The Impacts of Farm Size and Economic Risk on No-Till Rice Whole-Farm Profitability

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Abstract

This study evaluated the impacts of farm size and stochastic return variability on no-till (NT) rice profitability at the whole-farm level. Mixed integer programming was used to determine optimal machinery complements, fuel consumption, and machinery labor requirements for conventional till (CT) and NT rice-soybean farms of 1200, 2400, and 3600 acres in size. Crop yields, market prices, and prices for key production inputs were simulated to construct stochastic whole-farm net returns for each farm size under CT and NT management, and both first and second degree stochastic dominance analysis were used to rank cumulative distribution functions of whole-farm returns according to specified risk preferences. The results indicate NT farms exhibit second degree stochastic dominance over CT farms regardless of farm size, and high input prices have less downward effect on the profitability of NT farms relative to CT farms.

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Introduction

Arkansas is the top rice producing state in the U.S. and accounts for over 45% of total U.S. rice production (USDA ERS). Nearly all Arkansas rice production occurs in the eastern part of the state in the Mississippi Alluvial Valley. Surface water quality in this region is significantly influenced by geography, climate, and agriculture. The area has little topographic relief, and soils are predominantly composed of dense alluvial clay sub-soils that limit water infiltration (Kleiss et al.). Surface soils contain little organic matter and are comprised of silt and clay particles that are readily transported by runoff from tilled fields during heavy rainfall events (Huitink et al.). Sediment is the primary pollutant identified for most eastern Arkansas waterways, and conservation practices like no-till are commonly recommended as remedial mechanisms (Huitink et al.).

Conventional rice production in Arkansas involves intensive cultivation. Fields are “cut-to-grade” every few years, disked annually in either late fall or early spring, and “floated” (land planed) annually in early spring to ensure smooth water movement across the field. In 2009, conventional till (spring tillage and floating) accounted for 52.5% of all planted rice acres in Arkansas, while stale seedbed (fall tillage followed by burn-down herbicides prior to planting in the spring) accounted for over 35.3% of planted rice acres. True no-till management (rice planted directly into the previous crop residue without tillage at any time) accounted for 12.2% of planted Arkansas rice acres in 2009 (Wilson, Runsick, and Mazzanti).

The profitability of no-till rice (NT) has been investigated both using whole-farm analysis (Watkins, et al.) and risk analysis (Watkins, Hill and Anders). Watkins et al. used mixed integer programming (MIP) to model optimal machinery selection and evaluate the whole-farm profitability of NT management for rice-soybean farms ranging in size from 1200 to 3600 acres. The authors found modest monetary gains for NT relative to conventional till (CT) resulting from lower machinery ownership, fuel, and labor expenses. However, this study excluded the impacts of risk. Watkins, Hill and Anders evaluated the profitability and return variability of no-till management in rice production from both the perspective of the tenant and the landlord using stochastic efficiency with respect to a function (SERF). The authors found positive NT risk premiums for both risk-averse and risk-neutral tenants regardless of the rental arrangement. However, this study excluded the impacts of farm size on the likelihood of NT profitability.

This study combines MIP with simulation to evaluate the impacts of farm size and stochastic return variability on no-till rice profitability at the whole-farm level. Mixed integer programming is used to determine optimal machinery complements, fuel consumption, and machinery labor requirements for CT and NT rice-soybean farms of 1200, 2400, and 3600 acres in size. Rice and soybean crop yields by tillage method (NT and CT), market prices, and prices for key production inputs such as diesel, irrigation electricity, fertilizer, and glyphosate are simulated using SIMETAR (Richardson, Schumann, and Feldman). Stochastic net return distributions are constructed for each rice-soybean farm, and both first degree and second degree stochastic dominance analysis are used to rank cumulative distribution functions according to specified risk preferences.

Materials and Methods

The Mixed Integer Programming Model Specification. The MIP analysis in this study is a modification of the MIP models used in Watkins et al. As in the former study, the current MIP model maximizes returns above operating and ownership expenses and is solved subject to acreage constraints on total cropland, owned cropland, and rented cropland available. The model includes operation sequencing rows (disked acres to floated acres; floated acres to cultivated acres, etc.) yield balance rows to account for the production and sale of rice and soybeans, a non-machinery input purchase balance row to account for purchase of inputs such as seed, fertilizer, and herbicides, rice-soybean rotation requirement balance rows, tractor, implement, and well annual capacity rows, and labor, diesel, and irrigation electricity purchase balance rows. For a more detailed description of the MIP framework used in this study, see Watkins et al.

The current study differs from Watkins et al. in two ways. First, the current study uses one MIP model instead of two separate models to determine optimal machinery complements for typical rice-soybean farms of varying sizes under either CT or NT management. The present model allows for tillage equipment to be included in the optimal machinery complement of the NT farm to accommodate field repair following extremely wet production years. Arkansas farmers experienced such a weather year in 2009 (Hignight et al, 2010). No-till fields were assumed to require tillage to repair ruts in 3 out of 25 years as a result of extremely wet growing seasons. Second, the current study allows irrigation to be powered by both electric and diesel power units. Rice producers in Arkansas use a combination of both diesel and electric power units to supply irrigation water for rice production. The percentage of acres using electric units was set to 56 percent based on personal communication (Tacker).

