THESIS

TWO ESSAYS ON COLORADO STATE UNIVERSITY'S WHEAT BREEDING AND GENETICS PROGRAM

Submitted by

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ABSTRACT

TWO ESSAYS ON

COLORADO STATE UNIVERSITY'S

WHEAT BREEDING AND GENETICS PROGRAM

Colorado State University's Wheat Breeding and Genetics Program is nearing its' 50th anniversary and has had a large role in providing a vehicle of research for increasing wheat yields in Colorado. During this research process, a database has been compiled of the results of wheat variety experiments held on test plots statewide. The intent of this thesis is to demonstrate additional uses of the data collected by CSU's Wheat Breeding and Genetics Program and the Crop Variety Testing Program.

The first essay is an evaluation of the economic impacts that the breeding program has had on wheat yields attributable to the genetic improvement of wheat varieties. Regression analysis is used to estimate and track the genetic improvement that occurs with each newly released wheat variety. The analysis is followed by a monetization of the estimated benefits produced by the program as a result of the increase in wheat yields. Costs of running the program are also discussed.

Borrowing from finance literature, the second essay utilizes the Colorado Wheat Variety Database to generate a portfolio of wheat varieties that would result in minimizing variation while maximizing wheat yields to help producers lower their overall risk levels. Portfolio theory is widely used to select investments in the financial world. The intended application of this study is to aid wheat producers in their selection of wheat varieties.

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Essay 1 - An Evaluation of Colorado State University's Wheat Breeding Program: Economic Impacts on Wheat Yields

1.1 Introduction

Colorado State University's (CSU) Wheat Breeding and Genetics Program will celebrate its' 50th anniversary next year. Having released more than 30 different varieties since its' 1963 inception, the program has played an integral part in developing and releasing varieties of wheat appropriate for the growing conditions of Colorado. The role of the CSU program has become even more evident in recent times. According to the Colorado Agricultural Experiment Station (2003), "University-bred wheat cultivars now account for roughly 60 percent of Colorado's 2.6 million acres of wheat" (Pg. 1) (Figure 1.1).

Figure 1.1 Percentage of CSU Released Varieties Planted on Colorado Farms, 1974-2011

Colorado has a long history of wheat production and historical data show that wheat yields have steadily increased over the past 143 years, especially from 1963 to present, where the CSU program has been active (Figure 1.2).

