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SELECTION OF APPLE SCAB PEST MANAGEMENT STRATEGIES UNDER UNCERTAINTY: AN APPLICATION OF VARIOUS STOCHASTIC DOMINANCE TECHNIQUES*

by

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ABSTRACT

For most scenarios considered the conventional spray program used to control apple scab in Michigan orchards is risk efficient even though it has an expected return below the IPM programs. Several Stochastic Dominance techiques are applied and the results compared.

SELECTION OF APPLE SCAB PEST MANAGEMENT STRATEGIES UNDER UNCERTAINTY

Conventional pest control practices generally apply chemical pesticides on fixed time intervals. These calendar based spray programs have a large inherent insurance component since the programs are designed to always control large infestations of pests without regard to the probability of such occurrences. An alternative set of controls known under the general title of Integrated Pest Management (IPM) attempt to improve upon the performance of conventional pest management strategies. IPM is a conceptual approach to crop protection based upon ecological principles. Management strategies include an integration of such tactics as well-timed chemical applications, biological controls, resistant plant varieties and cultural practices. Reductions in pesticide usage often result from following IPM strategies as information, natural and introduced predators and cultural practices are substituted for chemical treatments.

Although IPM techniques began to evolve in the 1950's, it has not been until the last decade that their adoption has been considered by a large setment of the farm community. There are a number of forces which are influencing this situation. Rising chemical prices have stimulated interest in ways to reduce their usage and the development of resistance has encouraged the use of alternatives to chemical pesticides as well. Outbreaks of secondary pests have been experienced in many systems where conventional programs have been followed for years. Concerns about the ecological ramifications of prolonged use of chemical pesticides have also risen over time. Certainly, the development of commercial and extension services which provide the information necessary to manage an IPM program have had their impact. However, one obstacle to adoption is that if IPM programs reduce the insurance aspects of the management strategies, decision makers who are risk averse may still prefer the conventional spray programs (Carlson, Norgaard).

The risk associated with the IPM programs may or may not be greater than conventional spray programs depending upon the efficiency of the substitution of information, cultural practices and biological controls for the insurance sprays. It should be noted that the risk should measure the variation in net revenue and it can arise from pest damage and from the costs of chemical applications which may be unwarranted by the size of the pest populations. In many cases, the IPM programs have not increased the risk of pest management (Hall, Hänneman and Farnsworth).

Due to the wide differences across production systems and pest complexes, it is often difficult to generalize conclusions in the area of economics of pest management. The results of a study on the risk efficiency of particular IPM programs employed in a specific crop production system may not accurately represent the situation for other programs or production systems. The intent of this study is to determine if IPM scab control programs in Michigan apple production systems are risk efficient for some apple growers.

Apple scab, <u>Venturia inaequalis</u>, is the most important disease which attacks apples in humid-temperate climates. The spores of the fungus are discharged after periods of rain and infections may occur on the fruit, the branches or leaves. Damage can result in lower quality fruit and smaller yield produced by early difoliation. In Michigan control costs for scab alone can reach $165 per acre.

The distributions of net revenue which are used as the outcomes of the various pest management strategies have been generated from a stochastic Monte

