UNIVERSITY OF MINNESOTA
Extension
SERVICE

What is the Value of Bt Corn?

Yield Protection and Risk

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Overview

- Risky Production Decisions:
  - The Economist's Perspective
  - Two Approaches To Decision Making
- New Estimates of Bt Corn Yield Protection
- How Does Bt Corn Affect Profit and Risk?
- Evaluating The Value of Bt Corn

What is Risk?

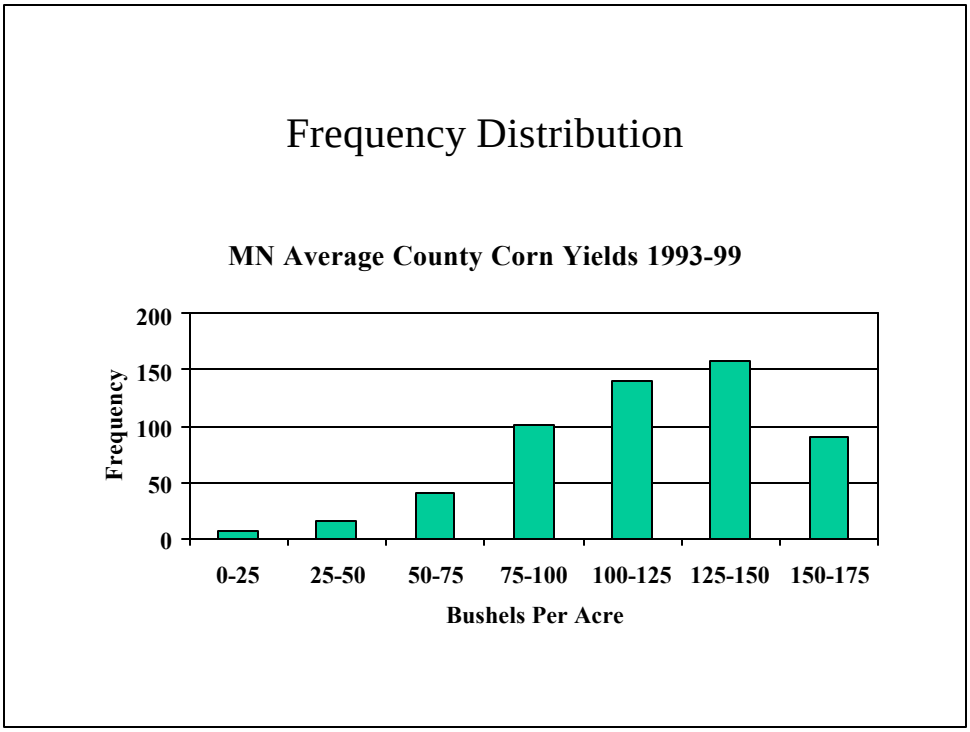
- Risk is Knowing What Can Happen, But Not What Will Happen
- Risk is Also Knowing What is More Likely to Happen and What is Less Likely to Happen

For Example

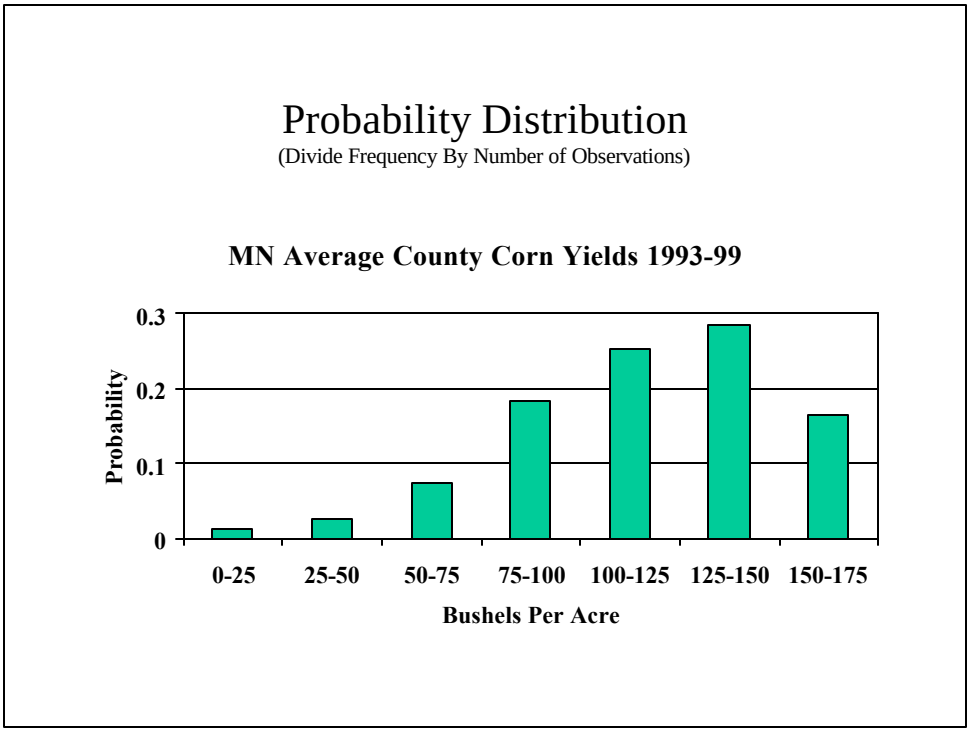
- What Can Happen
  - Net Return ($/Acre) From Planting Corn
- What Will Happen
  - Earn 30 ($/Acre) From Planting Corn
- What is More Likely
  - Earning 30 ($/Acre) is Twice as Likely as Earning 20 ($/Acre)

