# Analyzing Risk and Risk Management in Cropping Systems

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**Abstract**

Risk is an intrinsic part of cropping systems and cropping system management. A stochastic budgeting example using field plot data is used to illustrate common sources of risk and methods producers use to deal with risk. An additional example utilizes crop simulation modeling to illustrate the potential importance of timeliness risk in cropping system choices. The examples provide a framework for presenting risk concepts and risk analysis techniques.

**Introduction**

Agricultural management decisions are almost always made in the face of uncertain consequences. Crop planting decisions are generally made before a price for the crop has been set and long before yields are determined. Machinery and land is purchased with only a general idea about what the next government farm bill will bring, or what the farm economy will be like in the next several years. Nitrogen fertilizer is applied based on limited knowledge of the nutrient status of the soil or how the remainder of the season will play out in determining crop yield and quality.

Following Hardaker et al. (1997), uncertain consequences and especially unfavorable consequences are broadly defined as risk. Hardaker et al. (1997) divide risk sources into five general categories: production risk, price or market risk, institutional risk, human or personal risk, and financial risk. Production risk refers to uncertain crop yields or livestock performance due to such things as weather and pest infestations. Price or market risk refers to uncertain input and output prices. Institutional risk arises from changes in government policies such as environmental regulations or government subsidies. Human or personal risks are related to farm operators such as unforeseen illness or human error in farming operations. Financial risks refer to uncertainties related to use of borrowed funds such as changes in interest rates.

Individuals are generally ‘risk averse’. That is, they would be willing to give up some expected returns for a reduction in risk. However, the amount individuals would be willing to give up depends on individual preferences. There are many ways that agricultural operations can deal with risk. They can try to reduce or eliminate risk by seeking information to reduce uncertainty, by finding less risky ways to produce a commodity, or by building flexibility into their operations allowing them to rapidly respond to changing conditions. Alternatively, they can transfer risk to others by purchasing insurance, using futures markets, or through contracting or lease agreements.

In analyzing cropping systems, it is important to understand sources and effects of risk and how producers respond to risk. The approach in this paper is to use specific examples of risk in cropping systems to illustrate some useful tools for analyzing risk and the ways risk can affect producer behavior.

## Stochastic Budgeting – Cropping Systems Example

In order to evaluate risk, it is necessary to identify the distribution of possible outcomes under uncertainty. A useful tool is stochastic budgeting which allows uncertainty in some variables to be included in calculating potential outcomes. Although stochastic budgeting has been used for several years (e.g. Milham, 1992; Olson et al. 1991), it has become much easier to use due to the development of spreadsheet software add-ins such as @RISK (Palisade, 1997) and Simetar (Richardson et al. 2003) to automate stochastic simulation. The approach in stochastic budgeting is just like constructing a deterministic budget, however some variables are explicitly modeled as uncertain. The stochastic nature of the budget is captured by specifying probability distributions for the uncertain variables. Using a Monte Carlo procedure, random samples are drawn from these distributions and used to evaluate the budget. The results are recorded, another sample is drawn, and the results are again recorded. This simulation continues for a sufficiently large number of samples to generate a stable distribution of outcomes. The procedure is general enough to be used with almost any type of budget including partial budgets, enterprise budgets, or whole-farm budgets. For this example, an enterprise budgeting approach will be used.

A long-term study comparing alternative tillage and rotation systems initiated in 1990 at the Eastern South Dakota Soil and Water Research Farm near Brookings, SD will be used to illustrate the use of stochastic budgeting for risk analysis. The study included four tillage and rotation treatment combinations: continuous corn conventional tillage (CNT), corn-soybean conventional tillage (2YRC), corn-soybean ridge tillage (2YRR), and corn-soybean-wheat/alfalfa-alfalfa conventional tillage (4YRC). The study also included three input levels, however only data from the high input level treatments will be used in this example. Details on the experimental design are in Riedell et al. (1998) and Pikul et al. (2001).

