Staff Paper

A STOCHASTIC DOMINANCE ANALYSIS OF ALTERNATIVE SUGAR BEET- AND NAVY BEAN-BASED CROP ROTATIONS IN MICHIGAN

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ABSTRACT
(24 pages)

Sugar beets (Beta vulgaris L.) and navy beans (Phaseoulus vulgaris L.) have been important target crops in the crop rotation systems of many Michigan growers, particularly in the Saginaw Valley and the Thumb region. The recent decline in sugar beet yields combined with the erratic navy bean yields have led to concern about the optimal crop rotation for the East Central region in Michigan. Risk is an important consideration in a farmer's choice of cropping systems. This study uses 20 years of experimental data from the Michigan State University Saginaw Valley Research Farm to determine the risk efficiency of alternative sugar beet- and navy bean- based crop rotations that included corn (Zea mays L.), oats (Avena sativa L.), and alfalfa (Medicago sativa L.) as rotational crops. The crop rotations differed in rotation length and crop sequence. Stochastic dominance analysis showed that the two-year rotation of sugar beets followed by navy beans was first-degree stochastic (FSD) and second-degree dominant (SSD) over 11 other crop rotation alternatives. Crop rotations that included sugar beets in two-year rotations and both sugar beets and navy beans in three-year rotations were the next stochastic dominant systems.

Key words: crop rotation, cropping system, risk, stochastic dominance analysis, first-degree stochastic dominance, second-degree stochastic dominance.

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1. INTRODUCTION

Crop rotation is an important management practice that has long been studied and advocated to lessen problems with various pests, interrupt crop disease cycles, and enhance yields. In Michigan, sugar beets grown in various crop rotations with other field crops have been an economically important target crop. Sugar beets in 1992 accounted for 3.5 percent of the farm cash receipts in Michigan from a record high acreage until that time of 175,000 acres (Michigan Agricultural Statistics Service, 1994). The production of 3.1 million tons of sugar beets ranked Michigan fifth in production among states. Ferris (1990) showed that the sugar beet processing sector was quite important in its employment of about 889 full-time workers in 1989, with a multiplier effect of 2.3 producing additional jobs in the economy.

The sugar beet situation in Michigan that looked so clear and promising in 1992 has become somewhat clouded. Tonnage yield of sugar beets per acre declined continuously between 1992 and 1996 (Michigan Agricultural Statistics Service, 1994, 1995-96, 1996-97). With the declining yields, acreage of sugar beets declined and resulted in sugar beets producing only 1.8 percent of Michigan agriculture cash receipts in 1996. These declining sugar beet yields lessen the economically competitiveness of this crop and have generated questions about the crop rotation system that has the most promise for generating the highest return.

The dry edible bean complex has also been an important target crop in the crop rotation system of many Michigan growers, primarily in the Saginaw Valley and Thumb region. In 1996, Michigan was the largest state in the production of black, cranberry, and navy beans and was the second leading state in the production of all dry edible beans (Michigan Agricultural Statistics Service, 1996-97). The percentage contribution of dry beans to agricultural cash receipts in Michigan reached a recent peak of 4.25 percent in 1994 but declined to 3.2 percent in 1996 (Michigan

Agricultural Statistics Service, 1994, 1995-96, 1996-97). The yields of dry beans have been somewhat erratic and combined with declining sugar beet production have led to concern about the optimal crop rotation for the East Central region in Michigan.

Sugar beets and dry beans are considered to be high valued field crops and are often the target crops in a crop rotation system. Deciding on the optimal crop rotation to maximize profits requires knowledge about yields of the target crop as a function of rotation length, crops in rotation, and cropping sequence. As the crop rotation shortens, the target crop will be grown more often and thus the proportion of acreage planted to the target crop will be increased. If a shorter crop rotation is not sufficient to break disease and pest cycles, annual yields of the target crop would be expected to trend downward.

An experiment designed to evaluate the yield effects of rotation length and crop sequence involving sugar beets and navy beans was initiated in 1972 at the Michigan State University Saginaw Valley Research Farm. Twelve alternative crop rotations containing either one or both of the target crops of sugar beets and navy beans were evaluated with the rotation crops of corn, oats, and alfalfa. This experiment was conducted until 1994.