Probability

- Likelihood That What Can Happen Will Happen
- Must Lie Between 0 and 1:
  - 0 = Cannot Happen
  - 1 = Must Happen
- Sum of All Probabilities Equals One
- Probability Distribution
  - What Can Happen and Probability it Will
  - Normalized Frequency Distribution



This figure shows the frequency distribution for average county yields in Minnesota between 1993 and 1999. Each bar in the figure shows the number of counties during this seven year period that had average yields in the range indicated. Adding all the bars together tells us the total number of observations included in the sample, which is 530. We can use this information to figure out the likelihood or probability that the average yield falls in each range by dividing the height of each bar by 530.



The figure above shows the probability that average county yields were in each of the indicated ranges.

Useful Statistics

- Mean
  - Average of What Can Happen
  - Average Net Return, Average Yield, Average Cost, etc.
- Variance/Standard Deviation (SD)/Coefficient of Variation (CV)
  - Variability Around Mean
  - SD = Square Root of Variance
  - CV = SD/Mean
- Correlation Coefficient:
  - Relationship Between Different Sources Of Risk
  - Positive: Two Risks Often Occur At Same Time
  - Negative: Two Risks Often Occur At Different Times

How Economists Think About Risk?

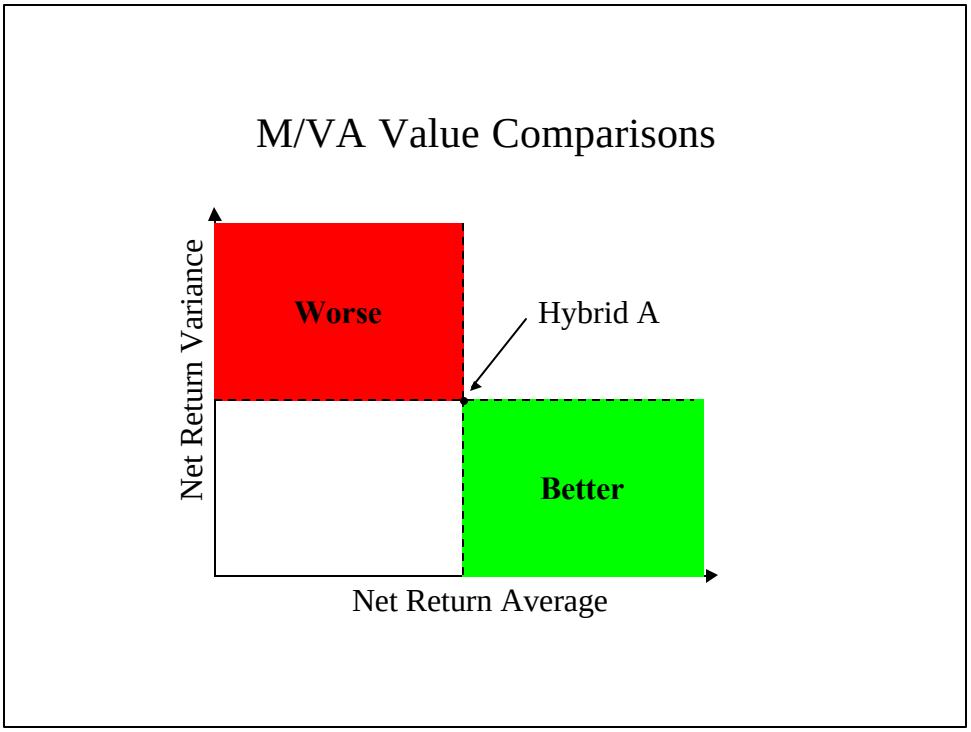
Value = Average Profit – Risk Premium

Calculating Average Profit Is Easy
Calculating Risk Premium Is Not
- Depends On Distribution of Profit
  (Mean, Variance, and More)
- Depends On Attitudes Toward Risk
  (How Someone Feels About Taking Chances)