For this analysis, the effects of uncertain prices and yields on returns for the alternative tillage and rotation systems will be evaluated. The BestFit distribution-fitting software program that is bundled with @RISK was used to estimate smooth cumulative distribution functions (CDF) for each treatment based on annual yield observations from 1991-1999. An example of a fitted CDF is given in Figure 1. Similarly, CDF's were estimated for crop prices from 1991-1999, using the season average prices for South Dakota (South Dakota Agricultural Statistics Service 1999, 2002). Note: no clear trends were observed in the yields, so the CDF was fit directly to the observed yields. Often, there will be time trends in yield data. In cases where there are time trends, regression can be used to estimate the time trend, and a CDF can be fit to the regression residuals.

Since yield distributions for each crop were driven at least in part by common weather conditions, it is likely they were not stochastically independent. In addition, it is possible that crop yields and prices may not be stochastically independent due to the possibility of weather influences over large regions affecting crop supplies. To fully account for this effect, it would be necessary to estimate a joint distribution function for the uncertain variables. However, this would be difficult at best. To account for some of the interdependence, @RISK allows correlations between each of the uncertain variables to be included into the sampling procedure. A correlation matrix was estimated for yields and prices based on the 1991-1999 observations. Enterprise budgets were constructed following the procedure outlined in Archer et al. (2002) based on the actual tillage operations and inputs used in the field study. The resulting cost estimates were averaged over the 9 years of the study and held constant for this analysis.

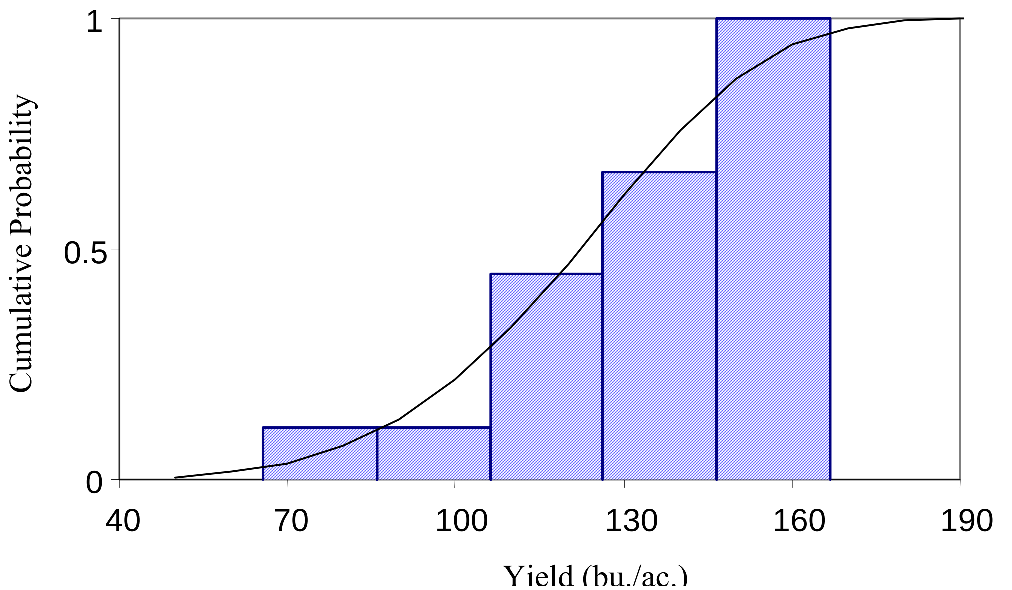

Figure 1. Estimated cumulative distribution function for corn yield in a corn-soybean rotation under conventional tillage.

Because @RISK is a spreadsheet add-in, there is considerable flexibility in setting up different scenarios to be evaluated within the spreadsheet. Four different scenarios are presented in this analysis: 1) no government program or insurance (baseline) 2) government program only (gp), 3) government program and crop insurance (gpi), and 4) government payments and crop insurance using old base acres (gpi ob). In each scenario, both yields and prices were stochastic. All four scenarios were run simultaneously using 2000 random samples from each of the yield and price distributions. Even with 2000 random samples, the simulation only took 11 seconds to run on a computer with a 1.6 GHz Pentium 4 processor and 256 MB RAM.