Strategy	Green Tip to Pink	Pink to Petal Fall	Petal Fall to 6/15	6/15 to 8/7	8/7 to 9/1
1	Do Nothing	Do Nothing	Do Nothing	Do Nothing	Do Nothing
2	Captafol (5 gal/acre) at green tip or 4/9	------	At petal fall, apply captan (8 lbs/acre) every 7 days (for 3 cover sprays)	After 3 weekly full dose captan cover sprays, apply captan (4 lbs/acre) every 14 days	Do nothing unless at least 2 infections have developed previously then apply captan (4 lbs/acre) every 14 days
3	Captan (8 lbs/acre) every 7 days starting on 4/10	Captan (8 lbs/acre) every 7 days	Captan (8 lbs/acre) every 7 days	Captan (8 lbs/acre) every 14 days	Do nothing unless at least 2 infections have developed previously; then apply captan (8 lbs/acre) every 14 days
4	Captan (4 lbs/acre) every 7 days starting on 4/10	Captan (4 lbs/acre) every 7 days	Captan (4 lbs/acre) every 7 days	Captan (4 lbs/acre) every 14 days	Do nothing unless at least 2 infections have developed previously, then apply captan (4 lbs/acre) every 14 days
5	Benomyl (16 oz/acre) when weather conditions have been suitable* for an infection--unless benomyl has been applied within the last week	Benomyl (16 oz/acre) when weather conditions* have been suitable for an infection--unless benomyl has been applied within the last week	Benomyl (16 oz/acre) when weather conditions* have been suitable for an infection--unless benomyl has been applied within the last week	Benomyl (16 oz/acre) when weather conditions* have been suitable for an infection--unless benomyl has been applied within the last week	Do nothing unless at least 2 infections have developed previously, then apply benomyl (16 oz/acre when weather conditions* have been suitable for an infection unless benomyl has been applied within the last week
6	Benomyl (12 oz/acre) and captan (4 lbs/acre) every 7 days starting on 4/10	Benomyl (12 oz/acre) and captan (4 lbs/acre) every 7 days	Benomyl (12 oz/acre) and captan (4 lbs/acre) every 7 days	Benomyl (12 oz/acre) and captan (4 lbs/acre) every 14 days	Do nothing unless at least 2 infections have previously developed; then apply benomyl (12 oz/acre) and captan (4 lbs/acre) every 7 days
7	Captan (8 lbs/acre) every 7 days starting on 4/10	Captan (8 lbs/acre) every 7 days	Captan (6 lbs/acre) every 10 days	Captan (4 lbs/acre) every 14 days	Do nothing unless at least 2 infections have previously developed; then apply captan (4 lbs/acre) every 14 days
8	Captafol 3 gal/acre) at green tip or 4/9	Captan (8 lbs/acre) every 7 days (for 5 cover sprays)	Captan (8 lbs/acre) every 7 days for 5 cover sprays	After 5 cover sprays, apply captan (4 lbs/acre) every 14 days	Do nothing unless at least 2 infections have previously developed; then apply captan (4 lbs/acre) every 14 days
9	Captafol (5 gal/acre) at green tip or 4/9	------	Benomyl (16 oz/acre) when weather conditions have been suitable for an infection*--unless benomyl has been applied within the last week	Benomyl (16 oz/acre) when weather conditions have been suitable for an infection*--unless benomyl has been applied within the last week	Do nothing unless at least 2 infections have previously developed; then apply benomyl (16 oz/acre) when weather conditions have been suitable for an infection*--unless benomyl has been applied within the last week
10	Captafol (3 gal/acre) at green tip or 4/9	Benomyl (16 oz/acre) when weather conditions have been suitable for an infection*--unless benomyl has been applied within the last week	Benomyl (16 oz/acre) when weather conditions have been suitable for an infection*--unless benomyl has been applied within the last week	Benomyl (16 oz/acre) when weather conditions have been suitable for an infection*--unless benomyl has been applied within the last week	Do nothing unless at least 2 infections have previously developed; then apply benomyl (16 oz/acre) when weather conditions have been suitable for an infection*--unless benomyl has been applied within the last week
11	When an infection actually occurs, benomyl (16 oz/acre)	When an infection actually occurs, benomyl (16 oz/acre)	When an infection actually occurs, benomyl (16 oz/acre)	When an infection actually occurs, benomyl (16 oz/acre)	When an infection actually occurs, benomyl (16 oz/acre)

* Weather conditions suitable for an infection are assumed to be when the average daily temperature has exceeded 35°F and precipatation is greater than .01 inches.