MIP Data and Methods. As with the former study, ownership expenses (depreciation, interest, taxes, insurance, and housing) for tractor and implement items were calculated based on ASABE machinery management standards (American Society of Agricultural and Biological Engineers, 2006, 2009). Depreciation was estimated for each machinery item based on 2010 current list prices and ASABE remaining value equations that account for the impact of machinery age (years of useful life) on implement value and the impacts of both machinery age and annual usage (hours) on the value of combines and tractors. Depreciation and interest were annualized for each tractor/implement item using the capital recovery method and an interest rate of 6.5 percent. Additional annual costs for taxes, insurance, and housing were estimated as 1.5 percent of list price for each tractor/implement item. Ownership expenses associated with irrigation items (well, pump, gearhead, and power unit) were based on data reported in Hogan et al. for a standard well less than 120 feet deep and supplying water for 120 acres. Irrigation ownership cost data reported in Hogan et al. were adjusted to 2010 dollars using the Producer Price Index.

Items related to the estimation of machinery operating expenses (repairs and maintenance, fuel, engine oil, and labor) were also obtained using ASABE standard formulas and recommendations. Per acre repairs and maintenance costs for each machinery item were estimated based on ASABE standard formulas that relate repair and maintenance costs to both accumulated use hours and list price. Per acre diesel fuel consumption rates for tractors were estimated based on Nebraska Tractor Test Data as reported in the ASABE, which calculate fuel consumption as a product of Power Takeoff (PTO) horsepower. Engine oil costs were estimated at 15 percent of per acre diesel costs as per ASABE recommendations. Per acre machinery labor hours were estimated for each tractor/implement combination as a product of per acre machinery use hours and a labor adjustment factor that accounts for additional labor involved in locating, hooking up, adjusting, and transporting machinery. Operating expense items associated with irrigation with the exception of electric power consumption were taken directly from Hogan et al. Power consumption for electric power units was estimated using an irrigation energy cost spreadsheet created by agricultural engineers at the University of Arkansas Cooperative Extension Service (Tacker). All irrigation operating expenses were calculated for a standard well less than 120 feet deep and irrigating 120 acres.

Per acre non-machinery operating expenses associated with crop inputs (seeds, fertilizer, pesticide) and custom chemical application were calculated based on input data from a long-term rice-based cropping systems study at Stuttgart, Arkansas (Anders and Hignight). All non-machinery input purchase expenses were calculated using average input prices for the period 2003-2010. Input prices were obtained from the USDA, National Agricultural Statistics Service (2006, 2007, 2010b) and were adjusted to 2010 dollars using the Producer Price Index. Average crop yields were obtained from the long-term cropping systems study for the period 2000-2009 to represent expected crop yields for a typical rice-soybean rotation under CT and NT management. Expected yields were 183 bushels per acre for rice and 49 bushels per acre for soybeans under CT management and 179 bushels per acre for rice and 50 bushels per acre for soybeans under NT management.

Market prices of $5.03 per bushel for rice and $8.84 per bushel for soybeans were used as expected prices in the MIP model. These market prices correspond to season average Arkansas prices for the period 2004- 2010 (U.S. Department of Agriculture, National Agricultural Statistics Service, 2010c). A rice drying and hauling expense of $0.57 per bushel and a soybean hauling expense of $0.22 per bushel were subtracted from expected crop prices to account for per unit custom charges.

Total cropland acres for each representative farm were split into 32 percent owned and 68 percent rented acres based on tenure data reported in Watkins et al. A typical 25 percent straight share arrangement was used to model land tenure in the study. In this arrangement, the landlord receives 25 percent of the crop, pays 25 percent of custom drying expenses, and pays 100 percent of all belowground irrigation expenses (well, pump, and gearhead). The farm operator receives 75 percent of the crop, pays 75 percent of custom drying expenses, pays 100 percent of all aboveground irrigation expenses (power unit, fuel), and pays 100 percent of all other production expenses.

Optimal whole-farm net return solutions were generated for CT and NT farms of 1200, 2400, and 3600 acres. A wage rate of $9.40 per hour was charged for farm labor in Arkansas in 2010 as reported by the U.S. Department of Agriculture, National Agricultural Statistics Service (2010a). A charge of $2.20 per gallon was used for machinery and irrigation diesel fuel, and a charge of $0.098 kWh was used for irrigation electricity. The MIP model was solved using the What's Best! Professional 9.0 Spreadsheet Solver (Lindo Systems, Inc.). The MIP solution parameters used in the stochastic analysis are presented in Table 1.

***Simulated Yields, Crop Prices, and Input Prices*.** SIMETAR, developed by Richardson, Schumann, and Feldman was used to simulate yield and price distributions in the study. Multivariate empirical distributions (MVEs) were used to simulate 500 iterations of yields and prices. A MVE distribution simulates random values from a frequency distribution made up of actual historical data and has been shown to appropriately correlate random variables based on their historical correlation (Richardson, Klose, and Gray). Parameters for the MVE include the means, deviations from the mean or trend expressed as a fraction of each variable, and the correlation among variables. The MVE distribution is used in instances where data observations are too few to estimate parameters for another distribution (Pendell et al.).