Figure 2 shows the net return CDF's for the four tillage and rotation treatments under the baseline scenario of no government payment or crop insurance. Although specific risk preferences will vary from individual to individual, the CDF's can be used to identify the treatments that would be preferred by individuals within a range of preferences using stochastic dominance analysis (Meyer, 1977). The simplest form of stochastic dominance is first-degree stochastic dominance. If a CDF 'A' lies entirely below and to the right of another CDF 'B', then 'A' dominates 'B' in the first-degree sense. 'A' would be preferred by any individual who prefers more of the performance measure (in this case net returns) to less, regardless of whether they are risk averse. In Figure 2, the 2YRR treatment dominates the 2YRC treatment in the first-degree sense, so a corn-soybean rotation under ridge tillage would be preferred over a corn-soybean rotation under conventional tillage by anyone who prefers higher net returns to lower net returns. Although it appears that the 2YRR treatment also dominates the 4YR treatment, there is a small area at the low end of the CDF's where the 4YR CDF lies to the right of the 2YRR CDF, so neither dominates. Even though the 2YRR treatment generally has higher net returns than the 4YR treatment, in the most extreme adverse instances losses are lower for the 4YR treatment. Since the CNT CDF crosses each of the other CDF's it neither dominates nor is dominated by the other distributions in the first-degree sense. The CNT treatment shows the greatest variability in net returns with the greatest losses in adverse years and greatest returns in favorable years. The 4YR treatment shows the least variability in net returns with the lowest losses in the most adverse years, but the lowest returns in the most favorable years. This illustrates the role of diversification in reducing risk.

A more powerful form of stochastic dominance is second-degree stochastic dominance. Second-degree stochastic dominance is based on the area under the CDF. If the area under CDF 'A' is less the area under CDF 'B' at every point along the x-axis, then 'A' is said to dominate 'B' in the second-degree sense. Activity 'A' would be preferred by any individual who is risk-averse for all values of the performance measure. In Figure 2, the CNT treatment is dominated in the second-degree sense by each of the other treatments. This is not surprising with the great variability in net returns for the CNT treatment compared to the other treatments. Since the 2YRC treatment was dominated by the 2YRR treatment in the first-degree sense, it is also dominated in the second-degree sense. Because of the small overlap of the 4YR CDF and the 2YRR CDF at the low end of the distribution, neither can be said to dominate in the second-degree sense. This problem of being unable to resolve dominance between treatments when CDF's cross at the low end of the distribution is well-known. McCarl (1988) has developed the RISKROOT computer program to determine the risk aversion levels where preferences would switch from one treatment to the other. The analysis was not conducted for this example, however the general result is that individuals with high risk aversion would select the treatment with the highest minimum value. In this example, individuals with high risk aversion would select the 4YR treatment.