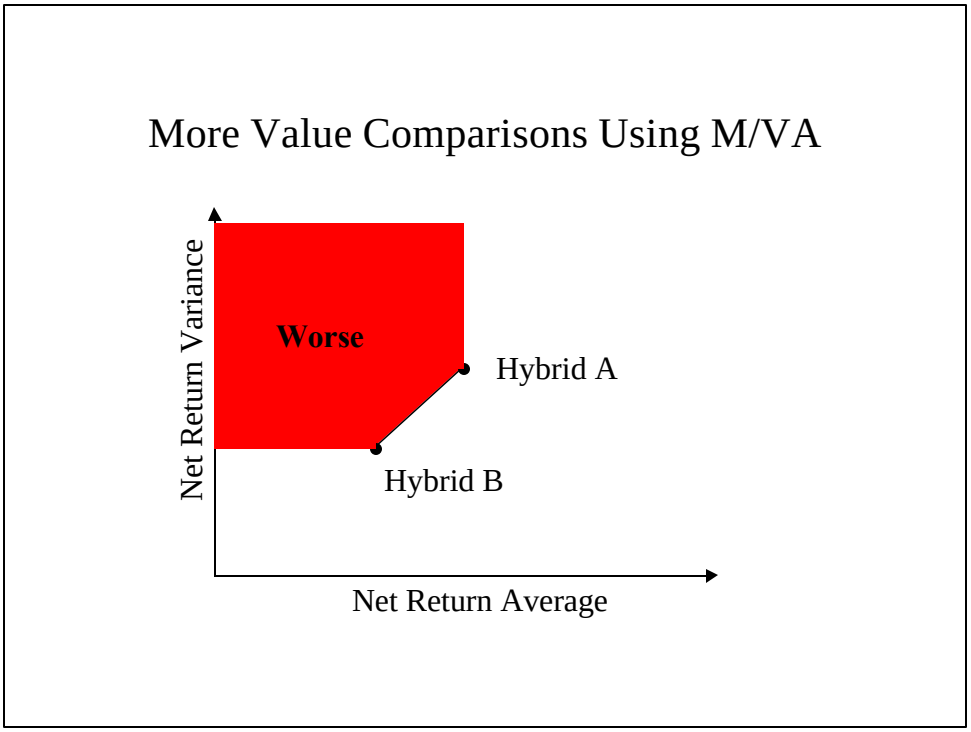
If we know for certain we will earn $30/acre for planting corn, the value of planting corn is $30/acre. However, if 50% of the time we earn $60/acre and 50% we earn $0/acre, the value of planting corn will be less than the average $30/acre. The risk premium tells us how much less. The size of the risk premium will depend on how comfortable we are with not knowing what is going to happen, our risk attitudes, and the probability distribution. The more uncomfortable we are with not knowing what will happen the higher our risk premium will be. The greater the probability of earning lower profits the higher our risk premium will be.

Mean/Variance Approach (M/VA)

- The Method
  - Calculate Mean and Variance/SD/CV (Variability)
  - Better: Higher Average and Lower Variability
  - Worse: Lower Average and Higher Variability
- Benefits
  - Easy To Use
  - Valid For Many Probability Distributions and Risk Attitudes
- Limitations
  - Ignores Characteristics of Risk Other Than Mean and Variance
  - Only Approximation For Many Risk Attitudes

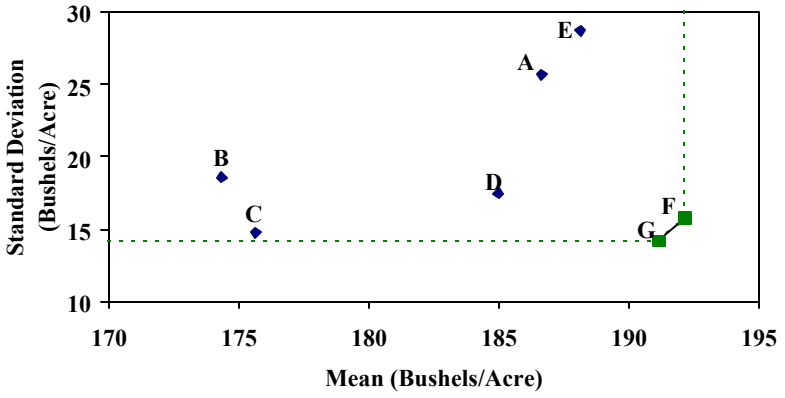


It is easy to compare and choose between lots of risky options using the mean/variance approach. For example, we can calculate and plot the expected net return and the variance of that net return for planting a particular hybrid (Hybrid A above). We can then do the same calculation for some other hybrid. If the point plotted for the second hybrid falls to the northwest of Hybrid A, Hybrid A has higher net return on average and the net return is less variable, so Hybrid A would be the best choice if we like higher and less variable profits. Alternatively, if the point plotted falls to the southeast of Hybrid A, Hybrid A has a lower net return on average and the net return is more variable, so Hybrid A would not be the best choice. If the point falls to the southwest of Hybrid A, Hybrid A has a lower net return and the net return is less variable on average. Now Hybrid A is not clearly better or worse. It is worse in the sense we will earn less on average. It is better in the sense that our earnings will be less variable. Which Hybrid we should choose then depends on whether a higher profit is more important to us than lower profit variability. If the point lies to the northeast of Hybrid A, Hybrid A has a higher net return, but that return is more variable. The choice of hybrid then again depends on whether we like more profit on average or lower profit variability.



In the figure above, Hybrid A has a higher net return on average, but also a more variable net return when compared to Hybrid B. Which hybrid is a better choice depends on whether we care more about average net returns or the variability of net returns. However, we can say that any other hybrid with an average net return and net return variance in the shaded region is not as good a choice as Hybrid A, Hybrid B, or some combination of the two, if we like higher average and less variable net returns. The dark boundary of this shaded region to the southeast is often referred to as the risk-efficiency frontier. It tells you which hybrid or combination of hybrids you should plant assuming you like higher average and less variable net returns.

Example Hybrid Yield Comparisons For Corn

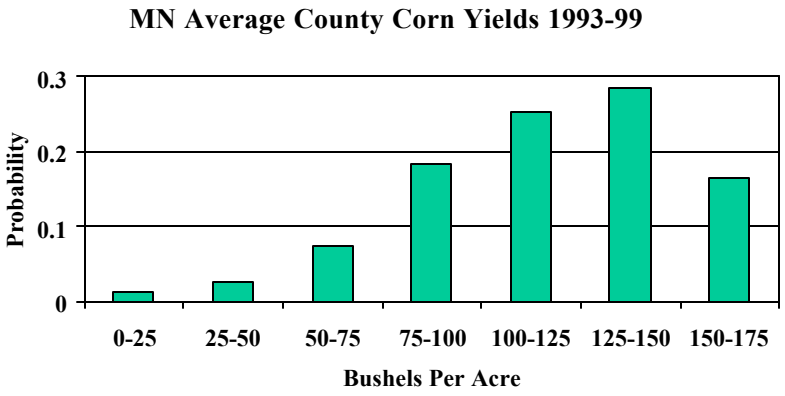


The figure above shows the mean and standard deviation of yields for seven different hybrids taken from recent variety trials publications. For this example, if we want a hybrid with a higher average yield and less yield variability, we need to plant Hybrid G, Hybrid F, or some combination of the two.