Rice and soybean yield distributions under CT and NT were simulated using ten years of historical yield data from a long term rice-based cropping systems study at Stuttgart, AR for the period 2000-2009 (Anders and Hignight). The historical crop yields represent yields obtained in a two-year rice-soybean rotation. Deviations from 10-year means were used to estimate the parameters for the MVE yield distributions, and mean yields over the 10-year period were used as expected yields for the MVE yield distributions. Summary statistics for the simulated yields are presented table 2.

Multivariate empirical distributions were used to simulate crop prices and prices for key production inputs. All price simulations were based on historical prices observed for the 2003-2010 period adjusted to 2010 dollars using the Producer Price Index. Deviations from 8-year means and their associated correlations were used to simulate the MVE price distributions for each price series. Historical prices for rice, soybeans, urea, phosphate, potash, diesel, and glyphosate were obtained from the USDA, National

Agricultural Statistics Service (2006, 2009, 2010b,c). Historical prices for irrigation electricity represent 2003-2010 Arkansas prices averaged for the months of May through August (U.S. Energy Information Administration). Summary statistics for the simulated crop and input prices are presented Table 2.

Risk Analysis. Stochastic dominance analysis is used in this study to rank stochastic whole farm net return distributions under CT and NT based on producer preferences. Stochastic dominance utilizes the entire distribution of outcomes rather than the first two moments (the mean and the standard deviation) to identify preferred alternatives for decision makers. Preferred alternatives are identified based on pairwise comparisons of cumulative distribution functions (CDFs) and specified decision rules known as efficiency criteria. An efficiency criterion defines the preferences of a particular class of decision makers by placing restrictions on their utility functions (King and Robison, 1984). Two types of efficiency criteria are used in this study: 1) first-degree stochastic dominance; and 2) second-degree stochastic dominance.

First-degree stochastic dominance (FSD) holds for all decision makers who have a positive marginal utility for wealth (King and Robison, 1984). It is based on the single assumption that the decision maker prefers more wealth to less. Under FSD, an alternative decision choice with an outcome distribution defined by CDF $F(y)$ is preferred to a second alternative decision choice with an outcome distribution defined by CDF $G(y)$ if:

$$F(y) \leq G(y) \qquad (1)$$

for all possible values of y and with the inequality strictly holding for some value of *y* (King and Robison, 1984). In graphical terms, the CDF that is stochastically dominant under FSD must lie nowhere to the left of the dominated CDF (e.g., the dominant CDF always lies to the right of the dominated CDF). Figure 1 demonstrates FSD graphically. In Figure 1, F(*y*) dominates G(*y*) by FSD, since F(*y*) lies everywhere to the right of G(*y*). The condition for FSD fails however when two CDF curves intersect one or more times. For example, neither F(*y*) nor G(*y*) in Figure 1 can be ordered with respect to H(*y*) using FSD.

Second-degree stochastic dominance (SSD) is a more restrictive efficiency criterion than FSD and can be used in instances where CDF curves cross. This criterion holds for all decision makers whose utility functions have positive, non-increasing slopes at all outcome levels (King and Robison, 1984). Under SSD, the decision maker is assumed to 1) prefer more wealth to less; and 2) be risk-averse. A risk-averse decision maker is one who would prefer an action that leads to a certain return to another action that leads to an equal but uncertain expected return (Robison et al.). The SSD criterion orders alternatives with uncertain outcomes according to the area under their CDF curves. Under SSD, an alternative decision choice with an outcome distribution defined by CDF *F*(*y*) is preferred to a second alternative decision choice with an outcome distribution defined by CDF *G*(*y*) if:

$$\int_{-\infty}^{y} F(y)dy \leq \int_{-\infty}^{y} G(y)dy \qquad (2)$$

for all possible values of y and with the inequality strictly holding for some value of y (King and Robison, 1984). A CDF that is dominated by FSD is also dominated by SSD.

A graphical example of SSD is shown in Figure 1. In Figure 1, H(*y*) dominates G(*y*) by SSD since the cumulative area under H(*y*) is less than or equal to that under G(*y*). However, neither F(*y*) nor H(*y*) can be ordered by SSD because the accumulated area under H(*y*) is smaller than that under F(*y*) for low values of y, while the opposite condition occurs for high values of *y*. First and second degree stochastic dominance analysis was conducted in this study by constructing cumulative distribution functions of whole farm net returns under CT and NT and making pairwise comparisons of the distributions graphically as demonstrated above with Figure 1.