Christenson et al. (1991) analyzed the yield effect of the rotation systems for the period 1975-90. They found that sugar beet and navy bean yields were higher in longer rotations, navy bean yields were higher when grown after corn than following sugar beets, corn following corn yielded 11.9 percent lower than corn following sugar beets or navy beans, and oats-alfalfa-navy bean-sugar beets rotation produced the highest oats, navy bean, and sugar beet yields. Economic analysis aimed at ranking the profitability of the rotation systems was also conducted by Christenson et al. (1995) for the period 1975-90. They found that the proportion of sugar beets and navy beans in the rotation was the determining factor for the relative ranking of the systems. Two- and three-year rotations that included sugar beets and navy beans had the highest return.

Farmers' choice of cropping systems does not depend on profitability considerations alone. Risk is another important consideration in the choice of cropping systems. A producer's attitude to risk and the probability distribution of the net returns jointly determine the choice of cropping systems (Zentner et al., 1990). In general, higher income with low variability is preferred by farmers (Anderson et al., 1977).

Stochastic dominance analysis has been widely used in risk analysis associated with cropping systems choice (Maynard et al., 1997; Williams, 1988; Brown, 1987; Klemme, 1985; Zacharias and Grube, 1984). Maynard et al. (1997) found in Pennsylvania that risk-averse and risk-neutral farmers would choose a rotation of two years corn and three years alfalfa hay from among five rotation systems, a result which was consistent with Pennsylvanian farmers' cropping practices. Brown (1987) found that consideration of production and price risks explained Saskatchewan farmers' persistence in using wheat-fallow rotations despite the existence of more profitable systems. Williams (1988) has shown for the central Great Plains that risk-averse farmers would prefer conservation tillage for wheat and grain sorghum over the traditional wheat-fallow cropping system.

This study builds on the economic analysis study conducted by Christenson et al. (1995) and extends it by incorporating the consideration of risk using stochastic dominance analysis. First, the profitability of each cropping system is determined. By growing each rotation crop each year, annual profitability for each year during the 1975-94 time period is determined. Stochastic dominance analysis was then conducted using the annual profitability data for each cropping system.

2. STOCHASTIC DOMINANCE ANALYSIS

Risk analysis in agriculture has been predominantly based on decision theory, the foundation of which is the expected utility model (EUM) (King and Robison, 1984). The EUM stipulates that maximization of expected utility is the best criterion to make choice under uncertainty. However, difficulty in the measurement of a decision maker's preference has rendered the model difficult to apply. Due to difficulties in preference solicitation and statistical estimation, an estimated utility function may not be an accurate representation of the preference of a decision maker (King and Robison, 1984).

To alleviate the shortcomings of the single-valued utility function, other decision criteria have been developed. Some criteria do not require probability estimates (e.g., maximin, maximax), while others require estimation of probabilities (e.g., maximizing expected monetary value). However, these criteria do not consider the inherent trade-off between expected return and dispersion of the return. Efficiency criteria that consider the trade-off between expected return and its dispersion provide an ordering of alternatives given specific restrictions on the decision maker's preferences and probability distribution of the return (Brown, 1987). By classifying the decision alternatives into two mutually exclusive groups (efficient set and inefficient set) without requiring detailed information on decision makers' utility functions, efficiency criteria provide decision makers the opportunity to make the final choice from the efficient set. Choice from the inefficient set is excluded because each decision alternative in the inefficient set is dominated by one or more of the alternatives in the efficient set.

Efficiency criteria can be useful in situations involving a single decision maker with unknown preferences, in situations involving several decision makers whose preferences conform to specific restrictions, or in policy or extension recommendation analysis that refers to diverse individuals (King and Robison, 1984). As such, efficiency criteria have been useful tools of risk analysis in agriculture.

Mean-variance trade-off efficiency criterion is the most commonly used efficiency criterion. Based on this criterion, decision alternatives that exhibit the lowest variance for a given level of expected return, or the highest expected return for a given level of variance are said to be on the risk efficiency frontier for risk-neutral or risk-averse decision makers. However, mean-variance efficiency assumes that the outcome measure is normally distributed or the decision maker's utility is a function of mean and variance only. Distributions of outcomes exhibiting skewness and higher moments are common in agriculture and a risk-averse decision maker may prefer an alternative not in the efficiency frontier when these additional distributional characteristics are considered (Brown, 1984). As a result, efficiency criteria that consider the total distributional characteristics of outcomes are preferred.