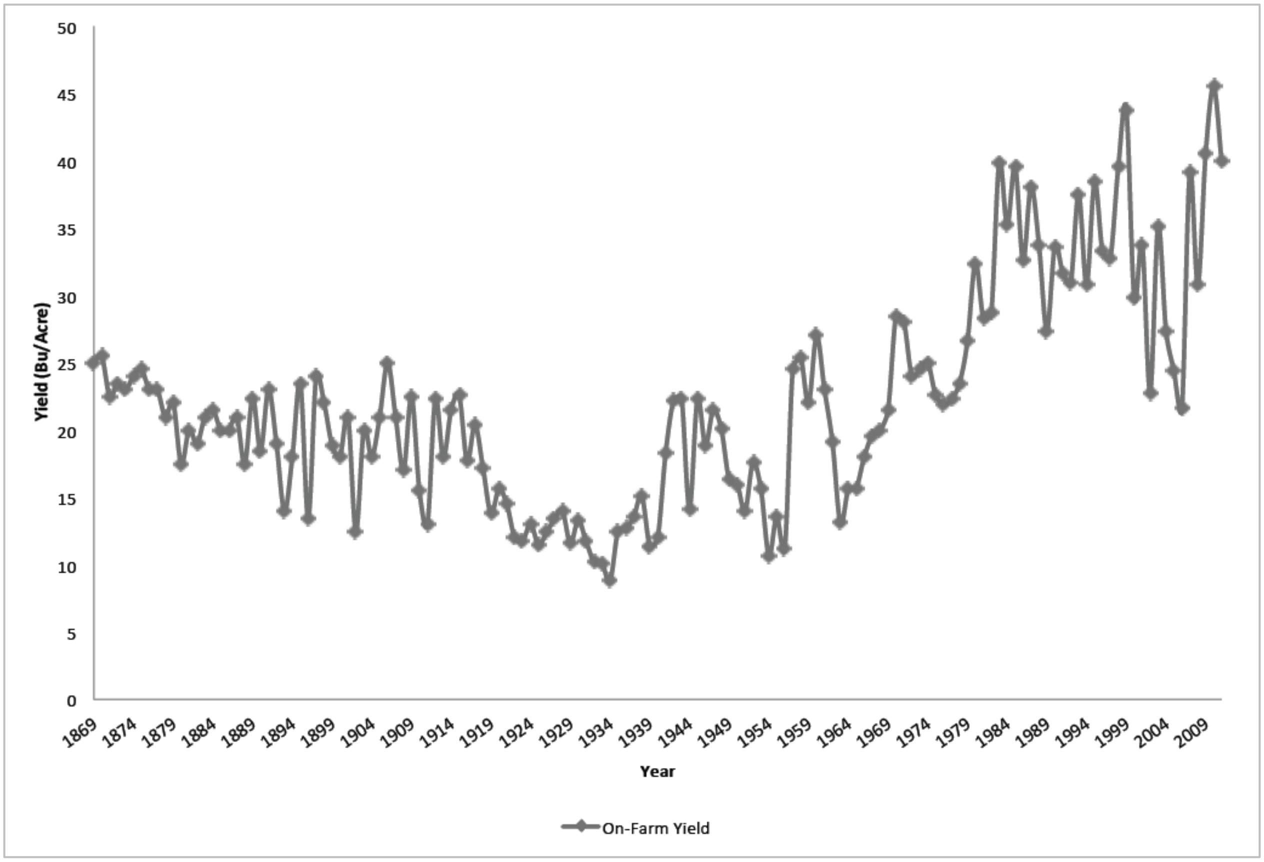

Figure 1.2 Colorado Historical Wheat Yields, 1869-2011

The intent of this paper is to analyze the economic impacts that the CSU Wheat Breeding and Genetics Program has had on Colorado wheat yields by estimating the yield improvement attributable to the program. Estimating the impact of the wheat breeding and genetics program can create a new source of information for scientists, administrators, policy makers, and future funding decisions. It also demonstrates additional ways of analyzing the data already collected by the CSU program.

This analysis is assuming that the increase in yield experienced over time on the experimental plots will result in yield increases for wheat producers. Figure 1.3 gives a visualization of the gap that exists between the average annual yields of the variety trial locations and of the on-farm production of wheat. Brennan (1984) argues that the trial data from these experiment stations are one of the only reliable sources for relative yields. An interesting observation in Figure 1.3 is that the trends of both the CSU variety trial location yield and the on-farm yield appear nearly parallel but with some widening as time goes on. This lends support to Brennan's theory that despite the gap, the yields have increased and decreased uniformly over time. Because of the variety trial locations and the on-farm yield data track each other, data from the Colorado Wheat Variety Database will be used as a proxy for estimating the overall impact on Colorado wheat yields attributable to the program.

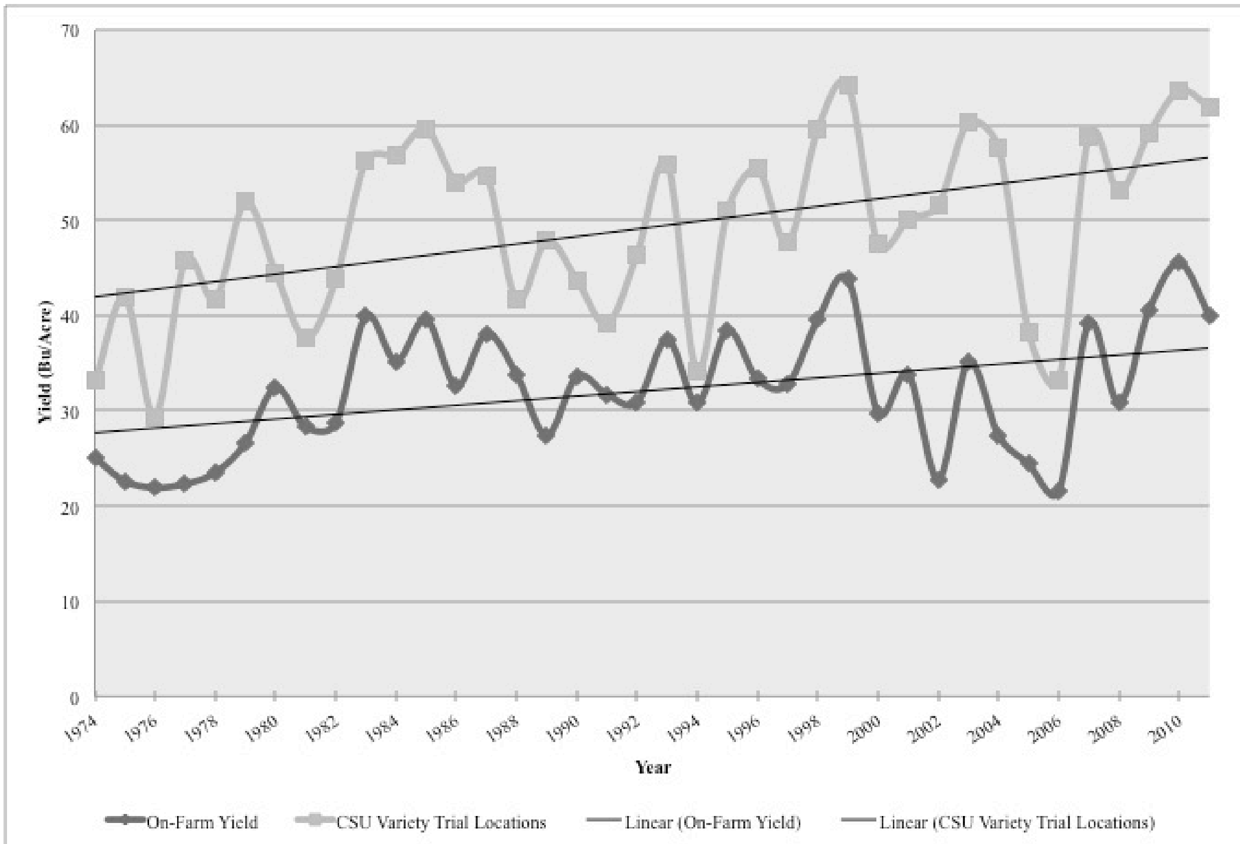

Figure 1.3 Average Wheat Yields for CSU Variety Trial Locations and Colorado On-Farm with Trends, 1974-2011