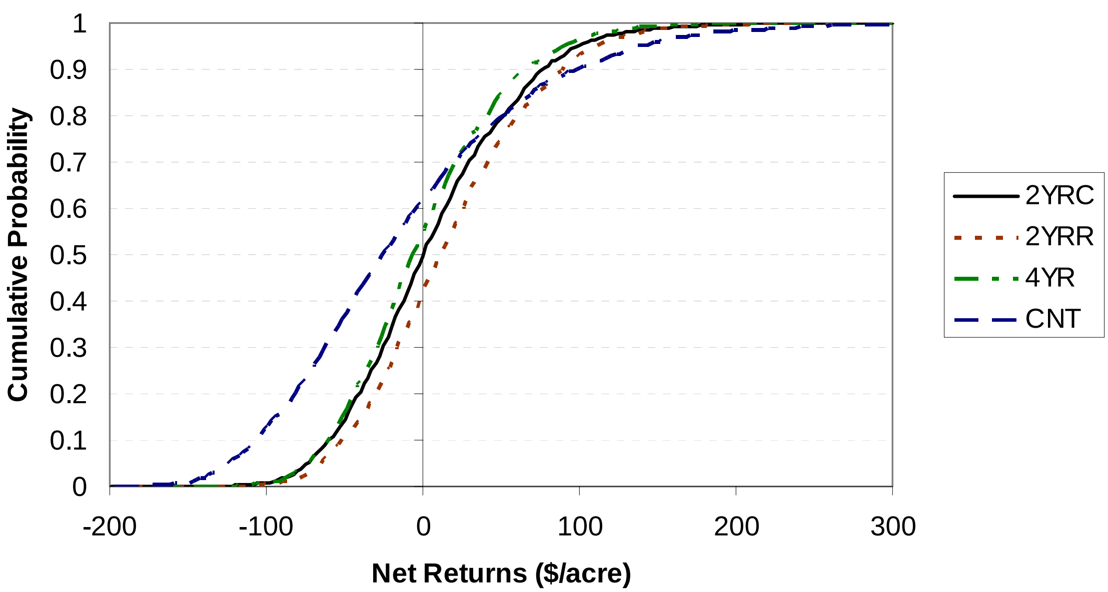


Figure 2. Cumulative probability distribution of net returns with no government payments or crop insurance for: corn-soybean rotation under conventional tillage (2YRC), corn-soybean rotation under ridge tillage (2YRR), corn-soybean-wheat/alfalfa-alfalfa rotation under conventional tillage (4YR), and continuous corn rotation under conventional tillage (CNT).

The baseline scenario shown in Figure 2 is an extreme risk case of risk exposure. In reality, producers have options to reduce the price and production risk shown in the baseline scenario. The 2002 Farm Bill has two provisions that are designed to reduce the price risk producers are exposed to. The countercyclical payment (CCP) provision provides payments to producers when prices of the crops in a farm's program base acres drop below a target level. The base acres depend on historical crop acreages, so CCP's are not affected by the crop mix chosen in the current year. The loan deficiency payment (LDP) provides payments to producers when prices of the crops they actually produce and sell fall below an established loan rate. LDP's are not tied to program base acres, so they offset low prices in the crops produced in the current year. In addition to the CCP and LDP payments, the 2002 Farm Bill also provides direct payments which are fixed payments calculated according to the producer's established base acres and program yields (Westcott et al., 2002). Although direct payments do not counteract variability of net returns, they reduce risk by shifting the entire distribution of net returns to the right.

Another tool producers have available to reduce risk is crop insurance. There are several different types of crop insurance available including options that protect against production risk alone (yield-based insurance) or both price and production risk (gross revenue insurance). For the government program (gp) scenario government payments were calculated assuming a 50% corn and 50% soybean established base and with program yields equal to the 9-year average of the 2YRC corn and soybean yields. This would reflect the situation of a farm that had been in a long-term corn-soybean rotation under conventional tillage. In addition, for the government payment and crop insurance scenario (gpi), it was assumed that the producer purchased the maximum available coverage level of Multiple-Peril Crop Insurance (MPCI) crop insurance. MPCI is yield-based insurance with coverage based on the actual production history (APH) of the farm.