Stochastic dominance criteria consider the total distributional characteristics of outcomes. As such, stochastic dominance analysis, a technique used to rank two cumulative distributions in terms of risk preference, has been widely used in the analysis of risk associated with crop rotation systems (Poe et al., 1991; Williams, 1988; Brown, 1987; Klemme, 1985; Zacharias and Grube, 1984). First-degree stochastic dominance (FSD) is the simplest and most widely used stochastic dominance criteria. FSD applies to decision makers who prefer more to less (who have positive marginal utility for the outcome of interest). According to FSD, a decision alternative with an outcome of a cumulative distribution function $F(x)$ is preferred to another alternative with cumulative distribution function of $G(x)$ if:

$$F(x) \leq G(x)$$

for all possible values of x and if a strict inequality holds for some values of x. Graphically, this means that the cumulative distribution function of the preferred alternative never lies to the left of the cumulative distribution function of the dominated alternative. The discriminatory ability of the FSD is limited by its rather general assumption that decision makers prefer more to less (King and Robison, 1987).

Second-degree stochastic dominance (SSD) requires that decision makers are risk-averse. In other words, SSD assumes that decision makers have positive but non-increasing marginal utility at all outcome levels. According to SSD, a decision alternative with an outcome of cumulative distribution function of $F(x)$ is preferred to another alternative with cumulative distribution function of $G(x)$ if:

$$\int_{-\infty}^{x} F(x)\,dx \leq \int_{-\infty}^{x} G(x)\,dx$$

for all possible values of x and a strict inequality holds for some values of x. Graphically, this means that the cumulative distribution of the outcome of the preferred alternative lies to the right more often than the cumulative distribution of the outcome of the dominated alternative. When the outcomes of interest are normally distributed, SSD is equivalent to the mean-variance trade-off criterion (Brown, 1987). SSD has more discriminatory power than the FSD. Although the assumption of risk aversion may not always hold, it is a reasonable assumption for many situations (Klemme, 1985).

Third-degree stochastic dominance (TSD) extends the requirements of FSD and SSD by making the additional requirement that decision makers become less risk-averse as their wealth increases. Mathematically, this means that decision makers have a utility function with a positive third derivative (Anderson et al., 1977). Graphically, it means that the cumulative distribution function of the outcome of the preferred alternative lies to the right more often and at lower outcome levels than the cumulative distribution of the outcome of the dominated alternative. In general, SSD and TSD efficiency sets may not be very different (Anderson et al., 1977).

Stochastic dominance analysis can be conducted with respect to a function or degree. Analysis with respect to a function requires the estimation of decision makers' risk aversion coefficients. This study did not elicit risk preferences of farmers. In the absence of such estimates, stochastic dominance analysis with respect to degree is used. FSD and SSD criteria are used to rank the cropping systems. FSD is equivalent to stochastic dominance with respect to a function when the lower and upper bounds of risk aversion are $-\infty$ and ∞, respectively, while SSD requires that the lower and upper bounds be zero and ∞ (Zacharias and Grube, 1984).

3. PROCEDURE

Average yield of each crop under each cropping system was computed for each year of the experiment. Annual returns to management and capital (RMC) per acre were calculated for each cropping system by subtracting the pre- and post-harvest production costs plus machinery ownership and operating costs from gross income. Twelve distributions of RMC (one for each cropping system) were derived by using 19 years annual RMC for each of the 12 cropping systems.

Each distribution of the 19 RMCs was arranged in ascending order. Differences of RMC were computed for all pair-wise combinations of the cropping systems. According to FSD, a cropping system A would dominate another system B if the differences in RMC are all positive when the differences were computed by subtracting the RMC of B from that of A. If the differences were all negative, system B dominates system A. If neither of these conditions are met for a pair of cropping systems, neither dominates the other by FSD, and SSD becomes the criteria to determine the dominance.

To determine dominance according to SSD, the cumulatives of the differences were computed for all cumulative probability levels. Then, system A would dominate another system B by SSD if all the cumulatives of the differences are positive when the differences were computed by subtracting RMC of system B from that of system A. If all the cumulative distributions were negative, system B dominates system A. If neither of these conditions are met for a pair of cropping systems, neither system dominates the other by SSD. Equal probabilities were assigned to each RMC in each distribution.

4. DATA

4.1 Yield

The Saginaw Valley Cropping System study was initiated in 1972 on Misteguay silty clay lake bed soil at the Michigan State University Saginaw Valley Research Farm. The experiment was arranged as a randomized complete block design with four replications. Each crop in each of the cropping systems was grown every year in order to avoid the confounding effects of climate. The 12 rotation systems included were corn-sugar beet (CSB), corn-navy bean (CNB), navy bean-sugar beet (NBSB), oats-navy bean (ONB), corn-corn-sugar beet (CCSB), corn-navy bean-sugar beet (CNBSB), navy bean-navy bean-sugar beet (NBNBSB), oats-navy bean-sugar beet (ONBSB), corn-corn-corn-sugar beet (CCCSB), corn-corn-navy bean-sugar beet (CCNBSB), corn-navy bean-navy bean-sugar beet (CNBNBSB), and oats-alfalfa-navy bean-sugar beet (OANBSB). Annual treatment yield averages for each crop in each cropping system were used for this study. Yields for 1986 are not included because of the incidence of heavy flooding. Table 1 presents the average yields of each crop under each cropping system for the period 1975-94.

