled. Such changes will affect the net present value of after tax cash flows. Both farms sharing machinery are assumed to have the same acreage. Effects of machinery sharing on different size of farms should be examined.

Thinking beyond these models, several inferences on potential effects of machinery sharing can be made and future research suggested. The models only consider the full information case. A more likely scenario is that of asymmetric information where the actions of one producer affect the other. A moral hazard problem, for example, may arise when one producer agrees to perform maintenance on the machinery as agreed in the contract, but only performs the maintenance shortly before delivery rather than according to manufacturers' recommendations. This and other asymmetric information issues should be studied in the machinery sharing context.

Several assumptions regarding contractually negotiated items and firm specific components are made *ex-ante* and are considered fixed over the five year machinery sharing contract. Fixed items include, for example, a lump sum penalty, the percentage of shared costs, and individual firm discount rates. Relaxing these assumptions to allow for variability between years may influence the decision to share machinery. Further, in addition to penalty payments for yield loss associated with untimely machinery delivery, penalties for reduction in grain quality may also be examined.

Manufacturers and dealers may also need to adjust their product mix. If by sharing machines, producers buy larger machines than they would without sharing, manufacturers and dealers may have to shift their product mix towards larger, more efficient machines to accommodate any increase in demand. Further, the equipment sector may want to offer specialized services as a strategy to gain additional profits from this emerging trend. Studies examining the potential impact of machinery sharing on equipment manufacturers and dealers, as well as, the effects of increased competition on custom operators are warranted.

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APPENDIX A

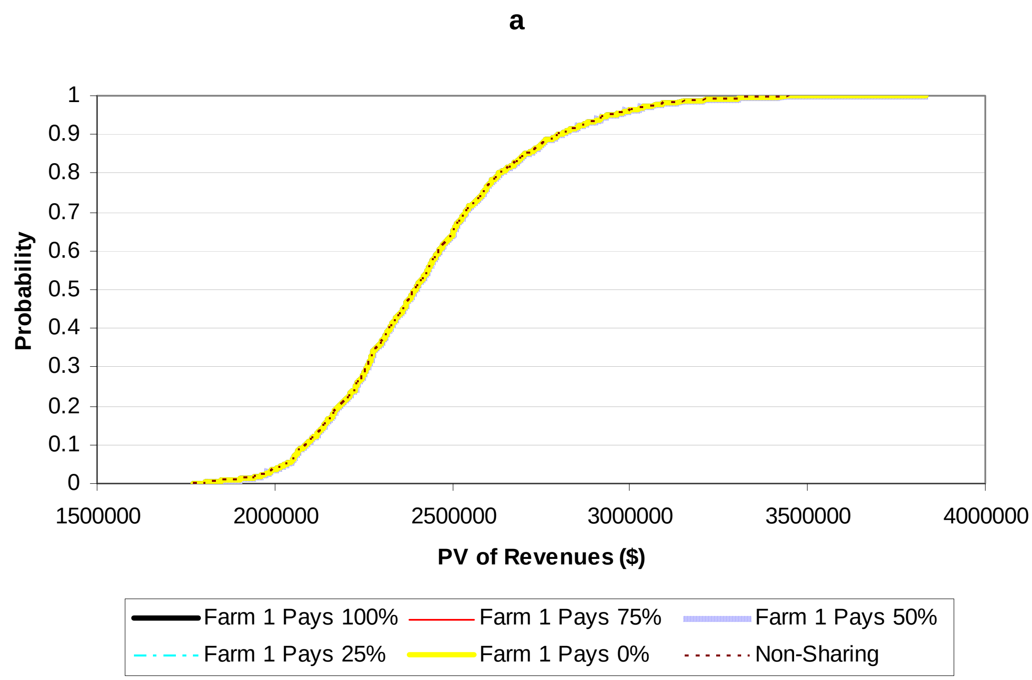
This appendix consists of cumulative distribution function graphs of present value (PV) of revenues, costs, federal self employment and income taxes, penalties, and NPV of after tax cash flows and changes in whole-farm ending net worth for the Pampa – Pampa combination. This combination is used to illustrate these different components of the model. Other combinations have different specific curves, but general inferences are consistent. Distributions at different percentages of shared costs when sharing harvesting machinery are illustrated in Figures A1 through A6 for the base penalty case. Distributions when non-sharing are also given as a comparison. Recall, in the base penalty case farm 1 bears all risk and compensates farm 2 for losses in yield associated with untimely machinery delivery.

Changes in solvency, liquidity, and profitability ratios over the five simulated years are also presented. Solvency is determined using the debt-to-assets ratio which measures the extent of which debt has been used to finance business activities. Liquidity is determined using the current ratio, which measures the ability of the firm to cover current liabilities with assets that can be converted to cash in the short term. Profitability is determined using the return-on-assets ratio, which measures return on total investment. Changes in the debt-to-assets ratio, the current ratio, and return-on-assets ratio are given in Figures A7 through A9. Changes in ratios are determined by subtracting calculated ratios in first year from ratios calculated in the fifth year and then averaged over the 1000 iterations.

Revenues

The distribution of farm 1 PV of revenues are identical, as expected, for all percentages of shared costs when sharing machinery and are equal to the revenues when non-sharing harvesting machinery (Figure A1). The distributions are identical because farm 1 uses the machinery first. Therefore, there is no delay in harvesting for farm 1 from untimely machinery delivery. In addition, farm 1 always chooses to complete harvest given that crop insurance payments are not larger than revenues generated from harvesting plus government payments.

Revenues for farm 2, however, vary only by sharing and non-sharing machinery. The decision made by farm 1 to continue harvesting or deliver the machinery is dependent on the penalty to be paid to farm 2. When sharing machinery, farm 1 is required to compensate farm 2 for yield loss attributed to untimely machinery delivery. Therefore, the decision to retain the machinery and complete harvesting is costly to farm 1 by the amount of the penalty payment. Because in some years farm 1 chooses to complete harvest, incur the penalty payment, and delay machinery delivery, farm 2 revenues are reduced. In this base penalty case, however, farm 2 is fully compensated for yield loss from untimely machinery delivery. Yield losses for farm 2 are not compensated for up to 25 days beyond farm 1's harvest start date. This explains why revenues from non-sharing are larger for farm 2 than when non-sharing machinery.