Results and Discussion

Summary statistics of stochastic and non-stochastic economic variables for rice-soybean farms varying by 1200, 2400, and 3600 acres are presented by tillage method in Tables 3-5. Simulated crop sales are slightly larger on average for CT farms than for NT farms across all farm sizes, but the minimum and maximum crop sales for NT farms are greater than those for CT farms, and this is reflected by a slightly lower CV for NT farms. Simulated fuel and electricity expenses are lower on average for NT than for CT, and the minimum and maximum values for fuel and electricity expenses are also lower for NT than for CT across all three farm sizes. These results imply an energy cost savings for NT relative to CT resulting primarily from fewer machinery operations. Labor and repair and maintenance expenses are also lower for NT than for CT across farm sizes, implying cost savings for NT resulting from fewer machinery operations. Simulated glyphosate expenses are larger for NT both on average and at the minimums and maximums, reflecting a tradeoff in herbicide for tillage in weed control.

Fixed expenses associated with machinery and equipment depreciation and interest are smaller for NT than for CT for all but the 1200-acre farms. The exception is due to the similarity in optimal machinery complements for the 1200-acre farms. Equipment is the same for both machinery complements with the exception of the grain drill. The 1200-acre NT farm uses a more expensive no-till drill, whereas the 1200-acre CT farm uses a less expensive conventional till drill. Optimal machinery complements for the 2400- and 3600-acre NT farms favor fewer and smaller tractors and smaller tillage equipment relative to their 2400- and 3600-acre CT farm counterparts, and thus have lower fixed expenses.

Average net returns are larger for each farm size under NT than under CT management. The relative variability of net returns as measured by the CV is also smaller for NT than for CT across all farm sizes. These results are due primarily to the cost savings from less fuel, labor, and repair and maintenance resulting from fewer machinery operations related to tillage. Whole-farm net return variability becomes smaller as farm size increases under both tillage methods due to greater economies of scale resulting from spreading machinery fixed expenses across more acres.

First and second degree stochastic dominance results of whole farm net return distributions are presented by tillage method and farm size in Table 6 and are based on pairwise comparisons of each farm's net return CDF in Figure 2. No-till dominates CT for every farm size by SSD, implying that risk-averse rice producers would prefer NT to CT regardless of farm size. This result occurs because the NT farms have smaller probabilities of achieving large negative returns relative to the CT farms, as demonstrated by the left tails of the CDFs mapped for each farm in Figure 2. The left tails become wider (minimum returns become more negative) as farm size increases for the CT farms but stay relatively stationary as farm size increases for the NT farms. Probabilities of achieving a negative return are also smaller for the NT farms relative to the CT farms as is demonstrated in Figure 3. Probabilities of achieving negative returns decline for both CT and NT farms as farm size increases, but the NT farms have lower negative return probabilities at all three farm sizes. The stationary left tails of the NT CDFs and the smaller probabilities of negative returns for the NT farms are the result of cost savings for NT relative to CT at each farm size and imply that high input prices have less downward effect on the profitability of NT farms relative to CT farms.

Although increasing farm size reduces net return variability regardless of the tillage method used as shown above, increasing farm size has no effect on CT rice producers exhibiting either FSD or SSD efficiency criteria. The CT CDFs all cross at least once and cannot be ordered by FSD. Furthermore, minimum net returns become more negative as farm size increases for the CT CDFs, indicating that these CDFs cannot be ordered by SSD. Farm size also has little effect on NT rice producers exhibiting either FSD or SSD efficiency criteria. The NT3600 exhibits stochastic dominance over all three CT farms (FSD over the CT1200 and CT2400 farms; SSD over the CT3600 farm). However, the NT3600 farm dominates only the NT2400 farm under both FSD and SSD. The NT3600 and NT1200 farms cannot be ordered by either FSD or SSD, since both CDFs cross at least once and the minimum net return of the NT3600 farm is slightly more negative than that of the NT1200 farm.

Summary and Conclusions

This study evaluated the impacts of farm size and stochastic return variability on no-till rice profitability at the whole-farm level. Mixed integer programming was used to determine optimal machinery complements, fuel consumption, and machinery labor requirements for CT and NT rice-soybean farms of 1200, 2400, and 3600 acres in size. Crop yields, market prices, and prices for key production inputs were simulated to construct stochastic whole-farm net returns for each farm size under both CT and NT management, and both first and second degree stochastic dominance analysis were used to rank cumulative distribution functions of whole-farm returns according to specified risk preferences.

The results indicate that NT management reduces whole-farm return variability, minimizes the likelihood of achieving a major profit shortfall, and reduces the likelihood of receiving a negative return relative to CT management at all three farm sizes evaluated. No-till farms exhibited second degree stochastic dominance over CT farms at all three farm sizes, implying that risk-averse rice producers would prefer NT to CT management regardless of farm size. The economic benefits to NT management are due to cost savings from reduced fuel, labor, and repair and maintenance expenses resulting from fewer machinery operations, and the results imply that high input prices have less downward effect on the profitability of NT rice-soybean farms relative to CT farms.

The results indicate that both CT and NT farms benefit from increased farm size. Return variability becomes smaller for both CT and NT farms as farm size increases due to greater economies of scale for the larger farms. However, farm size appears to have little impact on the producer's risk preferences for either NT or CT management based on the results of this study. The three CT farms could not be ranked by either first or second degree stochastic dominance, since CT farm CDFs crossed each other at least once and minimum net returns for CT farms became more negative as farm size increased. The NT 3600-acre farm did dominate the smaller NT 2400-acre farm by both first and second degree stochastic dominance but did not dominate the NT 1200-acre farm by either risk efficiency criteria.