Distribution Approach (DA)

- Method
  - Compare Probability Distributions
  - Better: Probability Lower Net Return/Yield Never Greater
  - Better: Sum Of Probability Lower Net Return/Yield Never Greater
- Benefits
  - Valid For Any Distribution If You Do Not Like To Take Chances
- Limitations
  - Harder to Use
  - Requires More Specific Information
  - Less Likely To Provide A Definitive Answer

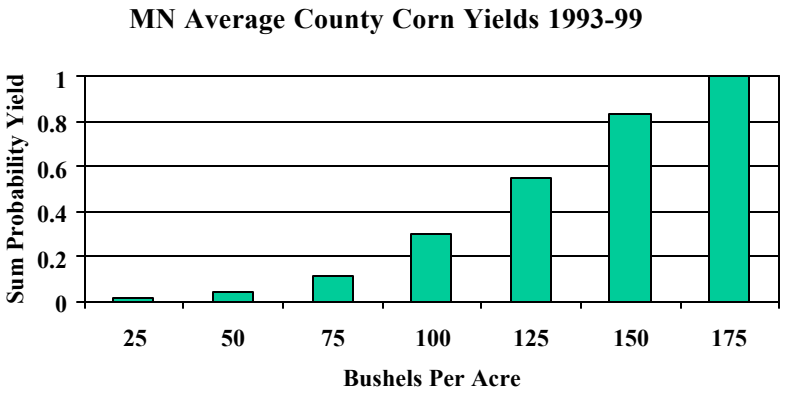
Probability Distribution



To calculate the probability of lower yields, we need to add to each bar all bars to the left.

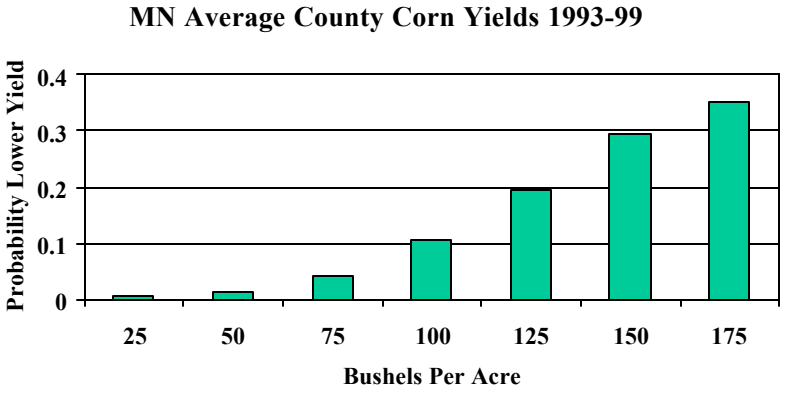
Sum Probability Yield

(Cumulative Probability Of Yield)

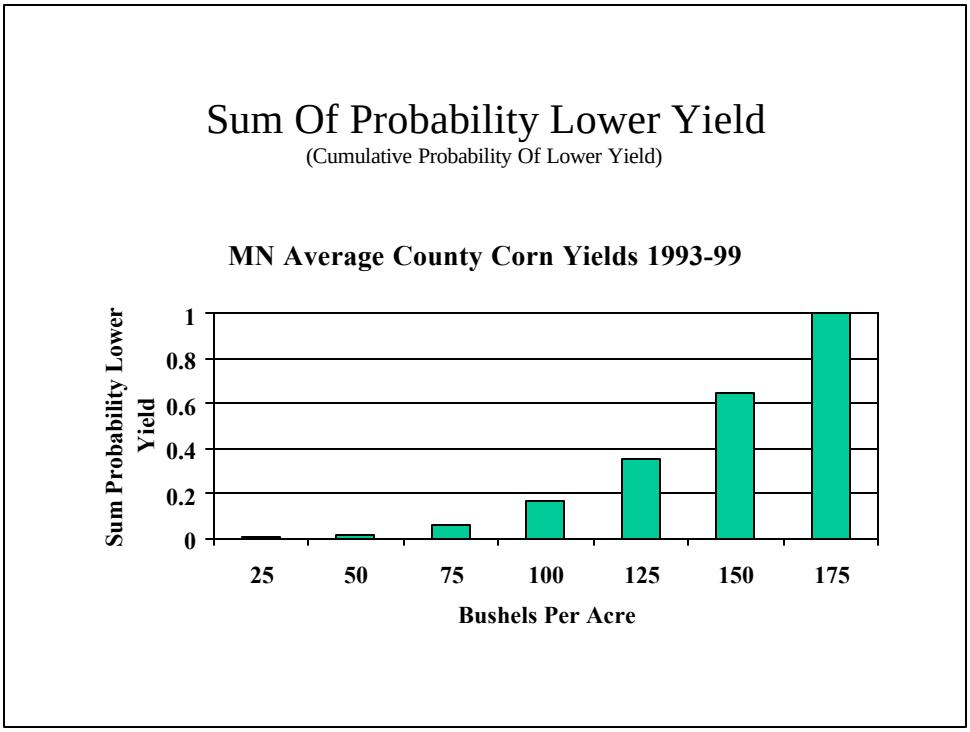


For example, the probability average yield is less than 50 is equal to the probability average yield is between 0-25 and 25-50. This gives us what is called a cumulative probability distribution. If we sum up these probabilities, the value will exceed 1.0 so it is not a probability distribution. To calculate the probability that average yield is less than the value indicated, we need to sum up all the bars and then divide each bar by this sum.