1.2 Literature Review

The conceptual model developed for this analysis is based on the methodology of several previous works. Beginning with the foundation of the analysis, Alston, Norton and Pardey (1995) provide a wealth of in-depth procedures for various approaches to estimating the gains resulting from research depending on the data available and research goals. Specifically, Alston et al. discuss conceptual models used to estimate production, productivity and technical change. Combined with the work from Huffman and Evenson (2006), they provide well-grounded material for the analysis of the economic impacts of agricultural research. Additional reviewed literature demonstrates the different applied techniques that can be used to estimate the impacts of breeding programs. Feyerherm, Paulsen and Sebaugh (1984) estimate the increases in wheat yields attributable to genetic gains by calculating differential yield ability values for popular wheat varieties used throughout several regions of the United States. These calculations are based on “check” or control varieties. The authors found that some regions of the U.S. have experienced a greater increase in yields due to genetic improvements. This is largely due to environmental differences between the regions as some regions have harsher growing conditions.

Nalley, Barkley and Chumley (2008) apply multiple regressions to estimate wheat yield increases attributable to the genetic improvements from the efforts of the Kansas Agricultural Experiment Station (KAES) wheat breeding program through regression analysis. Nalley, Barkley and Chumley estimate the gain in wheat yields as a result of the genetic improvement in wheat varieties. They find that the average annual benefit to wheat producers is nearly $79 million (2006 dollars) during the 1977-2006 period of their analysis. Nalley, Barkley and Chumley also estimated a cumulative genetic gain of 0.206 bushels per acre per year. Using the same methods, Nalley, Barkley, and Crespi (2008) analyze the increase in wheat yields and improvement in wheat quality resulting from the efforts of CIMMYT (International Maize and Wheat Improvement Center) wheat breeding program and found that the benefits gained from increasing wheat yields outweighed the costs of the program nearly 15 to 1. Nalley, Moldenhauer, and Lyman (2011) use similar methods evaluate the rice breeding program at the University of Arkansas. They found that the average annual economic benefit resulting from the increase in rice yields was $34.3 million (2007 dollars). The current study will use similar methods, including regression analysis, outlined in Nalley, Barkley and Chumley (2008) to evaluate the economic impacts resulting from the efforts of CSU’s Wheat Breeding and Genetics Program.

1.3 Methodology

The empirical model follows closely the framework used by Nalley, Barkley and Chumley (2008), Nalley, Barkley and Crespi (2008), and Nalley, Moldenhauer and Lyman (2011). To begin the analysis, an empirical model is developed allowing for the estimation of several variables as outlined in Equation 1:

$$(1) \qquad Yield_{ijt} = ß_0 + ß_1 White + ß_2 Private + ß_3 CSURL + ß_4 RLYR + \delta_t + \theta_j + \varepsilon_{ijt}$$

$Yield_{ijt}$ is the yield in bushels per acre for variety *i*, at station *j*, in time period *t*. *White* is a binary variable distinguishing between white wheat varieties and red wheat varieties (White = 1; Otherwise = 0) for variety *i*. *Private* is a binary variable indicating whether or not a given variety was released by a private or public institution (Private = 1; Public = 0). *CSURL* identifies those varieties that are developed by CSU's wheat breeding program (CSU Release = 1; Otherwise = 0). The *RLYR* variable is the year that variety *i* is released. The term δ_t is a vector of binary variables (0 or 1) for each year *t*, from 1974 - 2011. The base year for the regression analysis is 2011 and will be omitted. The term θ_j is another vector of binary variables (0 or 1) for each of the 51 variety trial locations. Location 1 (Akron) is omitted making it the base location. This model allows for the estimation of how much of an increase in wheat yields is attributable to the CSU released wheat varieties and compare that with other variety sources.

1.4 Data

Data used in this analysis are obtained from the Colorado Wheat Variety Database and consists of annual yield data from 1974 - 2011 of multiple varieties gathered from 51 variety trial locations across the state (both irrigated and non-irrigated).[1] Two hundred and twenty-five

[1] Some stations were converted from dryland to irrigated or vice versa at some point in time and were counted as different stations.

different varieties were identified by their source and release year to the public and had been grown on the experimental plots giving a total of 11,077-pooled observations. Due to the nature of the data, where the years vary between variety trial locations, the analysis is dealing with an unbalanced panel. The year variable constitutes the time series component of the panel data and the *Yield* variable constitutes the panel ID variable. The *White* variable is included as Nalley, Barkley and Chumley (2008) suggest that white wheat varieties are increasing in popularity mainly because of the end use advantages they may have over red wheat in baking, making noodles, etc. Two other dummy variables are created to estimate the differences between varieties released by private and public institutions and also the difference between CSU variety releases and all other varieties. The release year variable measures the progression made by wheat breeding programs and is used to estimate the impact of the wheat-breeding program on wheat yields. The year variable will allow for the changes in weather and technology to be held constant. The station variable is the cross-sectional portion of the panel data and allows growing conditions to be held constant based on the region of the state.