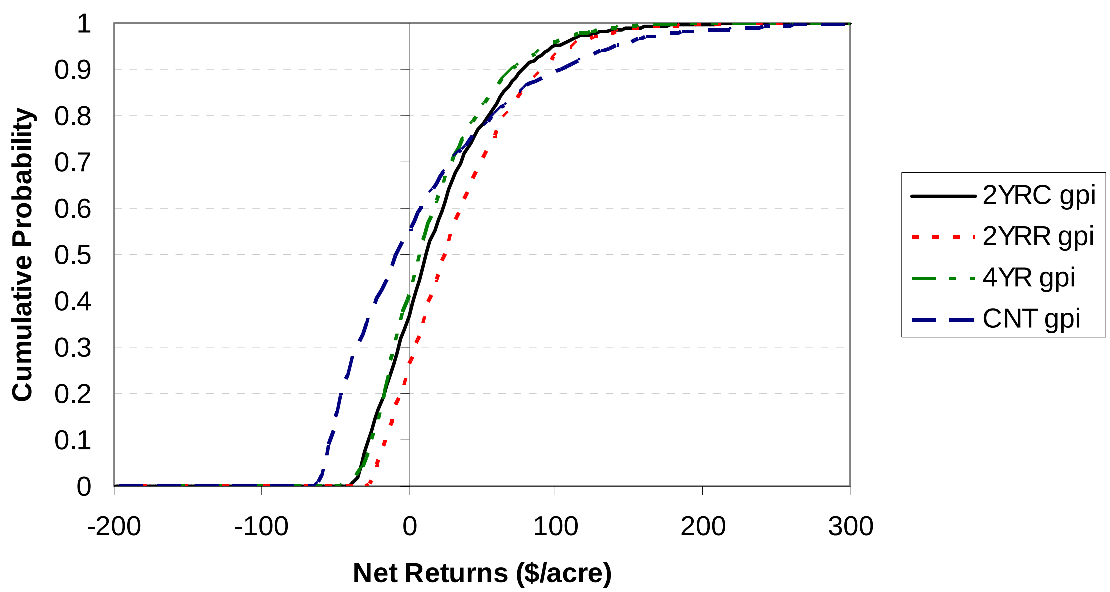


Figure 3. Cumulative probability distribution of net returns with government payments and crop insurance for: corn-soybean rotation under conventional tillage (2YRC), corn-soybean rotation under ridge tillage (2YRR), corn-soybean-wheat/alfalfa-alfalfa rotation under conventional tillage (4YR), and continuous corn rotation under conventional tillage (CNT).

Figure 3 shows the CDF's for the tillage and rotation treatments when both government payments and crop insurance are available. The lower tail of each of the CDF's is truncated compared to the baseline scenario. This illustrates the effect of government payments and crop insurance in limiting the adverse price and yield outcomes. With government payments and crop insurance, the 2YRR treatment dominates both the 2YRC and 4YR treatments in the first-degree sense. The 2YRR treatment also dominates the CNT treatment in the second-degree sense, so the 2YRR treatment would be preferred over all others by all individuals who were risk averse over all net return outcomes. With the availability of government payments and crop insurance, the level of diversification in the 4YR treatment is less important in reducing risk.

Figures 2 and 3 illustrate the effects of price and yield risk. However, another source of risk is institutional risk. One source of institutional risk is changes in farm programs. The previous farm bill, known as Freedom-to-Farm was designed to slowly phase out government payments that were based on established base acres and program yields. This would eliminate any incentives for farmers to produce a crop just to maintain program base or to over-apply inputs to maximize yields. However, the 2002 Farm Bill reintroduced payments tied to base acres and program yields, and allowed producers to update base acres and program yields using production records from the Freedom-to-Farm years. In the 2002 Farm Bill, alfalfa is not a program crop, so acres that were planted to alfalfa did not contribute to establishing a base acreage or yields for program payments. In addition, soybeans were not a program crop in previous farm programs, so any soybean base for the 2002 program would be based on production during the Freedom-to-Farm years. Suppose a producer, believing that base acres would not be important in the future, decided to grow crops in a corn-soybean-wheat/alfalfa-alfalfa rotation during the Freedom-to-Farm years. Under the 2002 Farm Bill, the producer could update program yields and base acres based on this four-year rotation or they could add the soybean base acres only and use the old corn base acres and program yield. The effect of institutional risk is illustrated assuming the producer decided to add the soybean base acres only and use the old corn base and program yield. This scenario includes government payments and crop insurance, but relies on the old base (gpi ob).