Probability Lower Yield

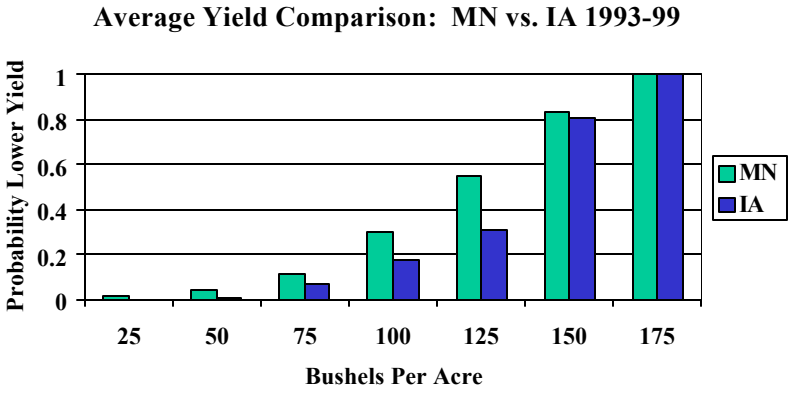


This figure shows us the probability that yields are less than the value indicated or the probability distribution for lower average yields.



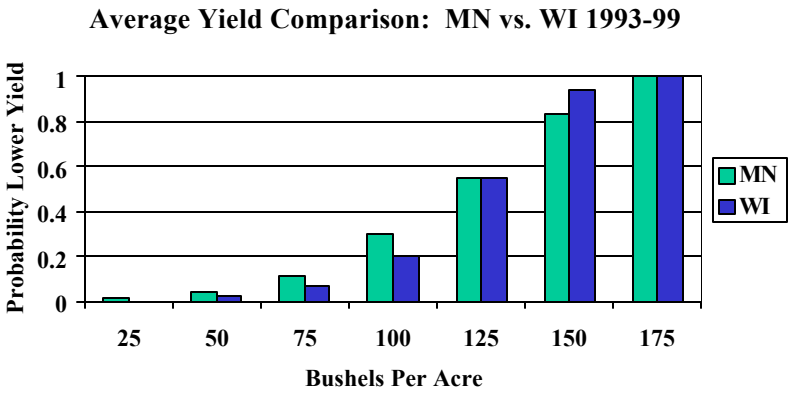
Summing up all bars to the left gives us the cumulative probability of lower yields.

Example: Probability Lower Yield Never Greater For IA



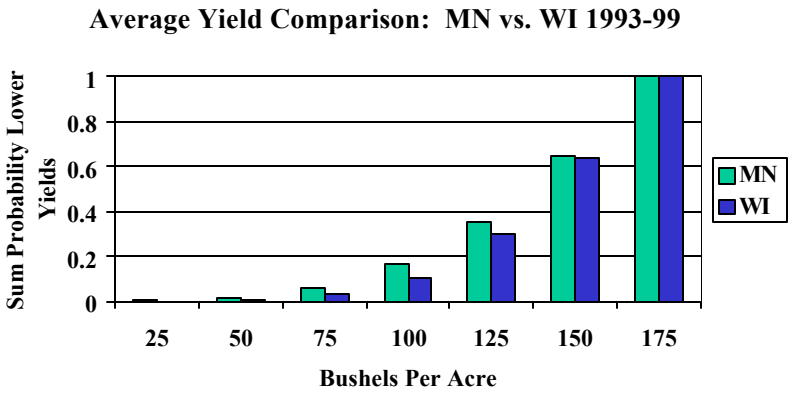
The Distribution Approach uses the probability of lower yields and the cumulative or sum of probability of lower yields to determine what is better. If the probability of lower yields is never higher for one hybrid compared to another and we like higher yields, we should choose that hybrid. In the figure above, the probability of lower average yield in Iowa is never higher than the probability of lower average yield in Minnesota. Therefore, Iowa average yields are better, if we like higher average yields.

Example: Probability Lower Yield Sometimes Greater For WI



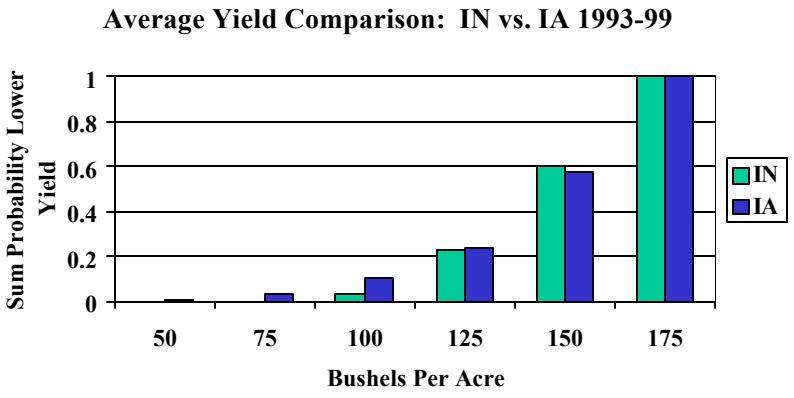
Above, the probability of lower average yield is sometimes higher in Minnesota (e.g. 100 bushels/acre) and sometimes higher in Wisconsin (e.g. 150 bushels/acre). So we need to look further to see if yields are better in Minnesota or Wisconsin.