1.5 Estimation Procedures and Results

A pooled panel ordinary least squares (OLS) model is estimated first without the year and location terms (δ_t and θ_j, respectively). The OLS model is estimated first to act as a base model used as a comparison for the other models. The estimated parameter of the variable *White* is negative and statistically significant. The variable *Private* is statistically significant and large with an estimated 5.34 bushels per acre advantage over varieties released by public institutions. The *CSURL* variable's estimated parameter is positive, but not statistically significant. Finally, the variable *RLYR* has an estimated parameter that is positive and statistically significant. The lack of overall fit ($R^2 = 0.04$) shows evidence of the necessity of additional variables. The complete results are shown in the column entitled Regression 1 in Table 1.1.

A second model, including the year and location terms, is estimated which created a least squares dummy variable (LSDV) fixed effects (FE) model (Greene, 2002). A Lagrange multiplier test provided evidence toward the inclusion of the year and location terms. The addition of the year and location terms are also supported by Nalley, Barkley and Chumley (2008). The resulting parameter estimates are similar in significance as to those in the base model. The largest difference was the improvement in overall fit with an estimated $R^2 = 0.44$ as seen in the column entitled Regression 2 in Table 1.1. The estimated parameters for δ_t (year) and θ_j (location) can be found in Table 1.2 and Table 1.3, respectively, of the appendix.

Heteroskedasticity is found to be an issue in the above models. To address this issue, a third model is estimated using an iterated general least squares model (Wooldridge, 2001). The estimates from this model will be used for the remainder of the analysis.

As seen in the column entitled Regression 3 in Table 1.1, the variable *White* suggests that white wheat produces on average 0.76 bushels per acre less than red wheat varieties, but the result is not statistically significant. This result follows logic given there are very low levels of white wheat being tested and even lower levels being grown in Colorado. This finding concurs with Nalley, Barkley and Chumley (2008). They argue that despite the lower yields of some white wheat varieties, the end use qualities of white wheat, in comparison to red wheat, will bring a higher selling price.

The estimated coefficient for *Private* was equal to 0.92 and is significant at the 1% level (Table 1.1). This indicates that privately bred varieties, on average, have had higher yields when compared to varieties released by public institutions over the course of the study period. *CSURL* indicates the average yield advantage in bushels per acre as a result of a CSU released wheat variety. The *CSURL* provides evidence that CSU released varieties on average yield 0.74 more bushels per acre than the varieties released by both public and private institutions (Table 1.1). This particular result demonstrates that CSU is able to breed varieties that are more appropriate for the growing conditions of Colorado as opposed to private breeding institutions that may develop breeds aimed for a broader region or other public breeding institutions that are focused on their respective locations.

The *RLYR* variable offers insight as to how much, on average, a new wheat variety has increased wheat yields based on the year it was released. The estimated coefficient can be interpreted as an increase of 0.193 bushels per acre per year as a new variety is released over the 38 year time period. According to Nalley, Barkley and Chumley (2008) the estimation of the overall impact of the CSU Wheat Breeding Program is possible through the release year variable. This is a return to an earlier assumption made that experimenting and developing new varieties directly translates into increases in yield for wheat producers. During the 1974-2011 time period, actual wheat yields have increased by 15 bushels per acre. Of those 15 bushels per acre, 48.84% (7.33/15) can be attributed to the progress made by wheat breeders, both public and private. [2] The remaining 51.16% can be attributed to increases in technology, production management and agronomic factors.

[2] 7.33 is a result of the cumulative genetic improvement of 0.193 over the 38 time periods.

Table 1.1 Colorado Wheat Yield Regression Results

		Regression 1: OLS		Regression 2: GLS w/FE		Regression 3: IGLS w/FE Correcting for Heteroskedasticity	
Variable	**Mean**	**Estimated Coefficient**	**Standard Error**	**Estimated Coefficient**	**Standard Error**	**Estimated Coefficient**	**Standard Error**
Intercept		-507.596 ***	33.00	-347.279***	39.58	-331.45***	28.02
White	0.09	-2.921***	0.78	-0.953	0.62	-0.76	0.51
Private	0.30	5.338***	0.50	1.757***	0.40	0.92***	0.38
CSURL	0.29	0.248	0.51	0.642*	0.40	0.74**	0.35
RLYR	1987.76	0.280***	0.02	0.202***	0.02	0.193***	0.01
R^2		0.044		0.441			
Chi-square				8651.27		12005.88	
Log-likelihood						-46078	
Number of Observations		11,077		11,077		11,077	

Note: $Yield_{ijt}$ is the dependent variable for wheat yield at the j^{th} location, t^{th} year, and i^{th} variety.
The mean yield is 50.95 bu./acre.
The level of statistical significance is *** at the 1% probability level, ** at the 5% probability level and * at the 10% probability level.

The δ_t term allows the variation among the years to be held constant. Table 1.2 in the Appendix shows the differences in yield over the years based on 2011. The θ_j term allows the growing conditions to be held constant. This is important as wheat production varies throughout the state as a result of locational differences including weather and growing conditions. Table 1.3 in the Appendix shows the yield differences between the base location (Akron) and all other variety trial locations. These tables provide insight as to the production differences among the years and location.