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Table 1. Mixed Integer Programming Generated Parameters Used in the Stochastic Whole-Farm Analysis.

	1200-Acres		2400-Acres		3600-Acres	
MIP Generated Parameter	CT	NT	CT	NT	CT	NT
Owned Rice Cropland (acres)	192	192	384	384	576	576
Owned Soybean Cropland (acres)	192	192	384	384	576	576
Rented Rice Cropland (acres)	408	408	816	816	1,224	1,224
Rented Soybean Cropland (acres)	408	408	816	816	1,224	1,224
Total Cropland Acres	*1,200*	*1,200*	*2,400*	*2,400*	*3,600*	*3,600*
Labor Used, Owned Rice (hours)	493	347	907	695	1,425	1,042
Labor Used, Owned Soybean (hours)	299	164	532	329	772	476
Labor Used, Rented Rice (hours)	1,049	738	1,927	1,476	2,948	2,214
Labor Used, Rented Soybean (hours)	635	350	1,135	699	1,665	1,022
Total Labor Hours	*2,476*	*1,599*	*4,501*	*3,199*	*6,810*	*4,754*
Diesel Used, Owned Rice (gallons)	4,782	3,671	9,492	7,343	14,209	11,014
Diesel Used, Owned Soybean (gallons)	2,193	1,423	4,269	2,847	6,358	4,286
Diesel Used, Rented Rice (gallons)	10,162	7,802	20,171	15,603	30,050	23,405
Diesel Used, Rented Soybean (gallons)	4,659	3,025	9,058	6,050	13,606	9,147
Total Diesel Used (gallons)	*21,796*	*15,921*	*42,989*	*31,843*	*64,224*	*47,853*
Irr. Electricity Used, Owned Rice (kWh)	55,546	48,813	111,091	97,626	166,637	146,438
Irr. Electricity Used, Owned Soybean (kWh)	15,149	15,149	30,298	30,298	45,446	45,446
Irr. Electricity Used, Rented Rice (kWh)	118,034	103,727	236,069	207,454	354,103	311,182
Irr. Electricity Used, Rented Soybean (kWh)	32,191	32,191	64,382	64,382	96,574	96,574
Total Irrigation Electricity Used (kWh)	*220,920*	*199,880*	*441,840*	*399,760*	*662,760*	*599,640*
Machinery R&M, Rice, Owned Cropland ($)	4,477	3,069	8,728	6,139	12,807	9,208
Machinery R&M, Soybean, Owned Cropland ($)	2,430	1,228	4,680	2,455	6,826	3,606
Machinery R&M, Rice, Rented Cropland ($)	8,392	5,536	16,303	11,073	24,767	16,609
Machinery R&M, Soybean, Rented Cropland ($)	4,878	2,323	9,388	4,646	13,704	6,984
Total Machinery R&M ($)	*20,177*	*12,156*	*39,099*	*24,313*	*58,103*	*36,407*
Fixed Costs, Rice, Owned Cropland ($)	21,990	22,464	38,216	35,427	51,458	42,418
Fixed Costs, Soybean, Owned Cropland ($)	21,416	21,890	37,791	34,986	48,797	42,047
Fixed Costs, Rice, Rented Cropland ($)	37,444	38,451	66,317	60,389	79,195	65,962
Fixed Costs Soybean, Rented Cropland ($)	36,223	37,231	65,419	59,453	80,305	69,542
Total Fixed Costs ($)	*117,073*	*120,036*	*207,743*	*190,255*	*259,755*	*219,969*
Fixed Costs per Acre ($)	*97.56*	*100.03*	*86.56*	*79.27*	*72.15*	*61.10*

Table 2. Summary Statistics of Simulated Yields and Prices

Variable	Mean*	SD	CV†	Min	Max
NT Rice Yield (bu/acre)	179	13	7.4	163	209
CT Rice Yield (bu/acre)	183	13	7.0	160	199
NT Soybean Yield (bu/ac)	50	11	21.2	35	68
CT Soybean Yield (bu/ac)	49	14	29.3	17	66
Rice Price ($/bu)	5.03	1.02	20.3	3.82	6.55
Soybean Price ($/bu)	8.84	1.44	16.3	6.92	10.90
Diesel Price ($/gallon)	2.20	0.62	28.3	1.47	3.44
Electricity Price ($/kwh)	0.098	0.004	3.9	0.092	0.104
Urea ($/lb)	0.20	0.03	16.0	0.16	0.25
Phosphate ($/lb)	0.22	0.09	41.3	0.14	0.43
Potash ($/lb)	0.21	0.10	48.3	0.12	0.45
Glyphosate ($/pt)	4.96	1.33	26.9	2.85	7.21

* Summary statistics calculated from 500 simulated iterations.

† Coefficient of variation (CV) is a unitless measure of relative risk and is equal to 100 multiplied by the quotient of the standard deviation (SD) divided by the mean.