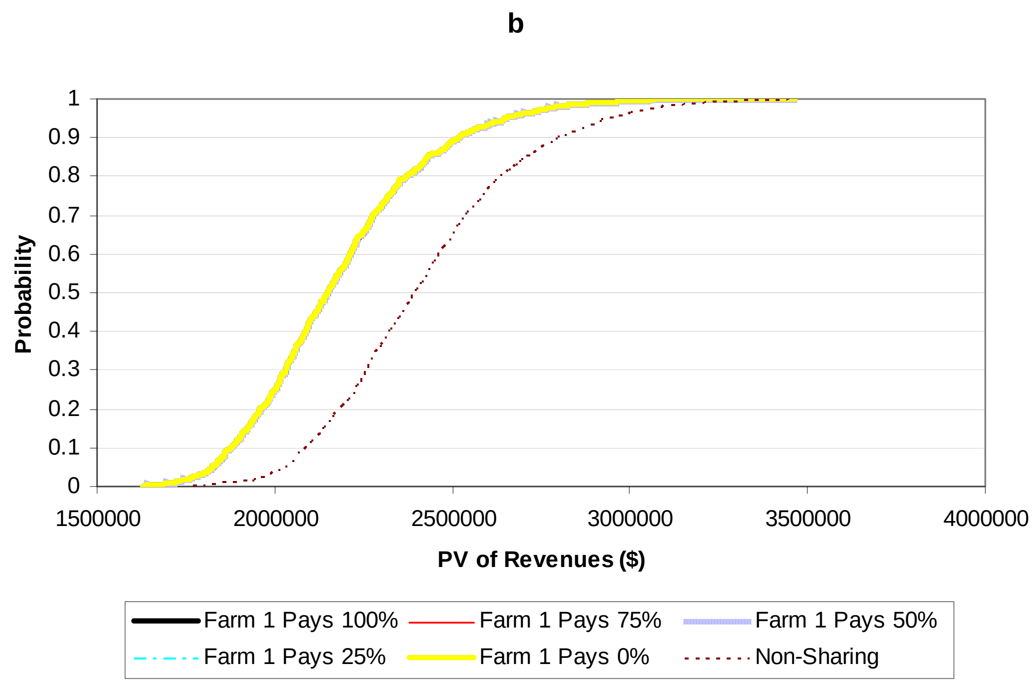
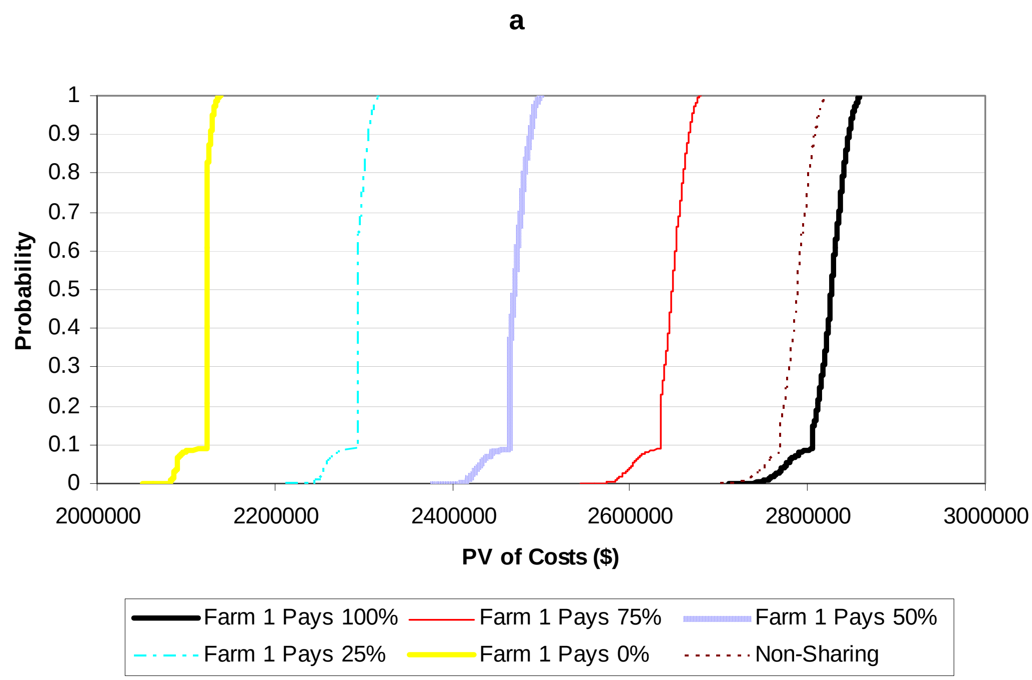


Figure A1. Cumulative distribution function graphs of present value (PV) of revenues for farm 1 (a) and farm 2 (b) in the Pampa – Pampa combination for non-sharing and sharing machinery at different percentages of shared costs

Costs

PV of costs, excluding federal income and self-employment taxes and penalties, are illustrated in Figure A2. For both farms, the distributions of costs are higher when paying a larger percentage of the shared costs. Also, sharing machinery is more costly than non-sharing when paying 100 percent of the shared costs.

There is little variation in the costs distributions. Costs of production for each farm are determined from budgets given in Chapter V. Variation in costs is caused by interest payments, and operating costs. In years where harvest is not completed, harvesting costs are reduced.



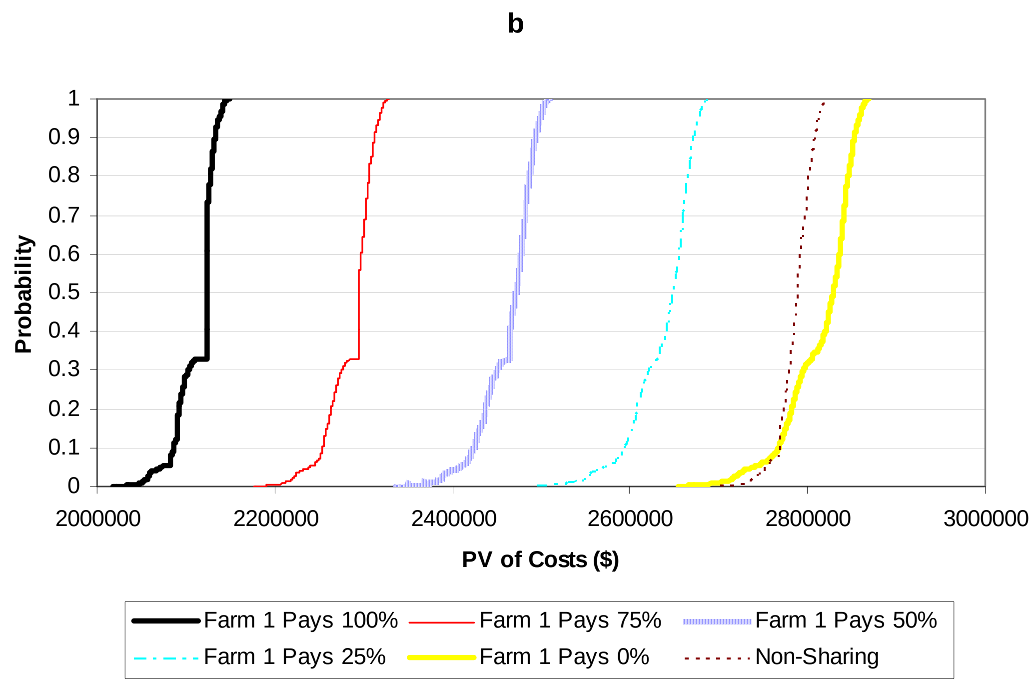


Figure A2. Cumulative distribution function graphs of present value (PV) of costs for farm 1 (a) and farm 2 (b) in the Pampa – Pampa combination for non-sharing and sharing at different percentages of shared costs