4.2 Production Costs

Production costs as specified in Christenson et al. (1995) were used for this study. Pre- and post-harvest production costs and costs of machinery ownership, repairs, maintenance, fuel, and wages were calculated in 1991 prices. Pre-harvest production costs of seeds, herbicides, fertilizers, and insecticides were computed based on the recommended rates by Michigan State University (Copeland et al., 1988; Landis and Geibink, 1992; Kells and Renner, 1991; Christenson et al., 1992). The same recommendations were used throughout the study. Annual survey of dealers (Nott et al., 1990) was used to determine prices of seeds, fertilizers, and pesticides. Second- and third-year consecutive corn included post-emergence herbicides due to weed pressure. Pre-harvest costs are presented in Table 2.

Post-harvest hauling costs were charged per unit of yield as follows: $0.20/bu for corn and oats, $0.35/cwt for navy beans, $3.40/ton for sugar beets. Drying cost for corn was charged at $0.30/bu. An estimated post-harvest handling cost of $24.20/ton was charged for alfalfa (Rotz, 1986).

Table 1. **Average Yields of the Crops Grown in the Saginaw Valley Cropping Systems Study (1975-94)**

Cropping System[a]	Position in Rotation			
	1st	2nd	3rd	4th
C-SB	134[b]	25.2	----	----
C-NB	132	19.0	----	----
NB-SB	17.0	25.9	----	----
O-NB	83	19.1	----	----
C-C-SB	131	118	25.0	----
C-NB-SB	135	19.4	26.6	----
NB-NB-SB	16.3	18.0	26.8	----
O-NB-SB	86	19.8	26.1	----
C-C-C-SB	129	118	111	24.7
C-C-NB-SB	129	116	20.5	26.2
C-NB-NB-SB	126	18.7	18.0	26.9
O-A-NB-SB	89	2.9	20.6	27.5

[a] C = corn; SB = sugar beets; NB = navy beans; O = oats; A = alfalfa.

[b] Units: corn and oats = bu/acre; sugar beets and alfalfa = tons/acre; navy beans = cwt/acre.

Table 2. Pre-Harvest Variable Costs for Crops Grown in the Saginaw Valley Cropping Systems Study

Crop		Pre-Harvest Variable Costs ($/acre)				
		Seed	Fertilizer	Weed Control	Insect Control	Total
Corn	1st year	23	37	36	0	96
	2nd year	23	37	39	12	111
	3rd year	23	37	36	12	108
Navy Beans	1st year	20	14	11	0	45
	2nd year	20	14	17	0	51
	after alfalfa	20	7	11	0	38
Sugar Beets		20	36	64	0	120
Oats		8	14	0	0	22
Alfalfa		26	17	10	0	53

Source: Christenson et al. (1995).

A machinery selection algorithm developed by Rotz et al. (1983) was used to select the machinery complements and associated annual costs for each cropping system for a 600-acre farm size. Least cost machinery complements capable of completing all field operations under specified time constraints and soil type were selected. Timeliness costs for not completing field operations were also included. Machinery and implement prices were based on data from Fuller et al. (1990). Table 3 presents machinery complements and annual operating costs.

Table 3. Machinery Ownership and Annual Operating Costs for 600-acre Farm for the Cropping Systems Included in the Saginaw Valley Cropping Systems Study ($/acre/year)

Cropping System[a]	Machinery Ownership[b]	Fuel and Lubrication	Labor	Timeliness	TOTAL
C-SB	79.75	9.80	10.74	0.00	100
C-NB	57.16	7.92	14.51	0.00	80
NB-SB	76.41	10.13	11.58	1.68	100
O-NB	69.18	7.12	9.19	0.00	85
C-C-NB	77.99	9.16	10.17	0.08	97
C-NB-SB	74.93	9.38	10.73	0.00	95
NB-NB-SB	76.57	9.15	9.90	0.00	96
O-NB-SB	93.12	9.48	10.99	0.00	114
C-C-C-SB	77.25	8.84	9.88	0.51	96
C-C-NB-SB	74.11	9.00	10.31	0.00	93
C-NB-NB-SB	74.32	9.17	10.73	1.68	96
O-A-NB-SB	102.36	8.14	11.27	0.00	122

[a] C = corn; SB = sugar beets; NB = navy beans; O = oats; A = alfalfa.