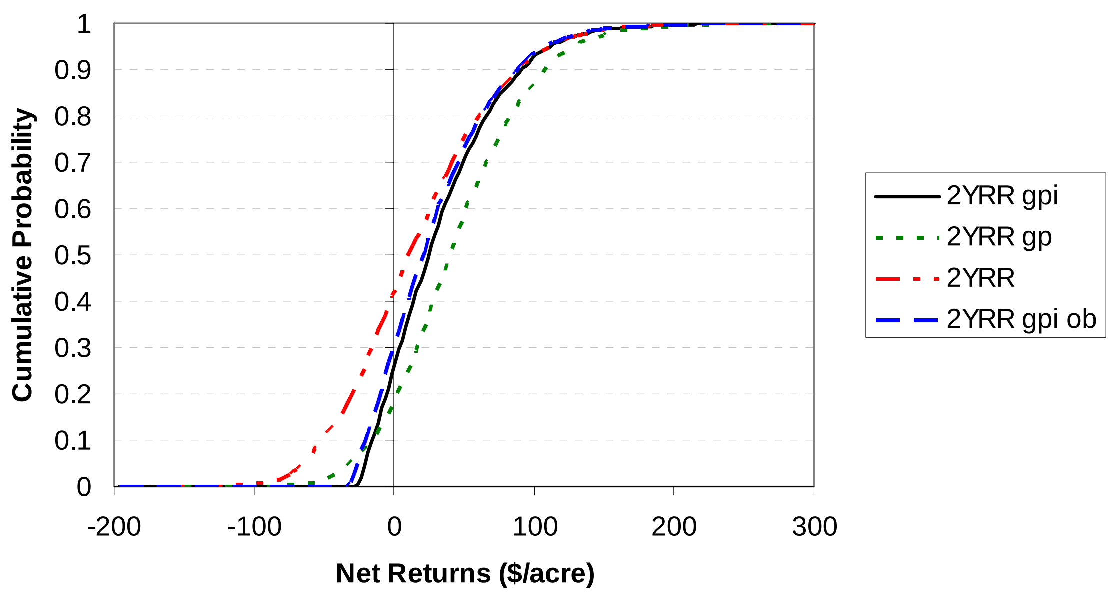


Figure 4. Cumulative probability distribution of net returns for the 2YRR treatment: without government payments or insurance, with government payments only (gp), with government payments and crop insurance (gpi), and with government payments and crop insurance using the old base acres (gpi ob).

The effects of the alternative risk management options and the effect of institutional risk are illustrated in Figure 4 for the 2YRR treatment only. The ‘gp’ scenario shifts the entire distribution to the right from the baseline scenario with the lower end being shifted more than the upper end. Government payments reduce risk largely by increasing net returns overall, with some decrease in the variability of net returns as well. The addition of crop insurance in the 'gpi' scenario truncates the lower end of the CDF compared to the 'gp' scenario, but the rest of the distribution is shifted to the left due to the cost of the premiums paid. The baseline scenario is dominated by both the 'gp' and 'gpi' scenarios by first-degree stochastic dominance. However, neither scenario dominates by first or second-degree stochastic dominance in comparing the 'gpi' and the 'gp' scenarios. This indicates a producer who prefers higher net returns would choose to receive government payments and possibly purchase crop insurance, with the crop insurance purchase decision dependant upon the individual's risk preferences. The effect of institutional risk is illustrated in comparing the 'gpi' and 'gpi ob' CDF's. The 'gpi ob' scenario is shifted to the left by about \$5 per acre at the low end of the distribution to about \$2.50 per acre at the upper end of the distribution compared to the 'gpi' scenario. This represents a persistent cost to a producer who did not correctly anticipate the provisions of the new farm bill.

**Timeliness Risk Example**

A source of risk that is often overlooked in comparing the performance of alternative cropping systems using field plot data is risk associated with timeliness of field operations. In most field plot studies, a field operation such a planting can easily be completed in a single day. While, in a farm setting, planting activities may take a matter of weeks for a single crop. Delays in field activities can have significant effects on crop yields and/or production costs, and ignoring these effects may lead to erroneous conclusions about the viability of a particular cropping system. To illustrate the effects of timeliness risk, a crop simulation modeling approach is used. The EPIC model (Sharpley and Williams, 1990) was used to simulate crop yields and days suitable for fieldwork as part of an analysis of the economic value of a new seed coating technology (Archer and Gesch, 2003). The simulation was run for weekly planting dates for both corn and soybeans under two tillage systems (conventional tillage (CT) and no-till (NT)), two soil type, and three crop maturity classes. For this example, only a single soil type (Parnell silty clay loam) and a single crop maturity class (normal maturity) will be used. The simulation was run using 51 years of historical weather observations from the University of Minnesota West Central Research and Outreach Center. The first year of the simulation was discarded to avoid initialization effects. Annual output of costs and yields were used to calculate distributions of net returns for each planting date. In addition, daily soil moisture and temperature conditions were used to determine the number of days suitable for fieldwork during each weekly planting period. Details on the simulation and field day estimation procedure are found in Archer and Gesch (2003).

For this example, a spreadsheet was constructed to estimate the whole-farm net returns for each of the 50 simulation years assuming a farm size of 625 acres with the entire farm in a corn-soybean rotation where 50% of the acres are planted to corn and 50% of the acres are planted to soybeans every year. It was assumed the producer would begin planting corn beginning April 29, subject to field day availability. Once corn planting was completed, soybean planting would begin (but no earlier than May 13), again subject to field day availability. Under CT, both spring tillage activities and planting were subject to field day availability constraints. However since there are no spring tillage operations under NT, only planting was subject to field day availability constraints under NT.