Based on the *RLYR* coefficient, an estimation of the average increase in yield (0.193 bushels per acre per year) over the 38 year time period for this study (1974-2011) can be calculated as 7.33 bushels per acre (0.193 x 38). Combining results from the regression model, average Colorado annual price for hard red winter wheat, percent of harvested wheat acreage in Colorado, and percentage of wheat acreage using a CSU released variety, the annual benefits of the CSU Wheat Breeding and Genetics Program can be calculated on an annual basis. The average annual benefit over the 38 year study period is estimated to be $14.72 million (Table 1.4).

1.6 Conclusions and Implications

This study provides an estimate of the economic impacts the CSU Wheat Breeding and Genetics Program has had on Colorado wheat production. During the research period of 38 years, CSU has had an increasing influence on wheat production and has offered many improved varieties developed uniquely for the local climate and expected growing conditions. As pointed out by Nalley, Barkley and Chumley (2008), white wheat tends to have lower yields than red wheat varieties that are consistent with the results presented here. However, white wheat has better end-use characteristics and tends to have greater extraction rates than red wheat, which could counter balance the yield deficit. Because the CSU Release variable is statistically significant, it suggests the progression of the program towards producing superior varieties. Using the regression results from this study, annual benefits can be estimated resulting from the CSU Wheat Breeding and Genetics Program. On average, the program has resulted in nearly $15 million in benefits to statewide wheat yields.

Costs for running the Program in 2011 were estimated at $3.22 million (Sommers, 2012). With an estimated benefit of more than $61.50 million, the benefits clearly outweigh the costs with a ratio of 19:1 for 2011. Cost data for the previous years are necessary to complete the cost-benefit analysis, as cost data prior to 2011 is unavailable to date, but it can be said that the program has brought a substantially large net benefit to Colorado wheat production.

Some limitations to this study include the exclusion of the experimental lines of wheat. The estimation of benefits in this analysis only considers those varieties that have been released publicly while there is intrinsic value within the breeding process. New varieties can be a result of crossing experimental variety lines to which this study does not give value. Nalley, Barkley and Chumley call this analysis a "crude" estimate of "cumulative economic benefits" due its' limitations.

A natural step in the analysis would be to obtain the previous annual costs to complete the cost-benefit analysis that, upon writing, was not readily available. Calculation of the net benefit of the CSU Wheat Breeding Program would bring further light onto the impacts of the CSU program. Further research might include more data from the years before those examined in this study to better track the total impact of the CSU program since its inception. Other insights may be gained from working closer with those that understand and track the progress of the CSU program and may offer insights that would be a great addition to this research.

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1.8 Appendix

Table 1.2 Fixed Effects Regression Results: Yield Difference between Locations (bushels per acre)

Location #	Variety Trial Location Name	Difference	Model #2: GLS Model	Model # 3: IGLS Heteroskedastic Model
1	Akron (base)	--	--	--
2	Amherst	-3.8	-0.7	-0.6
3	Anton	7.9	9.1	7.4
4	Arapahoe	-10.1	-10.7	-10.5
5	Bennett	-5.7	-3.4	-2.9
6	Briggsdale	-23.2	-22.8	-24.0
7	Burlington (I)	12.2	13.4	17.0
8	Burlington (NI)	-4.0	-4.1	-4.8
9	Cheyenne Wells	-6.8	-12.7	-12.0
10	Clarkville	12.4	12.7	5.6
11	Cortez	-10.4	4.0	2.8
12	Dailey (I)	35.5	24.4	24.8
13	Eads	-8.6	-6.1	-7.2
14	Fort Collins (I)	23.0	21.4	25.6
15	Fort Morgan	-3.2	2.1	4.6
16	Genoa	-3.4	-1.4	-2.3
17	Haxtun (I)	52.6	52.2	52.6
18	Holly (I)	2.0	2.2	3.2
19	Holyoke (I)	4.7	4.0	3.4
20	Hoyt	12.1	11.6	5.2
21	Julesburg (I)	20.2	20.4	18.8
22	Julesburg (NI)	1.4	1.4	0.7
23	Karval	-0.3	3.2	2.7
24	Kim	-10.6	-1.9	-1.2
25	Lamar	-7.4	-8.8	-8.6
26	Matheson	2.5	7.0	4.3
27	New Raymer	2.0	6.2	6.0
28	Nunn	-12.3	-8.1	-8.8
29	Orchard	0.9	-3.9	-3.2
30	Ovid (I)	30.9	20.3	21.2
31	Ovid (NI)	1.3	1.6	-1.6
32	Paoli (I)	5.7	10.3	10.5
33	Peetz	-4.7	-1.5	-4.0
34	Platner	-11.2	-5.8	-3.0
35	Proctor (I)	15.5	13.7	11.6
36	Punkin Center	-3.7	-0.2	-2.8
37	Rocky Ford (I)	23.8	23.1	25.9
38	Roggen	7.4	-1.1	-1.0
39	Sheridan Lake	-5.2	-3.7	-5.4
40	Springfield	-5.3	5.2	4.4
41	Sterling	5.2	5.2	-0.7
42	Stratton (I)	30.1	40.8	41.4

Table 1.2 Fixed Effects Regression Results: Yield Difference between Locations (bushels per acre), cont.