Federal Income and Self-Employment Taxes

As taxable income increases, the amount of federal income and self-employment taxes also increases. PV of taxes is illustrated in Figure A3. Farm 1 has a higher probability of paying taxes when sharing machinery than farm 2. As expected, taxes paid by both farms are identical when non-sharing machinery because the farms are identical. Farm 1 has approximately a 30 percent probability of paying zero taxes when paying zero percent of the shared costs and approximately a 60 percent probability of paying zero taxes when paying 100 percent of the shared costs. Farm 1 has approximately a 65 percent probability of paying zero taxes when non-sharing machinery.

As discussed previously, revenues are smaller for farm 2 when sharing machinery. This results in smaller net returns and less taxes paid by farm 2. When farm 2 pays 100 percent of the shared costs, the probability of paying taxes is almost 20 percent. Similar to farm 1, as farm 2 pays a smaller percentage of the shared costs the probability of paying taxes increases.

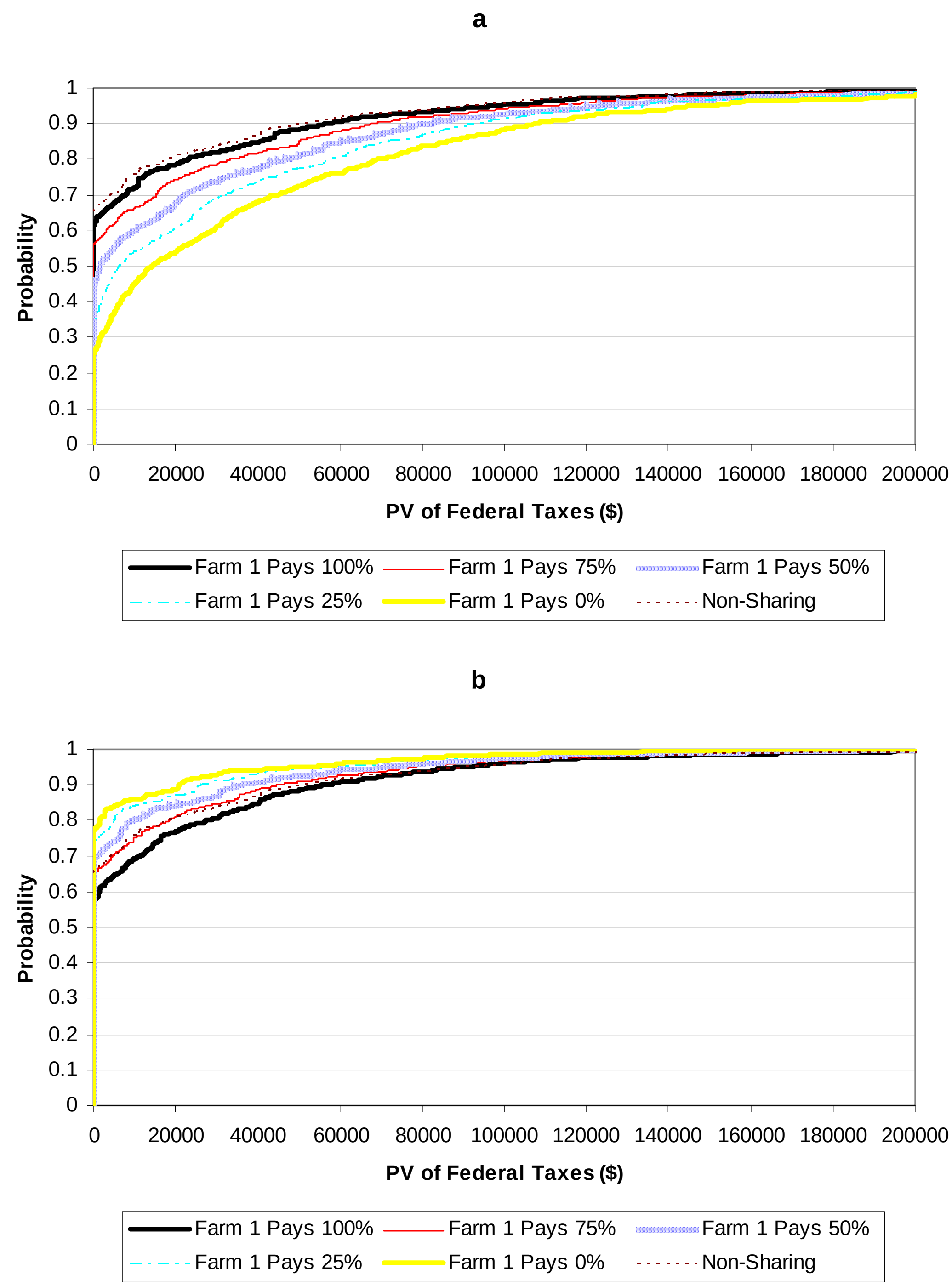
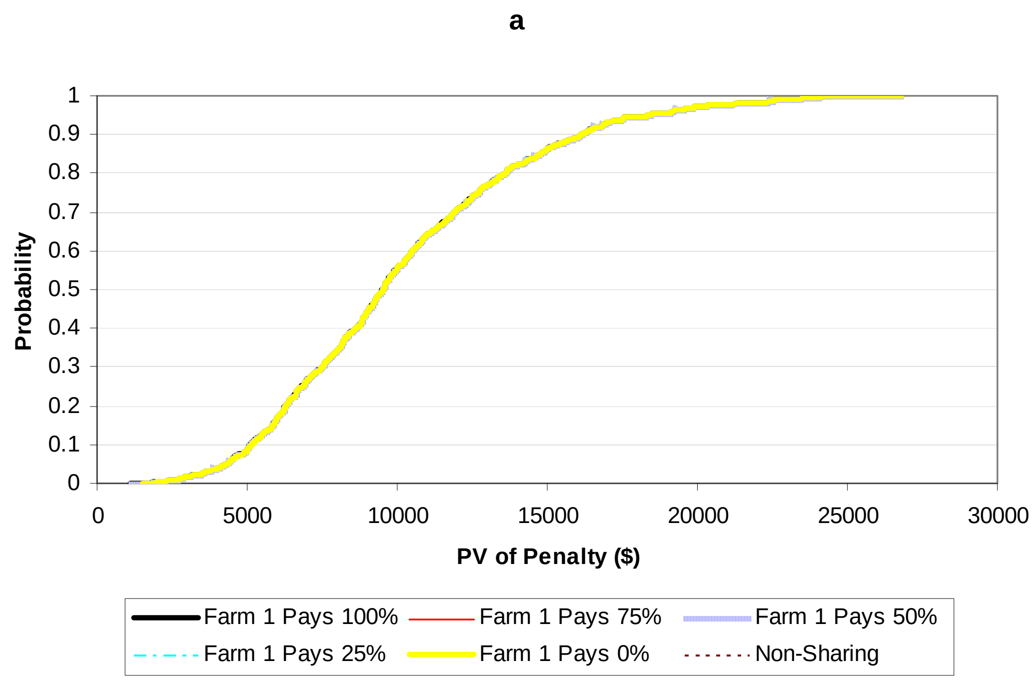