Table 4. Description of Scab Control Strategies

Carlo simulation model which examines the performance of the strategies in twenty independent seasons. No multi-seasonal effects have been considered. The sources of uncertainty in the apple scab model are the average daily temperature, the daily precipitation, the yield, the fresh and processed apple market prices, the determination of infection periods and the calculation of the scab damage estimates. The model is more completely described elsewhere (Cochran). A description of the scab control strategies appears in Table 1. The IPM strategies are 5 and 11. Rather than scouting the pest population, these strategies monitor the weather and apply a spray whenever conditions have been suitable for an infection to develop. Strategy 5 has an error in the prediction of infection periods while strategy 11 is 100% accurate. The most typical of the conventional spray programs is strategy 7.

Model results are displayed in Table 2.

Strategy	Medium Yield	Low Yield	High Yield	Medium Yield & High Benomyl Price*
1	-4405 (5770)	-6291 (2717)	-1058 (11491)	-4405 (5770)
2	3738 (6833)	-3291 (3239)	15213 (14072)	3738 (6833)
3	3499 (6748)	-3494 (3253)	14938 (13947)	3492 (6916)
4	3259 (6842)	-3222 (3309)	13935 (14091)	3092 (7009)
5	4198 (6876)	-2684 (3286)	15513 (14172)	3776 (7043)
6	3431 (6749)	-3562 (3254)	14869 (13947)	3034 (6922)
7	3814 (6728)	-3144 (3264)	15212 (13940)	3772 (6891)
8	3789 (6754)	-3179 (3212)	15187 (13971)	3762 (6928)
9	3579 (7008)	-3299 (3311)	14812 (14371)	3513 (7189)
10	4006 (6862)	-2903 (3278)	15364 (14149)	3740 (7026)
11	4298 (6770)	-2351 (3344)	15345 (14097)	4033 (6942)

*Price of Benomyl increased 36.7%

Standard Deviations appear in parenthesis.