Whole-farm net returns were calculated based on the acres planted during each weekly planting period and the net returns per acre planted in that period. In general, if planting was delayed, net returns decreased due to decreased yield. Whole-farm net returns were also calculated assuming that all of the corn was planted the week of April 29, and all of the soybeans were planted the week of May 13. This illustrates the situation where planting risk is ignored. CDF's for the whole-farm net returns ignoring planting risk are shown in Figure 5, while CDF's for whole-farm net returns including planting risk are shown in Figure 6.

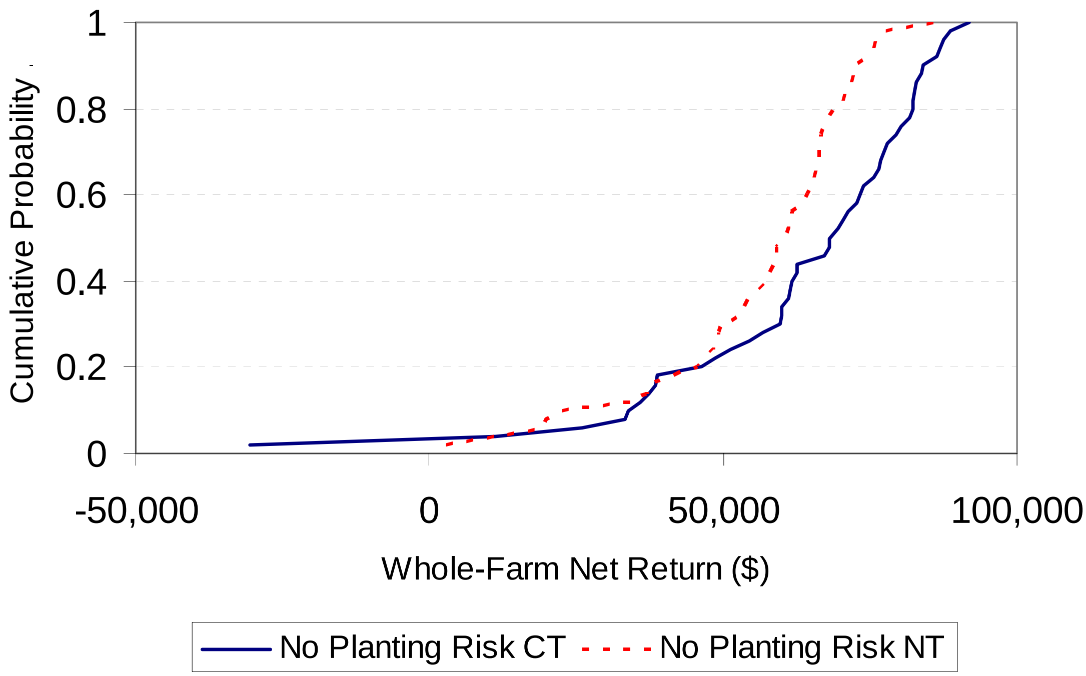


Figure 5. Cumulative distribution function of whole-farm net returns with no planting risk under conventional tillage (CT) and no-till (NT).