Example: Sum Of Probability Lower Yield Never Greater For WI



If the cumulative or sum of probability of lower yields is never higher for one hybrid compared to another, and we like higher yields and less yield variability, we should choose that hybrid. In the figure above, the cumulative or sum of the probability of lower average yield in Wisconsin is never higher than the cumulative or sum of the probability of lower average yield in Minnesota. Therefore, Wisconsin average yield is better, if we like higher average yields and less yield variability.

Example: Sum Of Probability Lower Yield Sometimes Greater For IN



Comparing the cumulative or sum of probability of lower yields in Indiana and Iowa above, we see that sometimes it is higher for Indiana (e.g. 150 bushels/acre) and sometimes higher for Iowa (e.g. 100 bushels/acre). If this is the case, the DA approach cannot tell you which is better.

Important Notes

- Sometimes M/VA Provides Answer When DA Doesn't
- Sometimes DA Provides Answer When M/VA Doesn't
- One Method Never Says Something Is Better, When The Other Method Says It Is Worse
- DA Best Place To Start Because More General
- Can Use M/VA When DA Is Inconclusive or Not Enough Information To Construct A Probability Distribution

Bt Versus Conventional Corn Hybrid

- New Estimates Of Bt Yield Protection
- DA versus M/VA
- M/VA Using Minnesota Averages
- Conclusions

European Corn Borer (ECB) Yield Loss

- Method
  - Estimate Annual Distribution of ECB
    - Late Season Larvae Counts (ECB/Plant)
  - Estimate Distribution of Tunneling Given ECB Larvae
  - Estimate Percentage Yield Loss Given Tunneling
- End Result
  - Distribution of Percentage Yield Loss
    - Mean Larvae Counts (ECB/Plant)
    - Coefficient of Variation for Larvae Counts (ECB/Plant)

There have been a number of estimates of the profitability of Bt corn published. Many of these estimates suggest Bt corn is not profitable. An important weakness in many of these estimates is that they look at only one year of data. This is a problem because ECB populations are quite variable. In 1997, ECB populations in Minnesota and across the Midwest were about average and estimates of the profitability of Bt corn for this year are generally favorable. In 1998-2001, ECB populations were typically much less than average and estimates of the profitability of Bt corn are generally unfavorable. Bt corn is profitable when there are lots of ECB, but not when there are no ECB. Since we do not know whether there will be lots or only a few ECB in any given year, we must look at how Bt corn performs on average, not just for a single year.

Data

- Annual Distribution of ECB
  - Illinois (1943-1984, 1987-1996)
  - Minnesota (1963-1998)
  - Wisconsin (1963-1998)
- Larvae and Tunneling Data
  - 1997 Bt Field Trials
  - 9 States (IA, IL, MD, MN, MO, NE, OH, SD, and WI)
- Tunneling To Yield Loss
  - 1997-1999 Bt Isoline Field Comparisons
  - 22 Iowa Counties

A weakness in the Larvae and Tunneling data is that it comes from only one year.

A weakness in the Tunneling and Yield Loss data is that it comes only from Iowa counties.

Table 1: Average Percentage Yield Loss

	Mean (Larvae/Plant)															
C.V.	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0.5	5.0	5.3	5.5	5.7	5.9	6.1	6.2	6.4	6.5	6.6	6.7	6.9	7.0	7.1	7.2	7.3
0.6	5.0	5.2	5.5	5.7	5.8	6.0	6.2	6.3	6.4	6.6	6.7	6.8	6.9	7.0	7.1	7.2
0.7	4.9	5.2	5.4	5.6	5.8	6.0	6.1	6.2	6.4	6.5	6.6	6.7	6.8	7.0	7.0	7.1
0.8	4.9	5.1	5.4	5.6	5.7	5.9	6.0	6.2	6.3	6.4	6.6	6.7	6.8	6.9	7.0	7.1
0.9	4.8	5.1	5.3	5.5	5.7	5.8	6.0	6.1	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0
1.0	4.8	5.0	5.3	5.4	5.6	5.8	5.9	6.1	6.2	6.3	6.4	6.5	6.7	6.8	6.8	6.9
1.1	4.7	5.0	5.2	5.4	5.6	5.7	5.9	6.0	6.1	6.3	6.4	6.5	6.6	6.7	6.8	6.9
1.2	4.7	4.9	5.1	5.3	5.5	5.7	5.8	5.9	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8