Table 3. Summary Statistics of Stochastic and Non-Stochastic Economic Variables by Tillage Method for 1200-Acre Conventional Till and No-Till Farms Producing Rice and Soybeans

Variable	Tillage	Mean*	SD	CV†	Min	Max
Crop Sales	CT	610,359	155,174	25	310,609	937,536
	NT	604,586	144,452	24	375,320	980,409
Fuel & Electricity	CT	76,934	16,442	21	57,150	109,147
	NT	59,979	12,152	20	45,306	83,743
Fertilizer	CT	96,331	33,390	35	64,040	170,773
	NT	96,331	33,390	35	64,040	170,773
Glyphosate	CT	4,461	1,198	27	2,565	6,489
	NT	13,384	3,595	27	7,694	19,466
Machinery R&M‡	CT	20,177	---	---	---	---
	NT	12,156	---	---	---	---
Labor‡	CT	22,771	---	---	---	---
	NT	14,707	---	---	---	---
Other‡±	CT	185,264	---	---	---	---
	NT	192,092	---	---	---	---
Fixed Expenses‡	CT	117,073	---	---	---	---
	NT	120,036	---	---	---	---
Net Returns	CT	87,348	120,575	138	-158,433	342,175
	NT	95,901	108,584	113	-80,714	398,348

* Summary statistics calculated from 500 simulated iterations.

† Coefficient of variation (CV) is a unitless measure of relative risk and is equal to 100 multiplied by the quotient of the standard deviation (SD) divided by the mean.

‡ Mixed integer programming generated parameters (non-stochastic variables).

±Expenses associated with seed, custom hire, irrigation supplies, pesticides (other than glyphosate), and interest on operating capital.

Table 4. Summary Statistics of Stochastic and Non-Stochastic Economic Variables by Tillage Method for 2400-Acre Conventional Till and No-Till Farms Producing Rice and Soybeans

	Variable	Mean*	SD	CV†	Min	Max
Crop Sales	CT	1,220,717	310,349	25	621,218	1,875,072
	NT	1,209,173	288,904	24	750,641	1,960,818
Fuel & Electricity	CT	152,341	32,451	21	113,284	215,912
	NT	119,958	24,304	20	90,613	167,487
Fertilizer	CT	192,661	66,780	35	128,079	341,546
	NT	192,661	66,780	35	128,079	341,546
Glyphosate	CT	8,923	2,397	27	5,130	12,977
	NT	26,768	7,190	27	15,389	38,932
Machinery R&M‡	CT	39,099	---	---	---	---
	NT	24,313	---	---	---	---
Labor‡	CT	42,308	---	---	---	---
	NT	30,070	---	---	---	---
Other‡±	CT	370,527	---	---	---	---
	NT	384,184	---	---	---	---
Fixed Expenses‡	CT	207,743	---	---	---	---
	NT	190,255	---	---	---	---
Net Returns	CT	207,116	241,399	117	-284,958	716,959
	NT	240,965	217,168	90	-112,267	845,857

* Summary statistics calculated from 500 simulated iterations.

† Coefficient of variation (CV) is a unitless measure of relative risk and is equal to 100 multiplied by the quotient of the standard deviation (SD) divided by the mean.

‡ Mixed integer programming generated parameters (non-stochastic variables).

± Expenses associated with seed, custom hire, irrigation supplies, pesticides (other than glyphosate), and interest on operating capital.

Table 5. Summary Statistics of Stochastic and Non-Stochastic Economic Variables by Tillage Method for 3600-Acre Conventional Till and No-Till Farms Producing Rice and Soybeans

	Variable	Mean*	SD	CV†	Min	Max
Crop Sales	CT	1,831,076	465,523	25	931,827	2,812,609
	NT	1,813,759	433,357	24	1,125,961	2,941,226
Fuel & Electricity	CT	227,852	48,491	21	169,488	322,841
	NT	180,161	36,520	20	136,068	251,579
Fertilizer	CT	288,992	100,170	35	192,119	512,319
	NT	288,992	100,170	35	192,119	512,319
Glyphosate	CT	13,384	3,595	27	7,694	19,466
	NT	40,152	10,785	27	23,083	58,399
Machinery R&M‡	CT	58,103	---	---	---	---
	NT	36,407	---	---	---	---
Labor‡	CT	62,614	---	---	---	---
	NT	43,715	---	---	---	---
Other‡±	CT	555,791	---	---	---	---
	NT	576,276	---	---	---	---
Fixed Expenses‡	CT	259,755	---	---	---	---
	NT	219,969	---	---	---	---
Net Returns	CT	364,584	362,205	99	-373,747	1,129,431
	NT	428,087	325,712	76	-101,685	1,335,370

* Summary statistics calculated from 500 simulated iterations.

† Coefficient of variation (CV) is a unitless measure of relative risk and is equal to 100 multiplied by the quotient of the standard deviation (SD) divided by the mean.

‡ Mixed integer programming generated parameters (non-stochastic variables).

±Expenses associated with seed, custom hire, irrigation supplies, pesticides (other than glyphosate), and interest on operating capital.