Table 2. Expected Net Revenues per Ten Acre Block for Scab Control Strategies

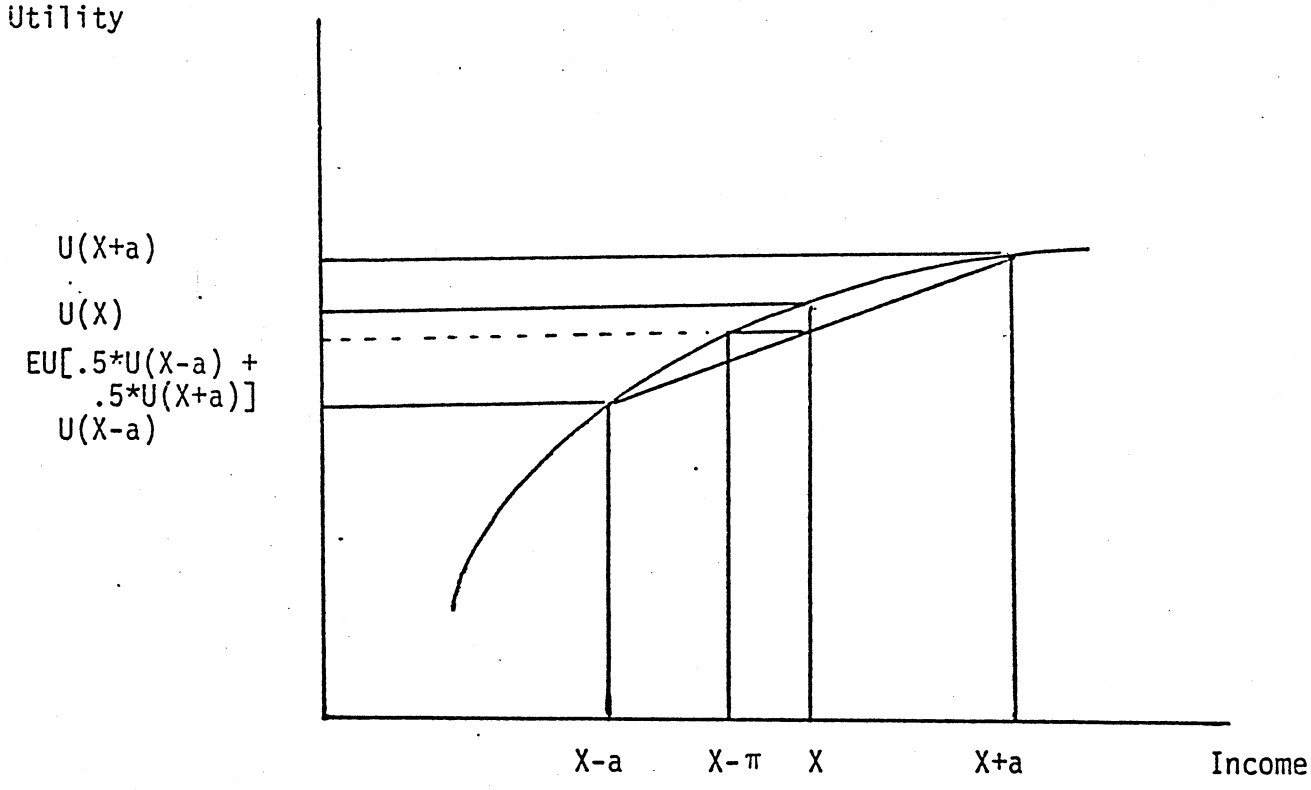

Figure 1 - A

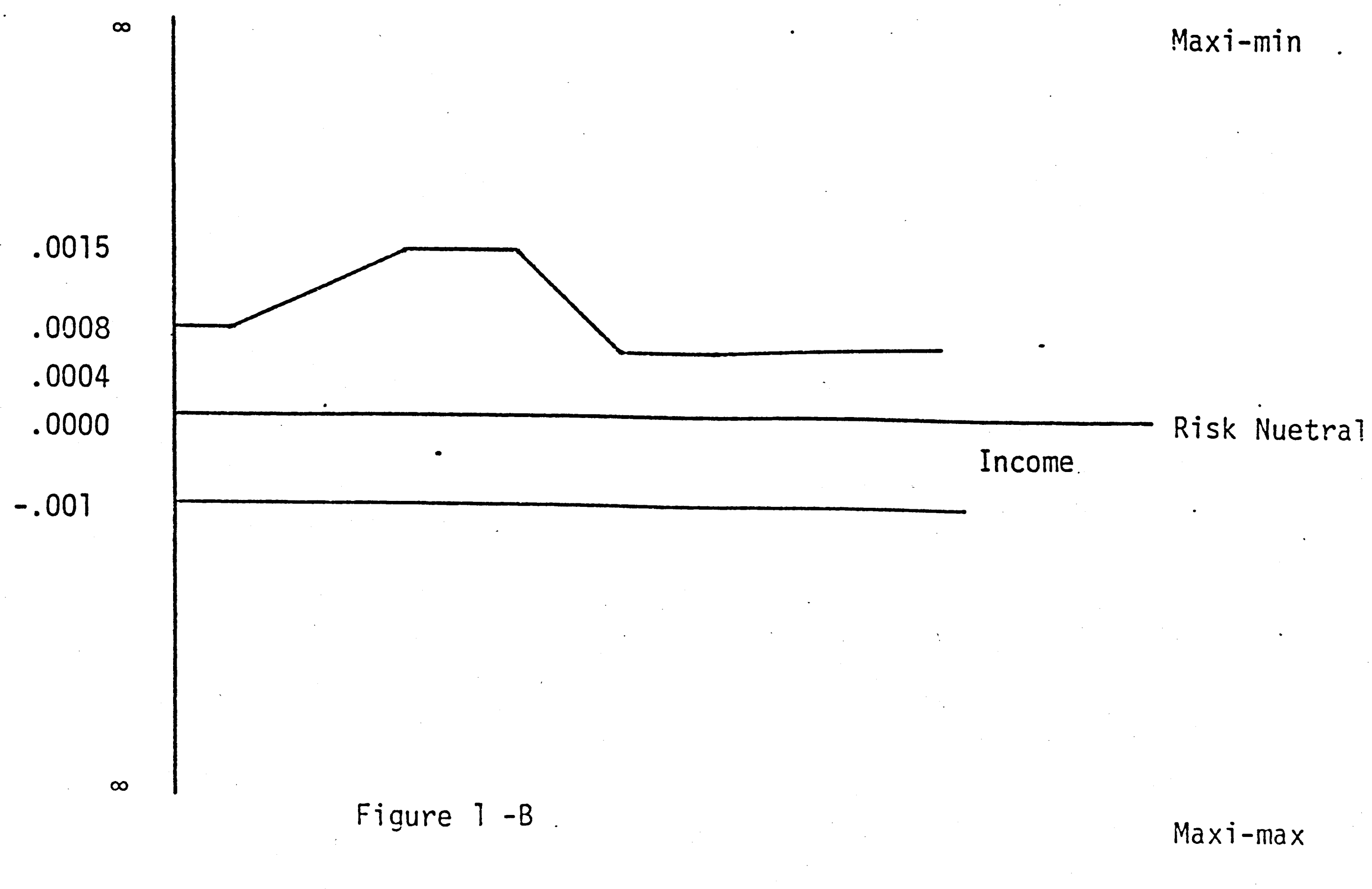

Figure 1 -B

It is often postulated that even if IPM programs can increase the average net return in a production system, the associated risk would be great enough that conventional control strategies would still be preferred by agricultural decision makers. The logic of the argument can be illustrated graphically. In Figure 1-A, the classical utility function is displayed. A utility function is a concept frequently used in economics to indicate the amount of satisfaction that is received by an individual. In this case the utility is a function of income and the first derivative (marginal utility of income) is increasing while the second derivative is decreasing. This case would reflect the preferences of a risk averse decision maker. The curvature of the function will indicate the degree of risk aversion and a straight line would represent a risk neutral individual. If a decision maker with this utility function is faced with a lottery of receiving (X-a) 50% of the time and receiving (X+a) 50% of the time the expected utility of the lottery [.5*U(X-a) + .5*U(X+a)] would be less than the utility of the expected value of the lottery, U(X). A risk neutral individual would receive the same utility from the lottery and the expected value of the lottery.