Table 2: Standard Deviation of Percentage Yield Loss

	Mean (Larvae/Plant)															
C.V.	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0.5	5.1	5.3	5.5	5.7	5.8	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0
0.6	5.1	5.3	5.5	5.7	5.8	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0
0.7	5.1	5.3	5.5	5.7	5.8	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0
0.8	5.1	5.3	5.5	5.7	5.8	5.9	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	6.9
0.9	5.1	5.3	5.5	5.6	5.8	5.9	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	6.9
1.0	5.1	5.3	5.5	5.6	5.8	5.9	6.0	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.8	6.9
1.1	5.1	5.3	5.5	5.6	5.8	5.9	6.0	6.1	6.3	6.4	6.5	6.6	6.6	6.7	6.8	6.9
1.2	5.1	5.3	5.4	5.6	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9

The tables above are look up tables for the average yield loss and the standard deviation of that loss based on the mean (average) and coefficient of variation of the number of larvae per plant in a fall survey of ECB populations. The data necessary to calculate these values is collected annually by the Minnesota Department of Agriculture. More information about these surveys can be found at http://www.mda.state.mn.us/pestsurvey/. These value can be used to estimate the effect of planting Bt corn on average net returns and the variability of net returns.

Table 3: Lower 95% Confidence Interval for Percentage Yield Loss

Mean (Larvae/Plant)

C.V.	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0.5	0.13	0.14	0.14	0.15	0.16	0.16	0.17	0.17	0.18	0.18	0.18	0.19	0.19	0.19	0.20	0.20
0.6	0.13	0.13	0.14	0.15	0.15	0.16	0.16	0.17	0.17	0.18	0.18	0.18	0.19	0.19	0.19	0.20
0.7	0.12	0.13	0.14	0.15	0.15	0.16	0.16	0.17	0.17	0.17	0.18	0.18	0.18	0.19	0.19	0.19
0.8	0.12	0.13	0.14	0.14	0.15	0.15	0.16	0.16	0.17	0.17	0.17	0.18	0.18	0.18	0.19	0.19
0.9	0.12	0.12	0.13	0.14	0.14	0.15	0.15	0.16	0.16	0.17	0.17	0.17	0.18	0.18	0.18	0.19
1.0	0.11	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.16	0.16	0.16	0.17	0.17	0.18	0.18	0.18
1.1	0.11	0.12	0.12	0.13	0.13	0.14	0.15	0.15	0.15	0.16	0.16	0.17	0.17	0.17	0.17	0.18
1.2	0.11	0.11	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.15	0.16	0.16	0.16	0.17	0.17	0.17

Table 4: Upper 95% Confidence Interval for Percentage Yield Loss

Mean (Larvae/Plant)

C.V.	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0.5	19.2	20.0	20.7	21.3	21.8	22.3	22.8	23.3	23.6	24.0	24.4	24.8	25.2	25.5	25.8	26.1
0.6	19.1	20.0	20.6	21.2	21.8	22.3	22.8	23.2	23.6	24.0	24.4	24.8	25.1	25.4	25.7	26.0
0.7	19.1	19.9	20.5	21.2	21.7	22.2	22.7	23.2	23.6	24.0	24.3	24.7	25.0	25.3	25.6	25.9
0.8	19.0	19.8	20.5	21.1	21.7	22.2	22.6	23.1	23.5	23.9	24.2	24.6	24.9	25.3	25.6	25.9
0.9	19.0	19.8	20.5	21.1	21.6	22.1	22.6	23.0	23.4	23.8	24.1	24.5	24.8	25.2	25.5	25.8
1.0	18.9	19.7	20.3	21.0	21.5	22.0	22.5	22.9	23.3	23.6	24.0	24.4	24.8	25.1	25.4	25.7
1.1	18.9	19.6	20.2	20.8	21.4	21.9	22.3	22.8	23.2	23.6	24.0	24.3	24.7	25.0	25.3	25.6
1.2	18.8	19.5	20.2	20.8	21.3	21.8	22.2	22.7	23.1	23.5	23.9	24.2	24.6	24.9	25.2	25.5

The tables above are look up tables for the upper and lower 95% confidence intervals for ECB losses based on the mean (average) and coefficient of variation in the number of larvae per plant in a fall survey of ECB populations.

How Does Bt Corn Affect Profit and Risk?

- Bt Corn Virtually Eliminates ECB Damage To Corn
- Bt Corn Costs More To Plant
- Bt Corn Does Not Completely Eliminate Risk
  - You Don't Have To Worry About ECB
  - You Do Have to Worry About Weather, Weeds, Other Insects, etc.

The Distribution Approach

- If Bt and Conventional Hybrid Have Same Yield Potential, The Probability of Lower Yield Is Always Greater With Conventional Hybrid
- Cannot Tell Which Hybrid Has A Better Net Return Distribution When Bt Corn Costs Extra To Plant
  - You Pay For Protection When No Corn To Protect
  - You Pay For Protection When Nothing To Protect Corn From

The Mean/Variance Approach

- Bt Corn Increases Average Profit When Average Value Of ECB Loss Is Greater Than Added Cost
- Bt Corn Can Increase Or Decrease Yield and Profit Variance
  - ECB Damage Higher When Yield Is Higher and Lower When Yield Is Lower (Positive Correlation), Variance Can Increase
  - ECB Damage Higher When Yield Is Lower and Lower When Yield Is Higher (Negative or No Correlation), Variance Decreases

Evaluating The Value of Bt Corn Yield Protection And Risk

- How Much Yield Protection Does Bt Corn Offer?
- How Much Extra Does Bt Corn Cost?
- How Much Yield Variability Is Due To ECB?
- How Much Yield Variability Is Not Due To ECB?
- How Is Yield Variability Due To ECB Related To Yield Variability Due to Other Factors?