Table 6. First and Second Degree Stochastic Dominance Results of Rice-Soybean Whole Farm Net Return Distributions by Tillage Method and Farm Size

Farm	First Degree Stochastic Dominance	Second Degree Stochastic Dominance
CT1200	None	None
NT1200	None	CT1200
CT2400	None	None
NT2400	CT1200	CT1200, CT2400
CT3600	None	None
NT3600	CT1200, CT2400, NT2400	CT1200, CT2400, NT2400, CT3600

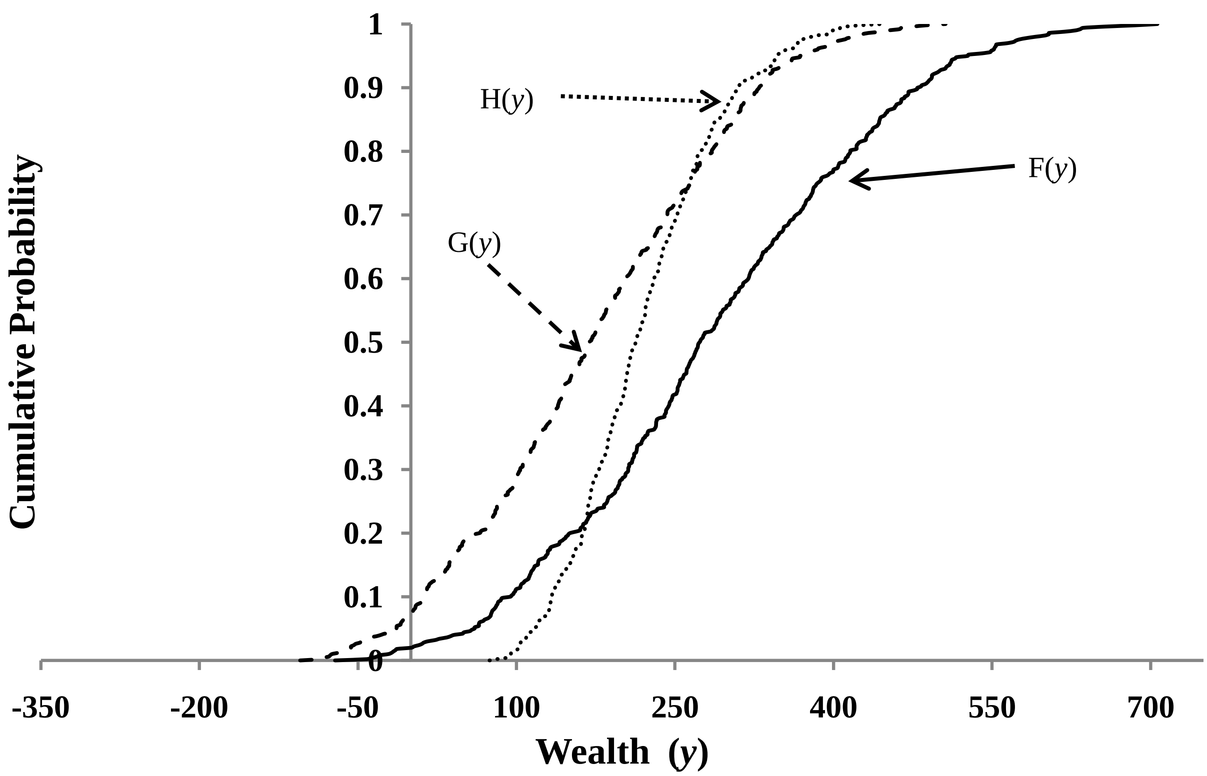

Figure 1. Demonstration of First-Degree Stochastic Dominance (FSD) and Second-Degree Stochastic Dominance (SSD) Using Three Alternative Cumulative Distribution Functions, F(*y*), G(*y*), and H(*y*). F(*y*) Dominates G(*y*) by FSD. H(*y*) Dominates G(*y*) by SSD. F(*y*) and H(*y*) Cannot be Ordered by Either FSD or SSD.