Location #	Variety Trial Location Name	Difference	Model #2: GLS Model	Model # 3: IGLS Heteroskedastic Model
43	Vernon (I)	8.3	15.3	16.2
44	Walsh (I)	10.3	9.9	8.2
45	Walsh (NR)	-8.4	-9.9	-9.7
46	Wiggins (I)	42.4	45.9	42.8
47	Wiggins (NI)	-13.2	-0.9	1.5
48	Willard	2.1	4.6	0.4
49	Wray (I)	14.5	12.7	13.4
50	Yuma (I)	32.8	28.9	30.5
51	Yuma (NI)	-2.0	-2.7	-2.7

Table 1.3 Fixed Effects Regression Results: Yield Difference between Years (bushels per acre)

Year	Difference	Model #2: GLS Model Difference	Model #3: GLS Heteroskedastic Difference
1974	-28.8	-14.8	-12.7
1975	-20.0	-6.9	-7.0
1976	-32.5	-18.8	-17.2
1977	-16.2	-9.0	-6.9
1978	-20.2	-12.9	-12.5
1979	-10.0	-5.5	-3.6
1980	-17.4	-9.3	-7.3
1981	-24.3	-15.0	-13.7
1982	-18.1	-11.4	-9.5
1983	-5.7	-0.5	1.2
1984	-5.1	0.7	0.9
1985	-2.3	3.9	5.0
1986	-7.9	-4.1	-1.9
1987	-7.2	-1.6	-1.7
1988	-20.3	-14.2	-11.6
1989	-14.0	-9.7	-7.8
1990	-18.2	-12.6	-10.7
1991	-22.8	-10.5	-7.9
1992	-15.5	-8.2	-7.4
1993	-6.0	3.4	5.5
1994	-27.8	-18.5	-16.8
1995	-10.9	-3.8	-2.1
1996	-6.5	-2.3	0.8
1997	-14.3	-7.9	-6.1
1998	-2.3	4.5	6.0
1999	2.2	10.1	11.7
2000	-14.5	-9.5	-8.1
2001	-11.8	-7.5	-6.1
2002	-10.3	-17.4	-16.9
2003	-1.5	3.2	3.8
2004	-4.3	-4.0	-2.8
2005	-23.7	-18.4	-17.0
2006	-28.6	-24.8	-23.4
2007	-3.1	2.9	4.3
2008	-8.9	-8.2	-6.9
2009	-2.7	0.6	2.5
2010	1.7	3.0	4.7
2011 (base)	--	--	--

Table 1.4 Annual Benefits of the Colorado State University Wheat Breeding Program

Year	Colorado Harvested Acres (in millions)	% Acres Using CSU Varieties	Nominal Colorado Wheat Price Received (bu./acre)	Cumulative Genetic Improvement (bu./acre)	Benefits
1974	2.90	0.0%	$3.81	0.193	$0
1975	2.50	2.4%	$3.24	0.386	$74,901
1976	2.44	7.3%	$2.36	0.578	$243,804
1977	2.58	12.2%	$2.12	0.771	$515,502
1978	2.52	18.0%	$2.81	0.964	$1,230,193
1979	2.64	22.4%	$3.53	1.157	$2,415,736
1980	3.40	27.6%	$3.70	1.350	$4,685,919
1981	3.11	29.5%	$3.58	1.542	$5,062,710
1982	2.96	35.3%	$3.35	1.735	$6,069,700
1983	3.06	47.2%	$3.24	1.928	$9,031,108
1984	3.27	48.5%	$3.19	2.121	$10,729,510
1985	3.52	47.7%	$2.77	2.314	$10,766,531
1986	2.96	43.3%	$2.26	2.506	$7,247,767
1987	2.56	40.5%	$2.51	2.699	$7,010,592
1988	2.35	31.0%	$3.69	2.892	$7,780,789
1989	2.27	26.2%	$3.66	3.085	$6,714,833
1990	2.59	19.6%	$2.46	3.278	$4,093,049
1991	2.34	15.6%	$3.07	3.470	$3,882,535
1992	2.40	18.9%	$3.15	3.663	$5,227,584
1993	2.58	16.8%	$3.21	3.856	$5,371,255
1994	2.59	14.4%	$3.48	4.049	$5,258,999
1995	2.74	15.4%	$4.64	4.242	$8,298,543
1996	2.27	18.0%	$4.26	4.434	$7,711,876
1997	2.75	21.6%	$3.17	4.627	$8,715,596
1998	2.61	34.2%	$2.49	4.820	$10,713,047
1999	2.45	42.5%	$2.22	5.013	$11,587,463
2000	2.40	50.6%	$2.70	5.206	$17,040,090
2001	2.04	58.5%	$2.72	5.398	$17,557,825
2002	1.67	59.7%	$3.63	5.591	$20,234,965
2003	2.23	57.5%	$3.32	5.784	$24,611,851
2004	1.71	57.9%	$3.25	5.977	$19,277,090
2005	2.22	55.4%	$3.43	6.170	$26,014,662
2006	1.92	51.0%	$4.54	6.362	$28,269,750
2007	2.37	45.6%	$6.01	6.555	$42,560,618
2008	1.94	54.4%	$6.62	6.748	$47,047,583
2009	2.48	61.4%	$4.57	6.941	$48,280,374
2010	2.38	60.5%	$5.54	7.134	$56,833,326
2011	2.03	62.2%	$6.65	7.326	$61,487,198
Mean	2.52	35.0%	$3.55	3.760	$14,727,760

Essay 2 - Colorado Wheat Variety Selection: An Application of Portfolio Theory

2.1 Introduction

Each year prior to the growing season, Colorado wheat growers are faced with choices when it comes selecting which wheat varieties to plant. Colorado State University annually publishes the results of the Colorado Winter Wheat Variety Performance Trials where both private and public wheat varieties are tested. From these publications, wheat growers can get a reliable sense of the expected performance of the trial varieties for their specific location. Intuitively, growers select wheat varieties based on previous experiences and the published trial results of the previous year. The correlation between yield performances of the different varieties is largely ignored and a more thorough investigation could lead to increased yield stability.