Figure A3. Cumulative distribution function graph of present value (PV) of federal income and self-employment taxes for farm 1 (a) and farm 2 (b) in the Pampa – Pampa combination for non-sharing and sharing at different percentages of shared costs

Penalty Payment

The PV of the penalty payment made by farm 1 and received by farm 2 is identical for both farms and always greater than or equal to zero (Figure A4). When sharing machinery, the penalty paid by farm 1 has approximately a 45 percent probability of being greater than or equal to $10,000. The penalty payment illustrated is that of the base case penalty payment where farm 1 bears all the risk and compensates farm 2 for all yield loss attributed to delayed machinery delivery.



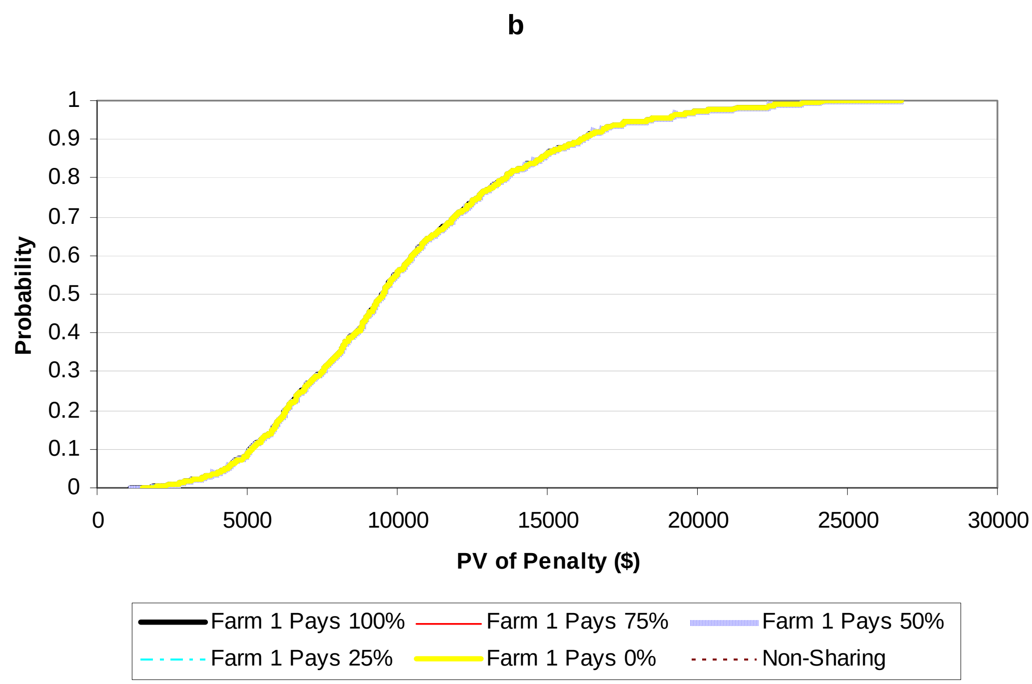


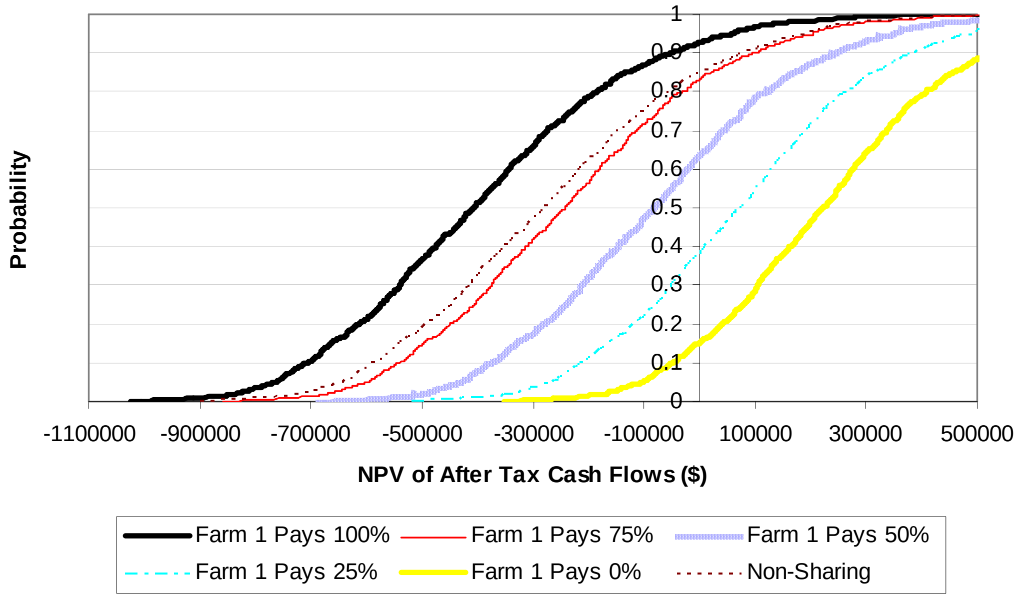
Figure A4. Cumulative distribution function graphs of present value (PV) of penalties for farm 1 (a) and farm 2 (b) in the Pampa – Pampa combination for non-sharing and sharing at different percentages of shared costs

NPV of After Tax Cash Flows

NPV of after tax cash flows are illustrated in Figure A5. Depending on the percentage of shared costs paid, sharing machinery increases the probability of having positive cash flows for both farms. For farm 1, NPV of after tax cash flows have a higher probability of being positive when farm 1 pays 75 percent or less of the shared costs than NPV associated with non-sharing of harvesting machinery. Scenarios where farm 1 pays 75 percent or less of the shared costs first-order stochastically dominate the non-sharing scenario. The non-sharing scenario, however, first-order stochastically dominates the scenario where farm 1 pays 100 percent of the shared costs. When paying zero percent of the shared costs, farm 1 has approximately an 85 percent probability of having a positive after tax cash flow as compared to less than 10 percent when paying 100 percent of the shared costs.