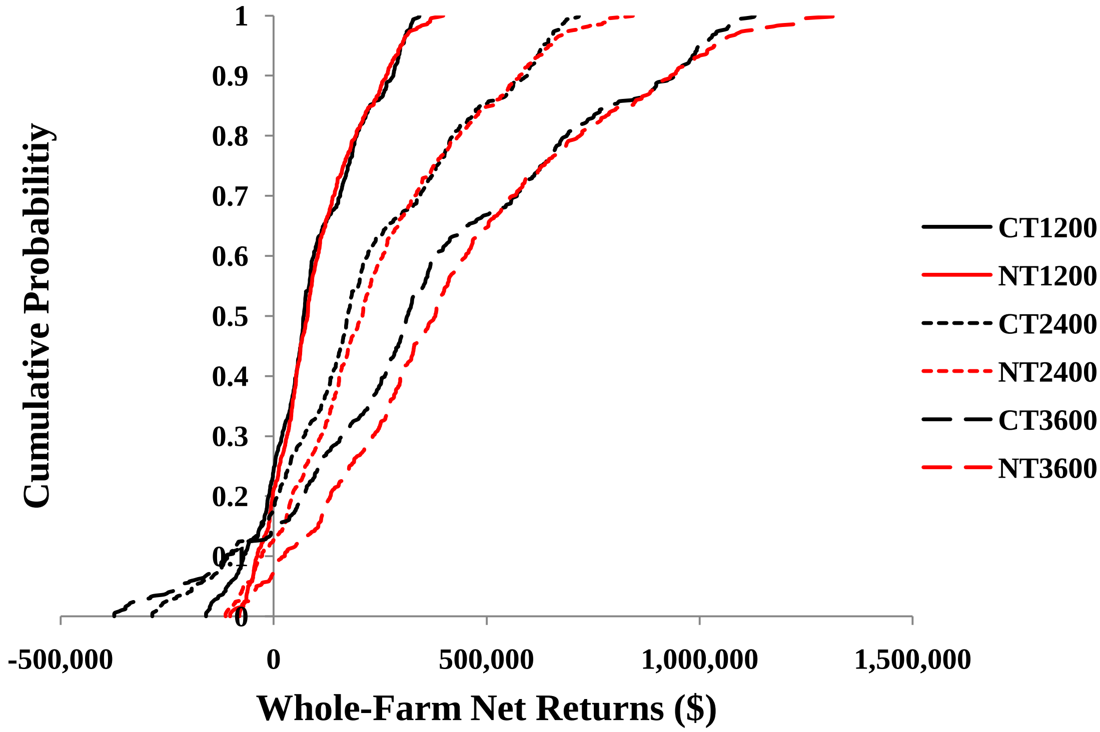

Figure 2. Whole-Farm Net Return Cumulative Distribution Functions by Farm Size and Tillage Method based on 500 Iterations

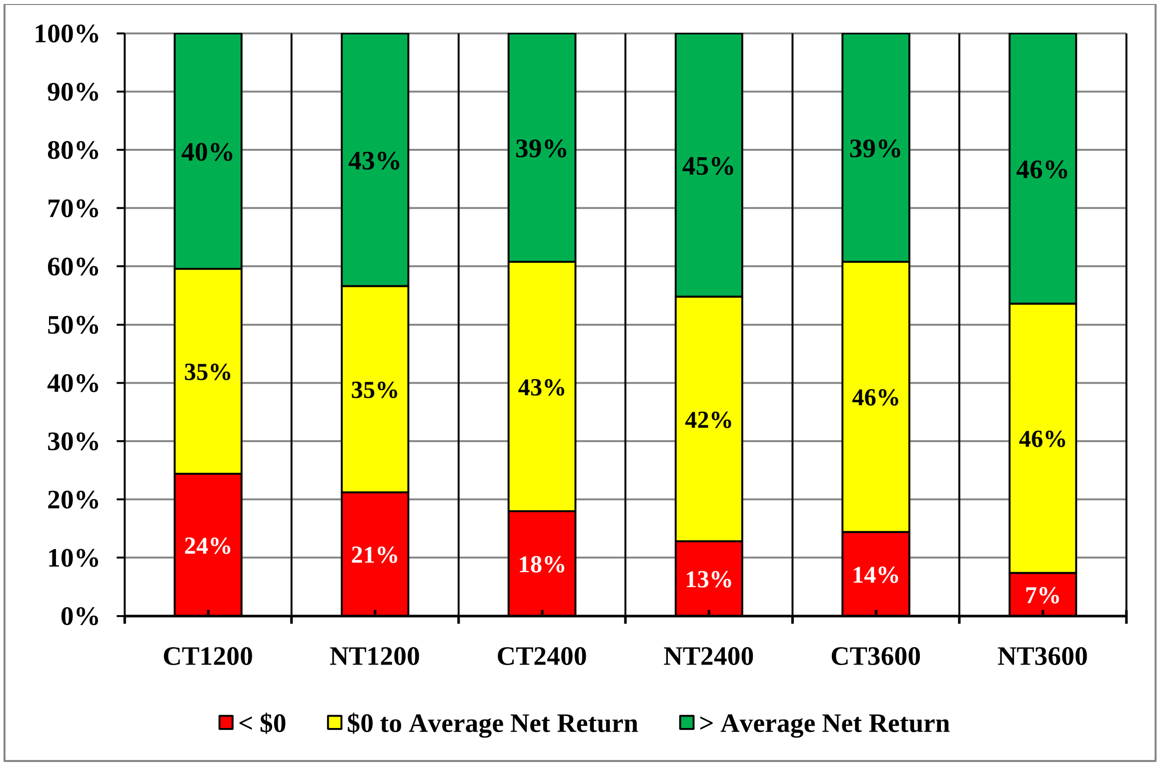

Figure 3. Whole-Farm Net Return Percents by Return Interval and Tillage Method Based on 500 Iterations. Average Net Return is Calculated as the Mean of the Average NT and CT Net Returns for each Farm Size ($91,625 for 1200-Acre Farms, $224,040 for 2400-Acre Farms, and $396,339 for 3600-Acre Farms).