Most risk averse decision makers would be willing to pay an insurance premium to eliminate the uncertainty. The amount of the premium depends on the degree of the decision maker's risk aversion reflected by the curvature of the utility function. The premium, π, that could be paid and leave the decision maker indifferent between the sure outcome $(x - \pi)$ and the lottery with outcomes $x - a$ and $x + a$ is indicated in Figure 1. It is the income level whose utility is equal to the expected utility of the lottery. The sure outcome is the certainty equivalent. The size of certainty equivalent will depend on the curvature of the utility function.

In the pest management example, the decision may be a choice between a conventional program which has less uncertainty in the system and an IPM strategy which has a higher expected return but perhaps more uncertainty. If the certainty equivalent is higher for the conventional program it will be preferred to the IPM strategy. In this case, the conventional program would be risk efficient and adopted even though it has an expected net return below that of the IPM program.

This argument is founded upon two crucial assumptions that may hinder its validity for understanding the dynamics of pest management strategy selection. The two assumptions are that conventional programs are less risky than IPM strategies and that decision makers are risk averse at all income levels. First, there is some evidence that not all IPM strategies are more risky than conventional ones (Hanneman and Farnsworth, Hall). Second, survey results indicate that many decision makers are not risk averse at all income levels (Halter and Mason, Carman, Whittacker and Winter, Love).