For farm 2, the non-sharing machinery scenario second-order stochastically dominates sharing machinery when farm 2 pays 50 percent of the shared costs and first-order stochastically dominates the scenarios where farm 2 pays more than 50 percent of the shared costs. When non-sharing, farm 2 has approximately a 15 percent probability of having a positive after tax cash flow and approximately a 50 percent probability of having a positive cash flow when paying zero percent of the shared costs. For this Pampa – Pampa combination, farm 1 would be willing to pay up to 75 percent of the shared costs and farm 2 would be willing to pay less than 50 percent of the shared costs.

a



b

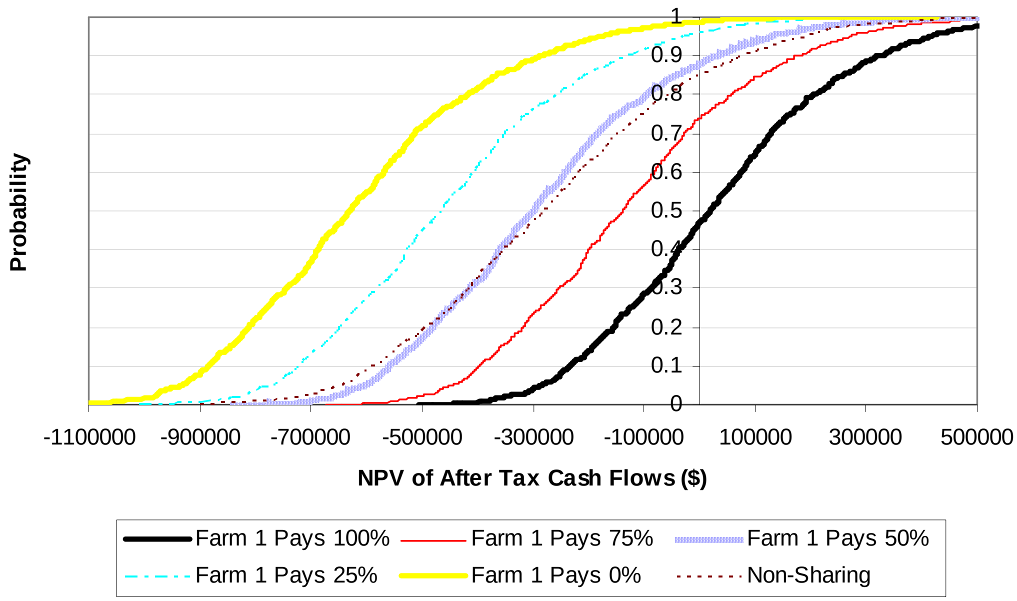
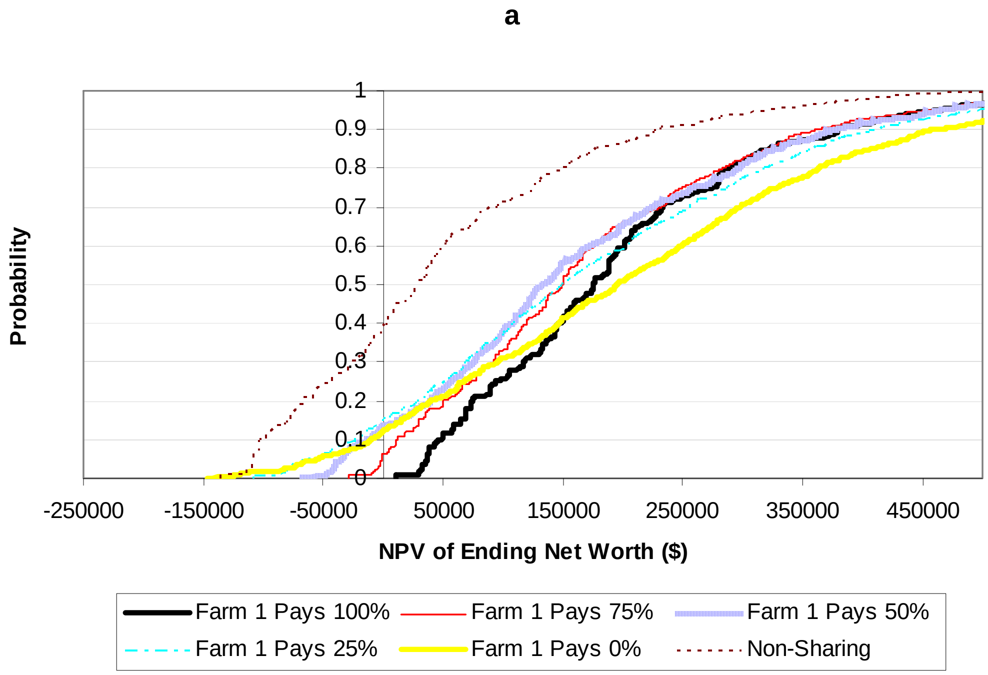


Figure A5. Cumulative distribution function graphs of net present value (NPV) of after tax cash flows for farm 1 (a) and farm 2 (b) in the Pampa – Pampa combination for non-sharing and sharing at different percentages of shared costs

Changes in Ending Net Worth

Changes in the NPV of ending net worth are illustrated in Figure A6. In the case of farm 1, changes in the NPV of ending net worth are larger when sharing at all percentages of shared costs than non-sharing. The probability of having a positive change in ending net worth is 60 percent when non-sharing and at least 82 percent when sharing machinery. For farm 2, scenarios where farm 2 pays less than 50 percent of the shared cost first-order stochastically dominate non-sharing, while paying zero percent of the shared costs only second-order stochastically dominates non-sharing. Farm 1 is clearly better off, from the stand point of changes in ending net worth, sharing machinery and paying any percentage of shared costs. Farm 2 is better off sharing machinery and paying 50 percent or less of the shared costs.