As expected, any agricultural activity involves risk from diverse sources such as weather variation or disease. Barkley, Peterson and Shroyer (2010) identified three major strategies to reduce risk in wheat production. The first strategy to reduce risk involves the development of new breeds with agronomic characteristics appropriate to the growing region. The primary source of the new breeds is a crop breeding program. The traits of multiple varieties can be combined to create new cultivars that will potentially reduce the variation of yields. The second strategy is to create mixtures or blends of the seed of a few different varieties prior to planting in order to increase the genetic diversity. This practice of risk reduction, however, is not widespread among Colorado growers. The third strategy is to create a portfolio by selecting a few wheat varieties and planting them on different fields.

According to a recent survey (Bosley, 2010), Colorado growers tend to plant two or three different varieties of wheat in a given year. The selection of varieties is made primarily by a combination of previous experiences, gut feelings, suggestions made by friends or family or seed distributors and an examination of the test plot yields from the previous year. Ultimately, wheat producers plant different varieties to increase biodiversity in the fields and thus reduce their exposure to risk.

Through the examination of the year-to-year variance of a given cultivar (variety), and comparing that with the variance and covariance of other cultivars, "portfolios" of wheat varieties can be developed. The portfolios lie graphically on a single line and represent points where variation is minimized for a given level of yield. This line represents the mean-variance efficiency frontier. Portfolios can be developed based on the producers' risk preferences, whether it is to maximize yield given a target variance or minimize variance given a target yield. The term "portfolio" comes from finance literature and refers to a group of financial instruments such as investments, holdings, and funds that are used to stabilize or reduce exposure to the risks of the financial market. The term is appropriate for wheat variety analysis in the sense that creating a portfolio of wheat varieties helps reduce wheat producers' exposure to risk.

It is the intent of this paper to apply existing portfolio theory methods, as established in financial literature, to wheat varietal selection to help Colorado wheat producers make more informed planting decisions. A statewide wheat portfolio is created followed by portfolios for northeast Colorado and southeast Colorado. The estimated standard deviation will be used as a proxy for measuring the "risk" or variation of a given wheat variety portfolio.

2.2 Literature Review

In a perfect world, a wheat producer would be able to plant the highest yielding variety and when it came time to harvest, the yields expected by the producer of the variety planted would be realized. However, production agriculture is subject to risk. Risk is inherent in nearly every aspect of life. However, there are many who have developed theories and mathematical procedures to help develop strategies to mitigate risk. Markowitz (1952) and Tobin (1958) developed portfolio theory for the financial world. Intended as an investment tool, portfolio theory enabled the creation of a model that allowed for the maximization of expected returns while accounting for the variation that occurs based on historical data from the stock markets. Others have offered their own extensions (Lintner, 1965 and Sharpe, 1970) to portfolio theory but the aforementioned authors have primarily been interested in financial applications.

In relation to the subject at hand, portfolio theory has seen various applications in agricultural economics. About the same time as Markowitz, Heady (1952) suggested the use of production function equations to help farm managers minimize risk by reducing income variation through diversification. Freund (1956) offered a computational example of a programming model applied to farm diversification. Freund estimated the optimum levels of production using a combination of potatoes, corn, beef (pasture) and fall cabbage including land allocation for farm production. The analysis optimized land allocation, expected levels of production, and expected profits subject to a level of risk. Heifner (1966) applied Markowitz's portfolio theory to grain inventories. Quadratic programming was used to more efficiently allocate storage space for a variety of grains while minimizing risk. Johnson (1967) built upon the models of Heady and Freund along with Tobin's separation theory. Robinson and Brake (1979) extend portfolio theory to farmer and lender behavior.

Within the last decade, portfolio theory application has gone through a renaissance. Nyikal and Kosura (2002) used both linear programming and quadratic programming to solve for the efficient mean-variance frontier to help understand producers' planting decisions in Kenya. Nalley et al. (2009) use portfolio theory on rice varieties grown in Arkansas. Nalley and Barkley (2010) apply portfolio theory to help wheat growers in the Yaqui Valley of Northwestern Mexico to reduce risk through varietal selection. Barkley, Peterson and Shroyer (2010) apply portfolio theory to Kansas wheat varietal selection. Park et al. (2012) applied portfolio theory to wheat selection for dryland wheat producers in the Texas High Plain. The authors used a multivariate simulation method to estimate the net economic returns from various wheat varieties taking into account the price of wheat and costs of production.