The argument can be used as an important base to derive hypotheses but there are some necessary improvements in the conceptual framework that must be made to realistically test those hypotheses. The use of a single valued utility function to measure risk preferences has been abandoned due to two major problems. It is extremely cumbersome to make statements about a class of decision makers with a single valued utility function -- it would be necessary to measure each individual's attitude to risk or to assume that all individuals had the same function to conclude anything about the preferences of the group. In addition, a variety of sources of measurement errors produce a high probability of Type I statistical errors in tests comparing the expected values of alternative strategies when preferences are represented by a single valued utility function. These problems led to the development of efficiency criteria. Efficiency criteria are designed to test hypotheses valid for classes of decision makers and to measure preferences not with a single valued utility function but with an interval which operates very similar to a statistical confidence interval. For wide intervals the probability of a Type II error will increase. Efficiency criteria identify efficiency sets of strategies which are risk efficient. A strategy is risk efficient if its expected utility is not less than the expected utility of any other strategy for every individual in the class.

The width of the interval can be set by assumption or inferred from survey data. When the class of decision makers is defined as all individuals who are everywhere risk averse, the boundaries of the interval are 0 and ∞ (Figure 1 - B). This is the case of Second Degree Stochastic Dominance. It suffers from large Type II errors and may be biased for any individuals who are risk loving over any range of the income domain. Stochastic Dominance With Respect to a Function (King and Robison) allows any width of interval and there are no restrictions on the location of the interval in risk preference space. In Figure 1-B, an interval inferred from the Carman survey datais displayed. This interval should reflect the preferences of 80-90% of the farmers in the state of Michigan. The coefficients are expressed in terms of the Pratt Risk Aversion Coefficient, $-U''(x)/U'(x)$.

Five intervals were used in this analysis and the efficiency sets for the various intervals were compared. The intervalsare described and the efficiency sets exhibited in Table 3.

It should be noted from the examination of the efficiency sets that the typical conventional spray program, strategy 7, is risk efficient for the fifth interval in all scenarios except when there is a low yield (250 bushels per acre). This result provides support for the argument that adoption of the IPM strategies may be hindered because conventional strategies may be more consistent with the risk preferences of some decision makers. In the case of the medium yield (500 bushels per acre) when the hypothetical IPM strategy (11) is ignored, it is interesting to note that strategy 7 does not appear in the efficiency sets of the third and fourth intervals but that it is risk efficient for the rest. It can be inferred from that that strategy 7 may be preferred only by decision makers who have at least more than moderately strong risk aversion (.0003) at some income level. The conventional spray program appears to be more consistent with preferences of the more risk averse apple growers.

It was hypothesized that as the yield (or value) of the crop increased the conventional spray programs would perfom better since the marginal value of damage avoided should be increased and more chemicals could be efficiently applied. For

Risk Interval	General Discription	Medium Yield (All Strategies)	Medium Yield (Excluding 11)	Low Yield (All Strategies)	Low Yield (Excluding 11)	High Yield (All Strategies)	High Yield (Excluding 11)	Medium Yield High Benomyl Price (All Strategies)	Medium Yield High Benomyl Price (Excluding 11)
) 0.0 to 0.1	Approximates Second Degree Stochastic Dominance: Includes risk neutral and maxi-min	7, 8, 11	5,7,8,9	11	5, 7, 8	2,5,7,8,9,11	2,5,7,8,9	2, 7, 8, 11	2, 5, 7, 8
) .0003 to 0.1	Ranges from maxi-min to moderately strong risk aversion	11	5, 7, 8	11	5, 7, 8	8, 11	2, 7, 9*	7, 8, 11	7, 8
) .0001 to .0003	Ranges from slight risk aversion to moderately strong aversion	11	5	11	5	7, 8, 11	7, 8	11	7,8
) -.0001 to .0001	Ranges from slightly risk loving to slightly risk averse; includes risk neutrality	5, 11	5	11	5	5, 7	2,7,8,10,11**	11	2, 5, 7, 8
) -.001 to .0008 at $0 -.001 to .0015 at $10,000 -.001 to .0004 at $25,000	Interval changes as income increases; ranges from moderately strong risk loving to various levels of moderately strong risk aversion; includes risk neutrality	2, 3, 5, 7, 8 9, 10, 11	2, 3, 5, 7, 8, 9, 10	11	5	2, 5, 7, 8 9, 10, 11	2, 5, 7, 8, 9, 10	2, 3, 4, 5, 7, 8, 9, 10, 11	2, 3, 4, 5, 7, 8, 9, 10