[b] Includes depreciation, interest, storage, insurance, and repair and maintenance costs.

Source: Christenson et al. (1995).

4.3 Crop Prices

Crop prices were estimated based on the AGMOD econometric model developed by Ferris (1991). The model estimates prices based on projected demand and supply relationships of corn and related crops. The prices of sugar beets, navy beans, oats, and alfalfa were estimated based on their historical relationship to the price of corn. The following prices were used: $2.40/bu for corn, $36.00/ton for sugar beets, $20.00/bu for navy beans, $1.65/bu for oats, and $80.00/ton for alfalfa.

5. RESULTS AND DISCUSSION

The navy bean-sugar beet rotation had the highest average return ($420/acre) and was significantly different from the returns of all other rotation systems (Table 4). This return was higher by $78/acre from the next highest average return of navy bean-navy bean-sugar beet. Apparently, the high values of sugar beets and navy beans resulted in the highest return despite the potential risk of lower yields of sugar beets and navy beans in short rotations.

The returns of two- or three-year rotations that included sugar beets together with one or two years of navy beans or one year of corn had the next highest average returns which were also significantly different from the average returns of all other rotations. Again, the presence of sugar beets and navy beans or the higher proportion of sugar beets in the two-year rotation (with corn) explained the return advantage of these rotation systems. Four- or three-year rotations that include sugar beets and one or two years of navy beans together with one or two years of corn or one year of oats were the third in the profitability ranking. The average return from the oat-navy bean-sugar beet rotation was lower by $64/acre than the average return from navy bean-navy bean-sugar beet rotation. The low value of oats appears to account for this wide difference in profitability.

Three- or four-year rotations that included two years of corn together with sugar beets or sugar beets and navy beans were the fourth in the profitability ranking. The fact that there was no significant difference in profitability between these two rotations can be explained by the high proportion of corn in the systems.

Table 4. Average Returns to Management and Capital (RMC) for 600-acre Farm for the Cropping Systems Included in the Saginaw Valley Cropping Systems Study

Cropping System[a]	Rank	RMC ($/acre)		
		Mean †	Minimum	Maximum
NB-SB	1	420 a	282	549
NB-NB-SB	2	342 b	198	489
C-NB-SB	2	340 b	243	453
C-SB	2	331 b	170	491
C-NB-NB-SB	3	285 c	174	420
O-NB-SB	3	278 c	147	387
C-C-NB-SB	3-4-5	245 cdf	140	355
C-C-SB	4-5	223 de	70	326
O-A-NB-SB	5	218 ef	95	308
C-C-C-SB	6	167 g	56	270
C-NB	6	155 g	52	250
O-NB	6	140 g	47	213

[a] C = corn; SB = sugar beets; NB = navy beans; O = oats; A = alfalfa.

† Figures followed by different letters are significantly different at 5% by LSD multiple range test.

The four-year rotation that included one year each of oats, alfalfa, navy beans, and sugar beets ranked fifth in profitability. Despite the highest yields of oats, navy beans, and sugar beets in this rotation system (Christenson et al., 1995), the low proportion and low total production of navy beans and sugar beets explain the low profitability. Four-year rotation that included three years of corn and one year of sugar beets, and two-year rotations that included navy beans together with either corn or oats had the lowest return.

In order to determine if there were fluctuations in profitability ranking during the study period, a separate profitability analysis of the cropping systems was conducted for each of the five four-year time periods. Results showed that the average profitability ranking was consistent with the profitability ranking of each of the time blocks.

Distributions of RMC for each cropping system included in the study are given in Table 5. In general, cropping systems that had the higher returns also showed lower variability as measured by the coefficient of variation. Navy bean-sugar beet rotation had the lowest variability followed by corn-navy bean-sugar beet. Corn-navy bean had the highest variability followed by corn-corn-corn-sugar beet.

Results of the stochastic dominance analysis are given in Table 6. FSD and SSD criteria had similar discriminatory power, with SSD showing slightly higher discrimination. This means that risk-neutral and risk-averse farmers would select similar cropping systems from those included in this study. Each of the risk efficiencies of corn-navy bean, navy bean-navy bean-sugar beet, and oat-navy bean rotations were determined exactly alike by FSD and SSD. SSD eliminated at least one rotation system from the FSD set of indifferent rotations with respect to all other rotation systems.