To use the mean/variance approach to evaluate Bt corn, you must answer the questions above.

Bt Corn Will Have Higher Average Net Return If

Added Cost of Bt Corn ($/Acre) < Average Price ($/Bushel) × Average Yield Loss (Bushel/Acre)

Average Yield Loss (Bushel/Acre) = Average Potential Yield (Bushel/Acre) × Average Percentage Yield Loss/100

Note: Average Potential Yield (Bushel/Acre) = Average Yield Without ECB

Average potential yield is how much corn can be produced if there are no ECB to contend with.

An Example Using Minnesota State Averages

- State Average Yield (1997-2000) = 145 (Bushel/Acre)
- Estimated Percentage Yield Loss From Table 1 = 5.7
  - Average Larvae (1963-1998) = 0.9
  - C.V. Of Larvae (1963-1998) = 0.8
- Estimated Value of Yield Loss For 2.00 ($/Bushel) Corn
  = $2.00 \times 145 \times 5.7 / 100$
  = 16.53 ($/Acre)
- 16.53 ($/Acre) Is Larger Than Any Technology Fee I Have Seen Reported, So On Average Bt Corn Has Higher Net Return

Bt Corn Will Decrease Net Return Variance If

$$2 \times \text{Correlation Coefficient For Yield Potential And Yield Loss} < \frac{\text{Standard Deviation Of Yield Loss}}{\text{Standard Deviation Of Yield Potential}}$$

$$\text{Correlation Coefficient For Yield Potential And Yield Loss} = \frac{\text{Standard Deviation Of Yield Potential} \times \text{Average Percentage Yield Loss}/100}{\text{Standard Deviation Of Yield Loss}}$$

$$\text{Standard Deviation Of Yield Loss} = \sqrt{\left[\text{Standard Deviation Of Potential yield}^{2} \times \text{Standard Deviation Of Percentage Yield Loss/100}^{2}\right] + \left[\text{Average Of Potential yield}^{2} \times \text{Standard Deviation Of Percentage Yield Loss/100}^{2}\right] + \left[\text{Standard Deviation Of Potential yield}^{2} \times \text{Average Of Percentage Yield Loss/100}^{2}\right]}$$

Continuing With Minnesota Example

- Coefficient of Variation For Midwest Farm Level Yields = 0.2 To 0.4.
  - Using CV = 0.3 and Average Yield = 145, Standard Deviation Of Potential Yield = CV × Average Yield = 0.3 × 145 = 43.5
- Estimated Standard Deviation Of The Percentage Yield Loss From Table 1 = 5.8

$$\text{Standard Deviation Of Yield Loss} = \sqrt{43.5^2 \times (5.8/100)^2 + 145^2 \times (5.8/100)^2 + 43.5^2 \times (5.7/100)^2}$$

$$= 9.1$$

$$\text{Correlation Coefficient For Yield Potential And Yield Loss} = \frac{43.5 \times 5.7/100}{9.1} = 0.27$$

$$\frac{\text{Standard Deviation Of Yield Loss}}{\text{Standard Deviation Of Yield Potential}} = 9.1/43.5 = 0.21$$

Conclusions For Minnesota Example

- Bt Corn Increases Average Net Return
- Bt Corn Increases Net Return Variance ($2 \times 0.27 > 0.21$)
- Bt Corn Is Not Insurance
  - Characteristics of Insurance
    - Lower Average Net Return
    - Lower Net Return Variability
  - Characteristics of Bt Corn
    - Higher Average Net Return
    - Higher Net Return Variability
- Cautionary Note
  - This Is Just An Example
  - Each Farm Should Be Evaluated Individually

Other Things Considered

- Benefits
  - Reduced Insecticide Use
  - Areawide Suppression
  - Improved Grain Quality
  - Reduced Lodging
  - Less Volunteer Corn
  - Etc.
- Limitations
  - Market Restrictions
  - Segregation
  - ECB Resistance
  - Etc.

Of course, there are always lots of other less tangible factors to consider. In particular, since Bt corn reduces the number of ECB around to produce new ECB, planting Bt corn may reduce the likelihood of future ECB infestations. If this is the case, using historical averages to estimate the mean and coefficient of variation for Tables 1 and 2 will tend to overestimate of the value of Bt corn.

Some Final Remarks

- Many Minnesota Farmers Will Find Bt Corn More Profitable on Average
- Many Minnesota Farmers Will Find That Bt Corn Is Not Good Insurance
- Bt Corn Should Be Evaluated And Reevaluated For Individual Farms
- EPA Mandated Requirements For Bt Corn In Minnesota
  - 20% Structured Refuge Planted Within ½ Mile of Bt Corn
  - Separate Field, Within Field Block, or Strips (Two or More)
  - Non-Bt Insecticides Using Economic Thresholds

Many entomologists and economists say Bt corn offers an insurance benefit. We find this is not typically the case. Insurance is designed to reduce income variability. To get this reduction in income variability, you must accept less income on average by paying the insurance premium. We find that Bt corn does just the opposite. It increases income variability, but also increases average income. Therefore, if you do not think the average value of increased yields from planting Bt corn exceeds the added cost of the technology fee, you are better off not planting it.

Continued Work

- Improve Yield Loss Estimates With More Data
- Explore Using Percentage Of Plants Infested
- Improving The M/VA Method
  - What Are The Best Measures Of Variability And Risk?

Thank You!

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