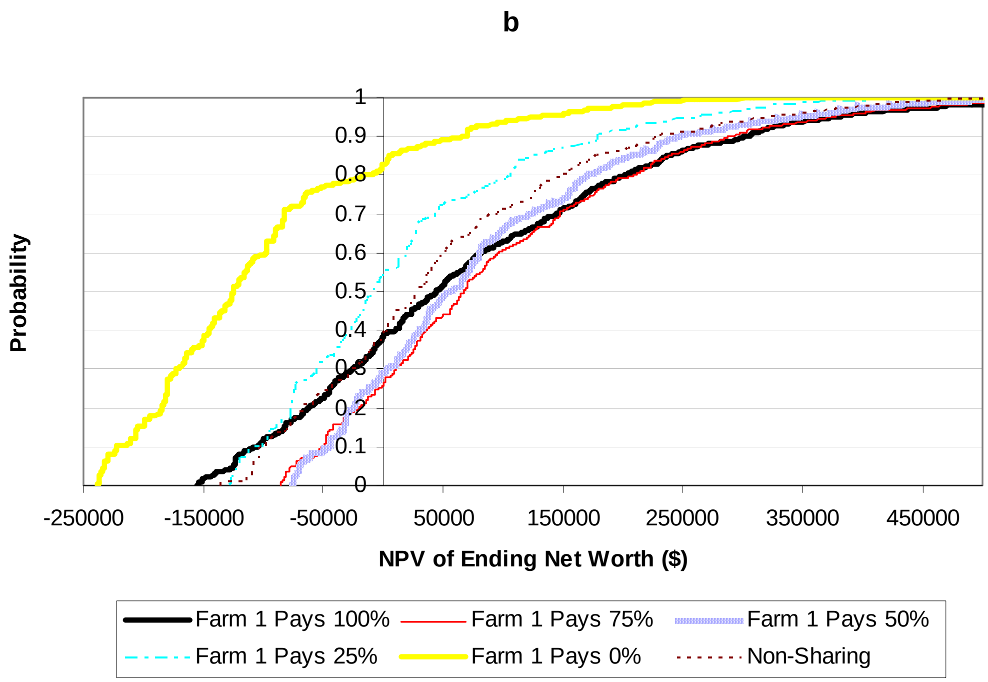
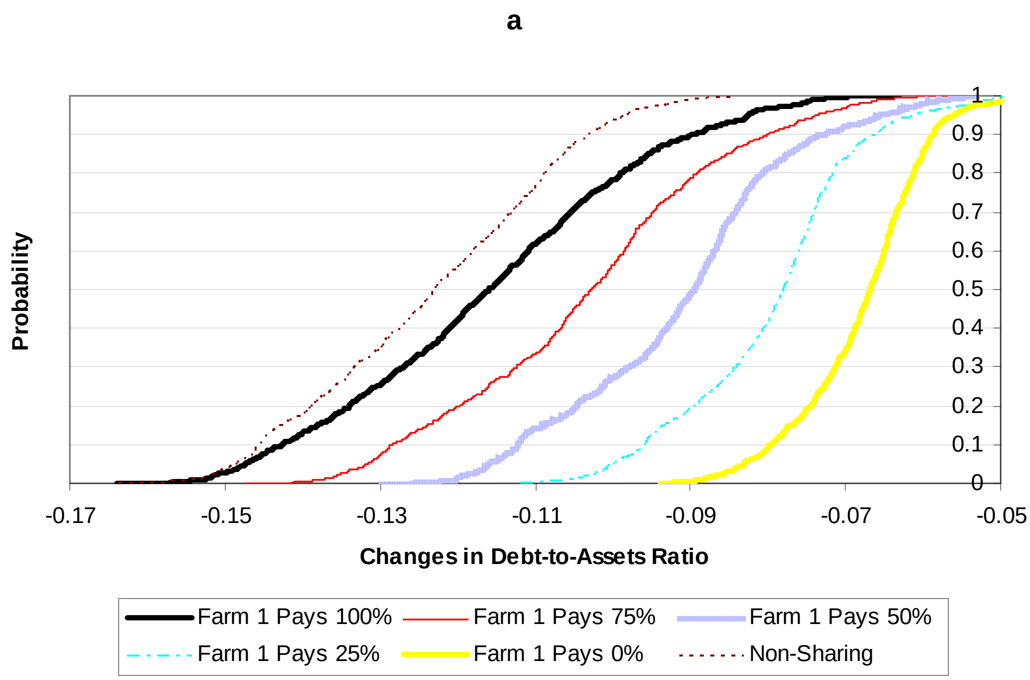


Figure A6. Cumulative distribution function graphs of changes in net present value (NPV) of ending net worth for farm 1 (a) and farm 2 (b) in the Pampa – Pampa combination for non-sharing and sharing at different percentages of shared costs

Changes in Debt-to-Assets Ratio

The debt-to-assets ratio is calculated by dividing total liabilities by total assets. Changes in debt-to-assets ratio are determined by subtracting the debt-to-asset ratio in year one from the debt-to-asset ratio in year five. For all scenarios of sharing and non-sharing machinery, debt-to-assets ratios for both farms at all percentages of shared costs are reduced (Figure A7). This result is not fully explained by sharing and non-sharing harvesting machinery because harvesting machinery is 100 percent financed in the first year and sold at the end of the fifth year. Consequently, changes in debt-to-assets ratios from machinery sharing in the first and fifth year nearly equals zero. The difference between harvesting machinery value and liabilities increases over the first four years as the value of machinery decreases at a slower rate than the liabilities. Both the value and liability are zero when the harvesting machinery is sold at the end of the fifth year.

Reduction in debt-to-assets ratios is partially explained by the increase in land value from the annual inflation rate of 6.7 percent. Because land values represents such a large portion of the whole-farm worth, the denominator in the debt-to-assets ratio increases substantially as the value of assets increases. As assets increase in value, the debt-to-assets ratio decreases, *ceteris paribus*. For the two scenarios, non-sharing and paying 100 percent of the shared costs, debt-to-assets ratios for both farms decrease by the largest amount. This indicates that the debt-to-assets ratio is reduced as the percentage of machinery ownership increases.