The profitability advantage of including both sugar beets and navy beans in a rotation system was also reflected in the dominance analysis results. Navy bean-sugar beet, the rotation that also had the highest average return, was the only rotation in the efficient set by both FSD and SSD (Table 6). The cumulative probability distribution function of this rotation lies entirely to the right of all other cumulative probability functions (Figure 1). Despite the somewhat lower yield levels of these crops in short rotation cycles, the high value of these crops coupled with less variability of yield explains this result.

Table 5. Distribution of RMC for the Cropping Systems in the Saginaw Valley Cropping Systems Study($/acre)

	csb*	ccsb	cccsb	cnb	cnbsb	ccnbsb	nbsb	nbnbsb	cnbnbsb	onb	onbsb	oanbsb
min.	170	70	56	52	243	140	282	198	174	47	147	95
	249	99	103	55	250	154	320	233	187	87	182	138
	254	174	106	104	250	157	333	263	206	100	199	164
	281	184	121	105	266	188	337	276	225	108	204	169
	294	186	121	127	274	193	351	288	229	110	206	178
	312	209	126	131	310	230	379	303	253	114	235	186
	312	214	137	131	314	232	387	304	256	129	261	206
	318	218	164	133	324	232	416	315	279	134	264	210
	318	233	166	142	343	233	427	340	279	138	270	212
	321	237	181	143	348	240	427	344	281	144	287	227
	324	239	184	161	351	255	441	344	292	145	298	233
	356	240	189	181	351	259	442	353	298	149	310	235
max.	356	240	193	187	367	263	447	361	314	151	313	242
	367	258	195	196	384	278	450	367	321	159	319	245
	368	262	199	203	387	284	475	411	330	166	319	257
	376	264	205	209	400	311	485	432	330	179	359	267
	393	270	205	211	404	320	509	435	342	187	359	287
	430	310	243	231	445	332	529	445	401	204	371	287
	491	326	270	250	453	355	549	489	420	213	387	308
mean	331	223	167	155	340	245	420	342	285	140	278	218
St. dev.	70.2	62.5	52.5	55.3	64.1	60.8	73.6	76.3	65.9	41.0	68.9	54.3
C.V. (%)	21.2	28.0	31.5	35.7	18.9	24.8	17.5	22.2	23.1	29.3	24.8	24.9

* c = corn; sb = sugar beets; nb = navy beans; o = oats; a = alfalfa.

Table 6. Stochastic Dominance Results of the Cropping Systems Included in the Saginaw Valley Cropping Systems Study

Cropping System[a]	First-Degree Stochastic Dominance (FSD)			Second-Degree Stochastic Dominance (SSD)		
	Dominates	Indifferent To	Dominated By	Dominates	Indifferent To	Dominated By
csb	ccsb, cccsb, cnb, ccnbsb, onb, onbsb, oanbsb	cnbsb, nbnbsb, cnbnbsb	nbsb	ccsb, cccsb, cnb, ccnbsb, onb, onbsb, oanbsb	nbnbsb, cnbnbsb	cnbsb, nbsb
ccsb	cnb, onb	cccsb, ccnbsb, oanbsb	csb, cnbsb, nbsb, nbnbsb, cnbnbsb, onbsb	cccsb, cnb, onb,	oanbsb	csb, cnbsb, ccnbsb, nbsb, nbnbsb, cnbnbsb, onbsb
cccsb	onb	cnb, ccsb	csb, cccsb, cnbsb, ccnbsb, nbsb, nbnbsb, cnbnbsb, onbsb, oanbsb	cnb, onb	-----	csb, ccsb, cccsb, cnbsb, ccnbsb, nbsb, nbnbsb, cnbnbsb, onbsb, oanbsb,
cnb	------	cccsb, onb	csb, ccsb, cnbsb, ccnbsb, nbsb, nbnbsb, cnbnbsb, onbsb, oanbsb	-------	cccsb, onb	csb, ccsb, cnbsb, ccnbsb, nbsb, nbnbsb, cnbnbsb, onbsb, oanbsb
cnbsb	ccsb, cccsb, cnb, ccnbsb, cnbnbsb, onb, onbsb, oanbsb,	csb, nbnbsb	nbsb	csb, ccsb, cccsb, cnb, ccnbsb, cnbnbsb, onb, onbsb, oanbsb,	nbnbsb	nbsb
ccnbsb	cccsb, cnb, onb	ccsb, oanbsb	csb, cnbsb, nbsb, nbnbsb, cnbnbsb, onbsb	ccsb, cccsb, cnb, onb, oanbsb	--------	csb, cnbsb, nbsb, nbnbsb, cnbnbsb, onbsb
nbsb	csb, ccsb, cccsb, cnb, cnbsb, ccnbsb, nbnbsb, cnbnbsb, onb, onbsb, oanbsb	-------	-------	csb, ccsb, cccsb, cnb, cnbsb, ccnbsb, nbnbsb, cnbnbsb, onb, onbsb, oanbsb	------	--------
nbnbsb	ccsb, cccsb, cnb, ccnbsb, cnbnbsb, onb, onbsb, oanbsb	csb, cnbsb,	nbsb	ccsb, cccsb, cnb, ccnbsb, cnbnbsb, onb, onbsb, oanbsb	csb, cnbsb,	nbsb