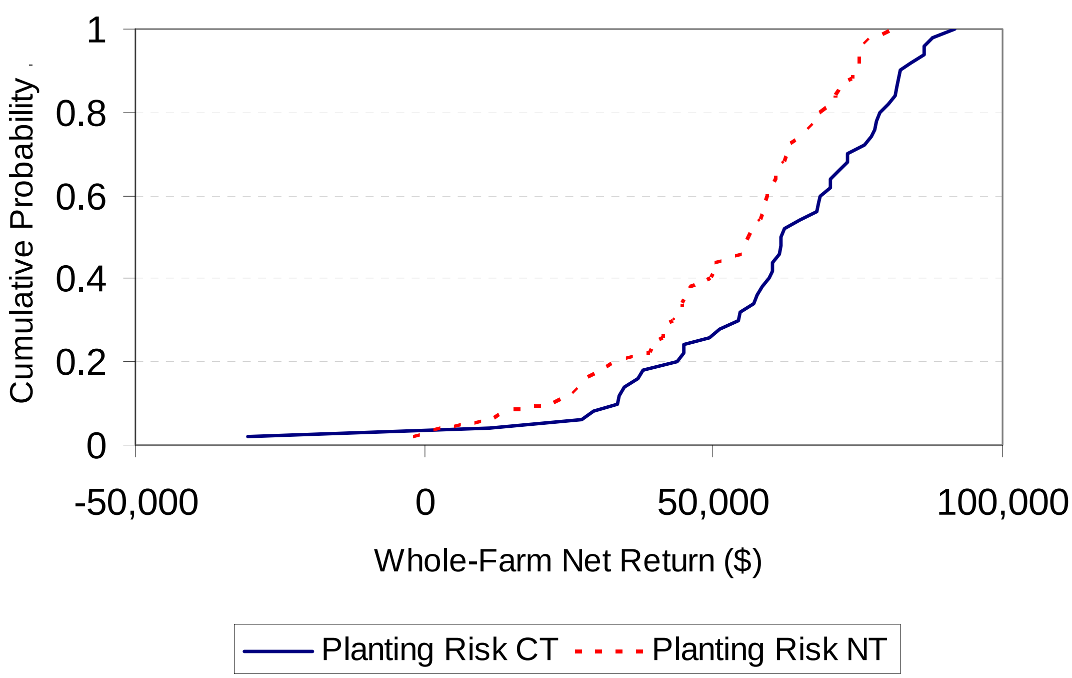


Figure 6. Cumulative distribution function of whole-farm net returns including planting risk under conventional tillage (CT) and no-till (NT).

Both the CT and NT distributions shift to the left when planting risk is included. However, in this example the NT distribution generally shows a larger shift. Expected whole-farm net returns decline by $4800 (8.5%) under NT compared to a decline of $3043 (4.8%) under CT when planting risk is included. While this is admittedly an extreme example of the effect of timeliness risk, with a soil that is limited in terms of field day availability and without including crop insurance, this represents a substantial reduction in expected net returns. Note: The results here would not be typical of more arid areas where planting should have a greater probability of being completed on time under NT since no spring tillage operations need to be completed prior to planting. For the cool, wet climate with a poorly drained soil illustrated here, the higher residue levels under NT hampered field drying. The net effect was that the probability of completing planting on time was lower under NT even though NT had lower field time requirements.

Regardless of whether or not planting risk is included, neither the CT nor the NT distribution dominates in terms of either first or second-degree stochastic dominance. However, when planting risk is ignored, the CT and NT CDF's are fairly similar over the lower 20% of the distribution, with much greater losses under CT in the lower 5% of the distribution. When planting risk is included, the CT and NT CDF's diverge more rapidly. While the losses are still much greater under CT in the lower 5% of the distribution the difference is less than when planting risk is ignored. Intuitively, this would indicate that the risk aversion level above which an individual would prefer NT to CT would be lower when planting risk is ignored than when planting risk is included. Indeed, this is confirmed by RISKROOT. So, ignoring planting risk might lead to overestimation of the number of individuals who would be willing to adopt NT in this example.

## Conclusion

While the examples illustrated just a few sources of risk, the techniques could be used to analyze a wide range of risk sources. With the computer software now available, stochastic simulation is a tool that is both powerful and easy to use. An extreme form of stochastic budgeting is the use of crop models or other process models. These models can be run using a distribution of uncertain variables (generally historical weather) to analyze the impact of alternative management options. While more complex than the simple stochastic budgeting examples presented, the results can be used for the same type of analysis, as illustrated in the timeliness risk example.

For the cropping systems example, stochastic budgeting illustrated the effect of risk management tools on the risks producers face. In the timeliness risk example, simulation modeling was used to illustrate the effect of alternative risk sources on the overall risks producers face. Both the available management tools and sources of risk can significantly change the riskiness of alternative cropping systems. The examples show the importance of including relevant sources of risk and available risk management tools in comparing alternative cropping systems.

In order to utilize stochastic simulation in analyzing field plot data, it is critical that there is enough information to characterize the distributions of the uncertain variables. The distributions of uncertain variables in this analysis were estimated based on historical conditions, however historical distributions may not be the best representation of potential outcomes. The techniques illustrated here could be used with any distribution estimates for the uncertain variables incorporating such things as expert opinion or forecasting tools. They also could be modified to account for the discovery of new information during the decision process and account for dynamic effects.

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