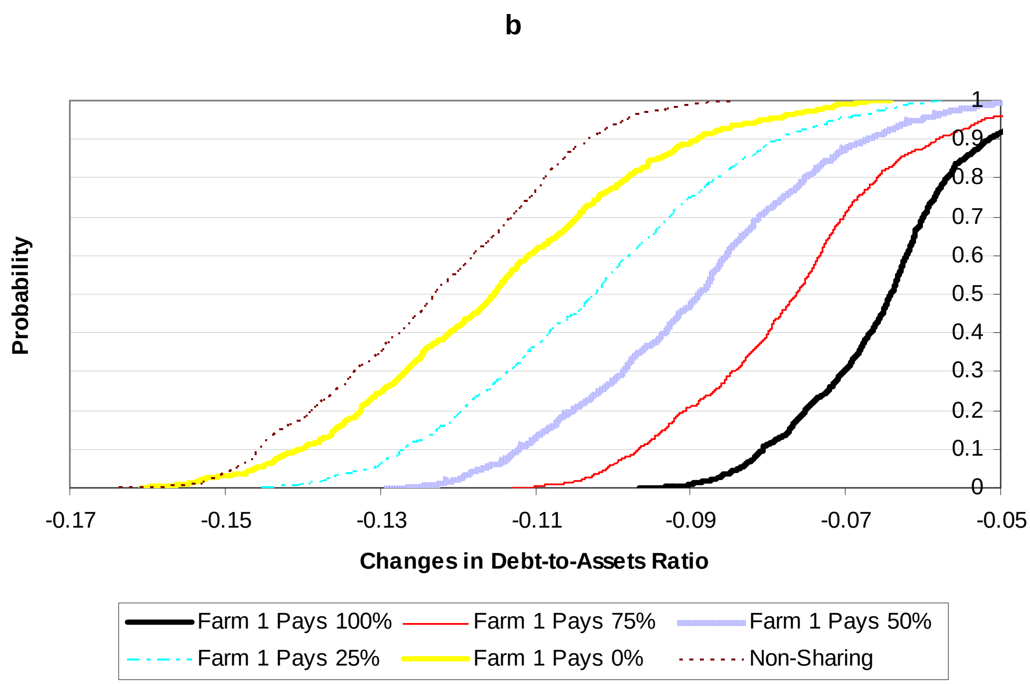
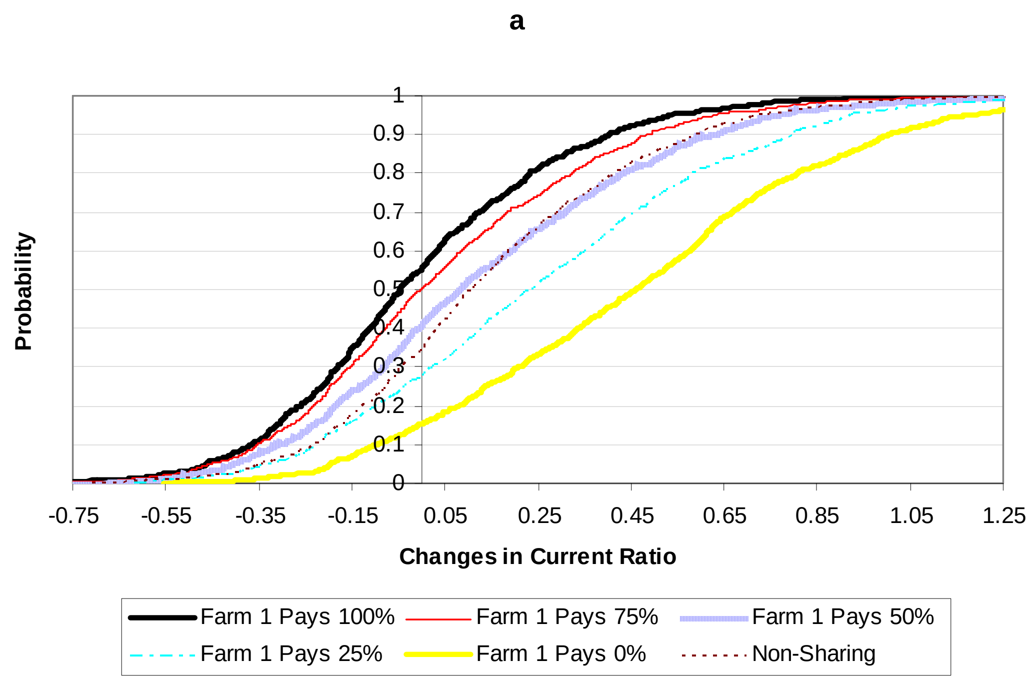


Figure A7. Cumulative distribution function graphs of changes in debt-to-assets ratios for farm 1 (a) and farm 2 (b) in the Pampa – Pampa combination for non-sharing and sharing at different percentages of shared costs

Changes in Current Ratio

A cumulative distribution function graph of changes in the current ratio from year one to year five for both farms in the Pampa – Pampa combination is given in Figure A8. The current ratio is determined by dividing total current assets by total current liabilities. Change in the current ratio is determined by subtracting the current ratio in year 1 from that of year five. If current liabilities are larger than current assets, the ratio is reduced and the farm may have trouble meeting its short-term debt obligations. When changes in the current ratio are positive, there is an improvement in the farm's ability to meet its short-term debt obligations. When paying 50 percent of the shared costs, farm 1 has approximately a 50 percent probability of having a positive change in its current ratio.

For farm 1, scenarios where farm 1 pays 25 percent or less of the shared costs first-order stochastically dominate non-sharing harvesting machinery. Non-sharing second-order stochastically dominates the scenario where farm 1 pays 50 percent of the shared costs and first-order stochastically dominates the scenario where farm 1 pays 75 percent or more of the shared costs. For farm 2, paying zero percent of the shared costs second-order stochastically dominates non-sharing harvesting machinery. Non-sharing, however, first-order stochastically dominates sharing when farm 1 pays 25 percent or more of the shared costs.