Cropping System[a]	First-Degree Stochastic Dominance (FSD)			Second-Degree Stochastic Dominance (SSD)		
	Dominates	Indifferent To	Dominated By	Dominates	Indifferent To	Dominated By
cnbnbsb	ccsb, cccsb, cnb, ccnbsb, onb, oanbsb	csb, onbsb	cnbsb, nbsb, nbnbsb	ccsb, cccsb, cnb, ccnbsb, cnbnbsb, onb, oanbsb	csb	cnbsb, nbsb, nbnbsb
onb	-------	cnb	csb, ccsb, cccsb, cnbsb, ccnbsb, nbsb, nbnbsb, cnbnbsb, onbsb, oanbsb	-------	cnb	csb, ccsb, cccsb, cnbsb, ccnbsb, nbsb, nbnbsb, cnbnbsb, onbsb, oanbsb
onbsb	ccsb, cccsb, cnb, ccnbsb, onb, oanbsb	cnbnbsb	csb, cnbsb, nbsb, nbnbsb	ccsb, cccsb, cnb, ccnbsb, onb, oanbsb	------	csb, cnbsb, nbsb, nbnbsb, cnbnbsb
oanbsb	cccsb, cnb, onb	ccsb, ccnbsb	csb, cnbsb, nbsb, nbnbsb, cnbnbsb, onbsb	cccsb, cnb, onb	ccsb	csb, cnbsb, ccnbsb, nbsb, nbnbsb, cnbnbsb, onbsb

[a] c = corn; sb = sugar beets; nb = navy beans; o = oats; a = alfalfa.