xcludes Strategy 8 as well as Strategy 11

Excludes Strategy 5 but includes Strategy 11

Table 12. Risk Analysis Results for Scab Control Strategies.

the class of Michigan farmers it can be seen that only for the low yield does the IPM strategy 5 dominate the conventional spray program. It is also interesting to note that with the high yield the conventional program is risk efficient for all intervals except for the fourth one. At this high yield level (900 bushels per acre) the conventional strategy may be preferred by individuals who are more than slightly risk averse (.0001). This is a lower degree of risk aversion than what was determined at the medium yield level. So as the yield increases, the minimum risk aversion level at which the conventional spray program may be preferred is decreasing.

Another interesting result is that in the eight scenarios examined in this analysis, in only one case is the efficiency set of the interval approximating Second Degree Stochastic Dominance equal to the efficiency set derived for the interval designed to represent the preferences of 80-90% of the Michigan farmers. In one case it is larger and in six cases it is smaller. It can be concluded that both Type I and Type II errors can be encountered by using Second Degree Stochastic Dominance as an efficiency criteria to measure agricultural decision makers' preferences.

In many cases the size of the efficiency sets identified for the fifth interval is quite large. This is because it is very difficult to discriminate amongst distributions when the class of decision makers is real large. With the stochastic dominance techiques discussed so far, for a distribution to be rejected from the efficiency set ,it is necessary to have a consensus on an alternative distribution which is preferred by every decision maker within the class. That is to say that every decision maker must concur that they prefer distribution A to distribution B for B to be dominated. With a heterogenous group of preferences this may be difficult to acheive. However, Convex Set Stochastic Dominance (Meyer) provides a mechanism whereby distributions can be removed from the efficiency set if everyone prefers an alternative distribution but no concensus is required as to which alternative is preferred. It can also examine the possibility that some combination of two or more strategies may be more efficient than following any one strategy independently.

Convex Set Stochastic Dominance can be applied to efficeincy sets identified for First Degree Stochastic Doimance, Second Degree Stochastic Dominance or Stochastic Dominance With Respect to a Function. Dominance is obtained with Second Degree Convex Set Stochastic Dominance when there exists a $\lambda \varepsilon \Lambda \eta$ such that $\int_0^y \lambda_i F_i(x)dx < \int_0^y G(x)dx \qquad y \varepsilon [0,1]$.

In the case of the scenario employing the medium yield, the original efficiency set for the fifth interval is reduced to three members by exercising the Convex Set Stochastic Dominance tool. The three strategies are: 5,7 and 8. This is interesting since it includes one representative from the IPM programs, one from the conventional spray programs, and one from the Single Application Treatment (SAT) family of controls. All three programs are currently being used by some growers in the state.

Conclusions

There is evidence to support the contention that in the case of apple scab control in Michigan orchards the conventional spray programs are generally consistent with the preferences of many growers and this risk efficiency may hinder the adoption of IPM programs. As yields increase the conventional programs become risk efficient for a larger class of decision makers. The use Second Degree Stochastic Dominance as an efficiency criteria for agricultural decision makers may lead to both serious Type I and Type II errors. Finally, the potential of Convex Set Stochastic Dominance to further reduce large efficiency sets without having to reduce the class of decision makers was demonstrated.

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