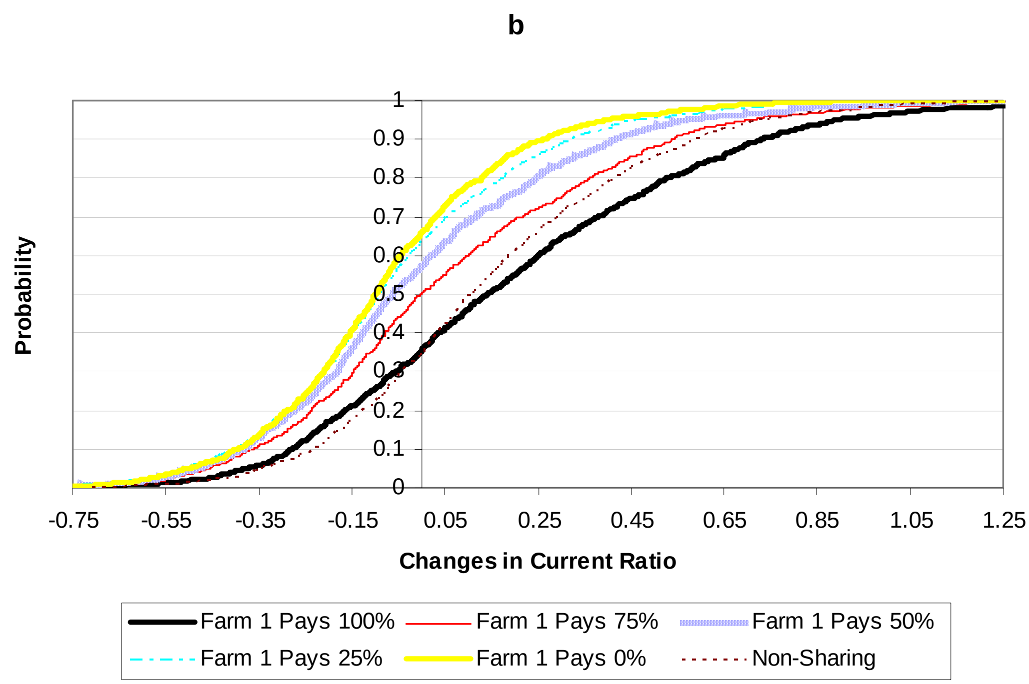
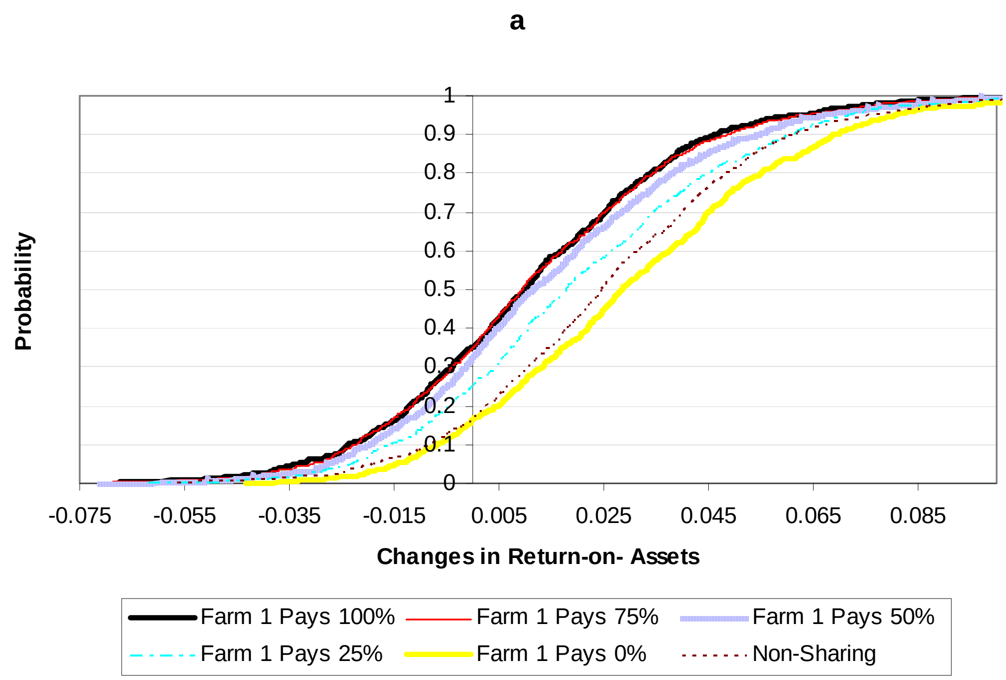


Figure A8. Cumulative distribution function graphs of changes in current ratios for farm 1 (a) and farm 2 (b) in the Pampa – Pampa combination for non-sharing and sharing at different percentages of shared costs

Changes in Return-on-Assets

Return-on-assets is a financial ratio for profitability that indicates how much profit is generated for each dollar of assets. To calculate return-on-assets, net after tax cash flow income is divided by total assets. Changes in the return-on-assets ratio is determined by subtracting the return-on-assets value in year one from the value of year five.

For farm 1, there is approximately an 85 percent probability that the change in return-on-assets will increase when non-sharing (Figure A9). Non-sharing first-order stochastically dominates sharing when farm 1 pays 25 percent or more of the shared costs. When farm 1 pays zero percent of the shared costs, however, sharing first-order stochastically dominates non-sharing. For farm 2, non-sharing first-order stochastically dominates sharing at all percentages of shared costs. This is expected because revenues are reduced for farm 2 when sharing machinery because of uncompensated yield loss (Figure A1).



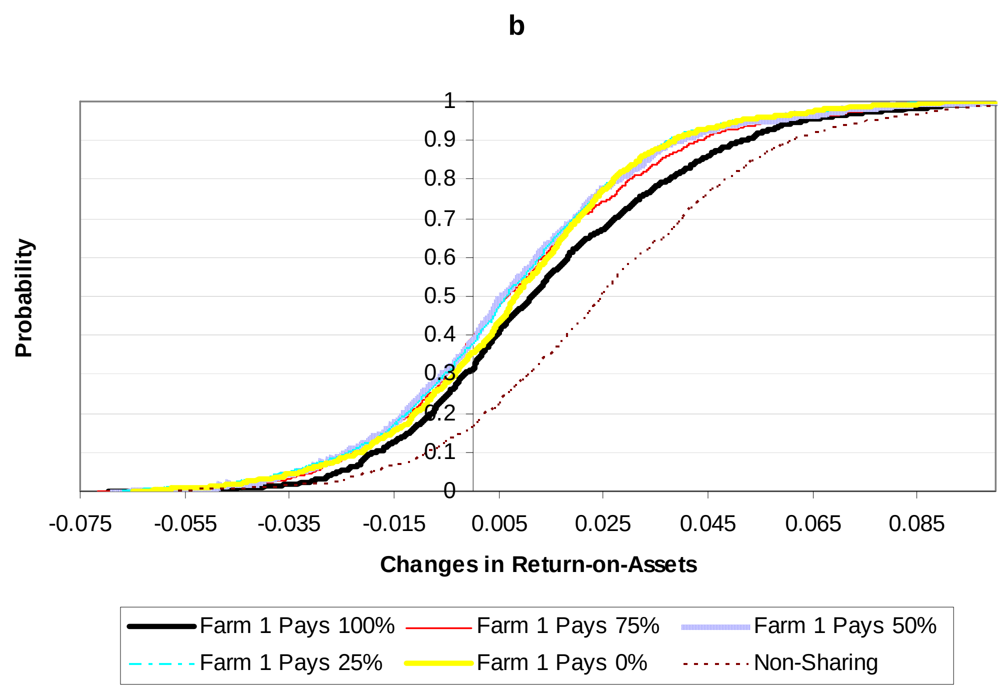


Figure A9. Cumulative distribution function graphs of changes in return-on-assets ratios for farm 1 (a) and farm 2 (b) in the Pampa – Pampa combination for non-sharing and sharing at different percentages of shared costs

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