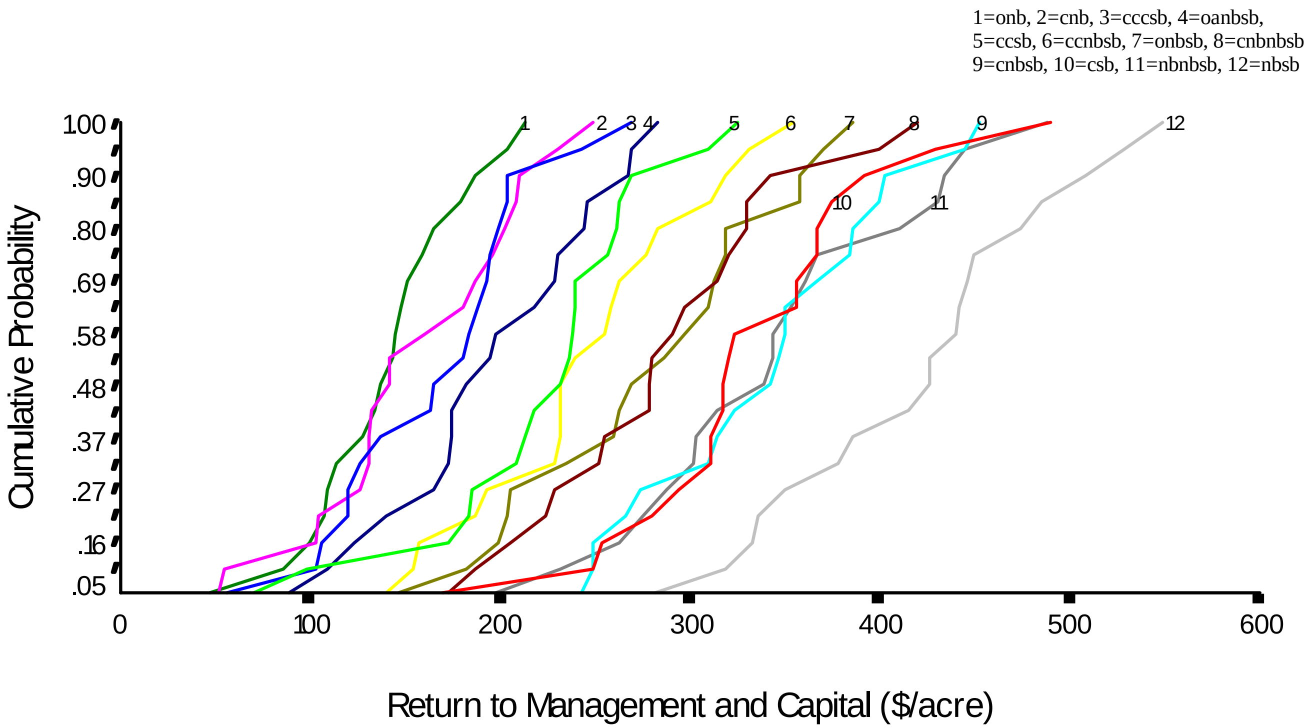

Figure 1: Cumulative Probability Distribution Functions of Returns to Management and Capital

Two-year rotations that included sugar beets and three-year rotations that included both sugar beets and navy beans were risk efficient with respect to most other rotation systems as seen from the SSD results. In particular, except for navy bean-sugar beet, corn-navy bean-sugar beet dominated all rotation systems but navy bean-navy bean-sugar beet, while navy bean-navy bean-sugar beet rotation dominated all rotation systems except corn-sugar beet and corn-navy bean-sugar beet. Risk-averse farmers would remain indifferent in their choice of two- or three-year rotations as far as the two-year rotation includes sugar beets but not navy beans, and the three-year rotations include both sugar beets and navy beans.

The SSD results also showed that four-year rotations that included both navy beans and sugar beets were less risk efficient than their counterpart two- or three-year rotations. In particular, the oat-alfalfa-navy bean-sugar beet rotation was dominated by all rotations except corn-corn-sugar beet, corn-corn-corn-sugar beet, corn-navy bean, and oat-navy bean rotations. Apparently, the highest yields of oats, navy beans, and sugar beets registered in this rotation were also accompanied by high yield variability.

Rotation systems that included two or three years of corn were risk inefficient with respect to most other systems. In particular, corn-corn-corn-sugar beet rotation was dominated by all rotations except corn-navy bean and oat-navy bean. The decline in corn yield with an associated yield variability when corn is grown successively provides a partial explanation of this result. Two-year rotations that included navy beans but not sugar beets failed to dominate any rotation system.

The cumulative probability distribution functions presented in Figure 1 show how the different rotation systems track together in groups. The cumulative distribution function of navy bean-sugar beet rotation crosses no other distribution and lies entirely to the right of all other distributions.

Cumulative distribution functions of rotation systems that include sugar beets in a two-year rotation or both sugar beets and navy beans in a three-year rotation crossed each other but were mostly to the right of most other rotations except that of navy bean-sugar beet rotation. Distributions of two-year rotations that included navy beans but not sugar beets lied to the far left indicating their risk inefficiency with respect to most other rotation systems.

6. CONCLUSION

The profitability ranking results were generally similar to the results from the stochastic dominance analysis. The navy bean-sugar beet (NB-SB) two-year crop rotation dominated all other crop rotations based on 19 years of data collected during 1975-94 at the MSU Saginaw Valley Research Farm. Using standardized product price relationships and determinant production costs, this two-year rotation produced not only the highest annual average return to management and capital (RMC) but also had the lowest variance earnings. Based on stochastic dominance analysis, the NB-SB rotation was first-degree and second-degree stochastic dominant over 11 other crop rotation alternatives.

Inclusion of sugar beets in two-year rotations and both sugar beets and navy beans in three-year rotations contributed as much to risk efficiency as it did to profitability. Farmers' persistence in using shorter rotations for sugar beets and navy beans than the recommended longer rotations can be explained by their consideration of both profitability and risk.

A note of caution on extending these results beyond this data set is that the long-term yield relations observed in this experiment did not exhibit consistent yield depressions from short rotations. Nor did the sugar beet yields in the trials decline during the 1990's as did the Michigan sugar beet grower yields from 1992 through 1996. One hypothesis for further study is that soil compaction generated from use of large machinery during occasional adverse harvesting conditions could result in depressed yields that the research trials might not experience in small plot experimental research.

The yield data, input, and price relationships contained in this study support the intensive crop rotations that feature sugar beets and navy beans. Any changes in these production and price relationships or other changes external to the farm as environmental, agricultural, and trade policy must be areas of necessary cognizance by Michigan growers as they decide on the crop rotation sequence that best satisfies their profitability and risk management objectives.

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