2.3 Methodology

The model used in this study to estimate the efficiency frontier for Colorado wheat varieties is based on the model developed by Markowitz (1952). In this research, the method of minimizing the expected variation, as measured by standard deviation, subject to a given level of expected (mean) yield, is used. The frontier is estimated by solving a sequence of quadratic programming problems.

It is assumed that a wheat producer has a given number of acres (X) and wishes to produce on the efficiency frontier of mean-variance (MV) by allocating X acres to a combination of varieties. The variable x_i represents the percentage of total acres planted of variety i where $i = 1, \ldots, n$ and $\Sigma_i x_i = X$ or 100% of the producer's land dedicated to wheat production. This frontier is the maximization of the mean yields given a target level of variation or the minimization of variation given a target mean yield. By defining y_i as the mean yield of variety i, the total wheat yield will be the weighted mean yield, equal to: $\Sigma_i x_i y_i$.

The total wheat variety yield variation (V) is defined in equation (1):

$$(1) \qquad V = \Sigma_i \Sigma_j x_i x_j \sigma_{ij}$$

where x_i is the percentage of total acres planted to variety i and x_j is the percentage of total acres planted to variety j, σ_{ij} is the covariance of yields for varieties i and j and σ_{ij} is the variance when $i = j$. Markowitz (1952) and Heady (1952) identified covariances as fundamental for a method of hedging against risk. Hazell and Norton (1986) explain that the intuition behind equation (1) is that by combining varieties that have negatively related covariates, a more stable yield will likely occur. Also, a variety that may appear to be risky or have a large variance can still be an option when combined with a variety that shares a negative covariate.

The mean-variance efficiency frontier is estimated by minimizing total farm variation (V) for each possible level of mean yields (y_i) as given in equation (2):

(2) $\min V = \Sigma_i \Sigma_j x_i x_j \sigma_{ij}$, for a given level of λ

The sum of the mean yields for varieties *x* and *y* are set equal to λ, where λ is the target yield for a given portfolio in equation (3). By varying the target yield (λ) over the feasible range, the mean-variance efficiency frontier can be drawn.

(3) $\Sigma_i x_i y_i = \lambda$

Equation (4) is the constraint used for each variety to ensure non-negative returns after the quadratic programming has run (i.e., it is not possible to plant a negative percentage of variety *i*).

(4) $x_i \geq 0$ for all i

The same process described above can be performed using a target variation (standard deviation) instead of a target yield. This allows a producer to maximize yield for a given target level of variation.

2.4 Data

Data on wheat yields are obtained from the Colorado Wheat Variety Database. Yields from 2000 – 2011 for dryland trial locations are used to carry out the analysis. The varieties selected are based on three sets of criteria: 1) the variety was tested in the CSU trials, 2) the variety appears within the National Agricultural Statistics Service (NASS) annual publication "Winter Wheat Seedings by Variety" for Colorado for the years 2009, 2010 and 2011 in order to analyze those varieties that are currently being planted in the state of Colorado and 3) there are at least three years of comparable mean yields between each variety used to estimate the covariates. A total of 13 wheat varieties met the above criteria and are selected for the analysis. The resulting varietal selection can be seen in Table 2.1.

Table 2.1 Selected Colorado Wheat Varieties Source, Year of Release, and Percent Planted Acres, 2000-2011

Variety	Source	Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Above	CSU	2001	0%	0%	0%	3.8%	5.8%	6.1%	6.1%	5.0%	4.8%	3.2%	3.2%	2.8%
Akron/Ankor	CSU	1994/2002	24.3%	24.4%	25.3%	22.3%	20.8%	24.2%	18.4%	13.0%	7.5%	2.8%	2.6%	1.3%
Bill Brown	CSU	2007	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2.5%	5.1%
Bond CL	CSU	2004	0%	0%	0%	0%	0%	0%	0%	1.9%	3.6%	4.8%	4.9%	3.9%
Danby	KSU	2005	0%	0%	0%	0%	0%	0%	0%	0%	1.3%	1.2%	0%	0%
Hatcher	CSU	2004	0%	0%	0%	0%	0%	0%	0%	6.5%	22.2%	32.9%	26.5%	34.5%
Jagalene	Agripro	2001	0%	0%	0%	0%	1.2%	4.4%	8.6%	14.2%	10.7%	8.4%	6.8%	1.6%
Jagger	KSU	1994	2.1%	2.9%	6.7%	7.7%	8.9%	2.9%	7.2%	7.4%	5.7%	4.0%	3.2%	1.9%
Prairie Red	CSU	1998	3.1%	11.5%	13.9%	16.0%	14.8%	6.7%	9.3%	10.3%	8.5%	5.6%	5.6%	1.5%
Prowers 99	CSU	1999	2.3%	4.0%	5.9%	3.9%	4.0%	8.3%	6.1%	2.9%	3.0%	2.0%	1.6%	0%
Ripper	CSU	2006	0%	0%	0%	0%	0%	0%	0%	0%	0.9%	6.8%	12.5%	12.1%
TAM 111	TAMU	2002	0%	0%	0%	0%	0.9%	1.2%	5.1%	6.3%	8.9%	8.0%	7.5%	9.5%
Yuma	CSU	1991	6.9%	7.8%	6.9%	4.9%	5.7%	5.5%	6.7%	2.5%	2.6%	2.7%	1.1%	0%

Source: USDA/NASS Colorado Agricultural Statistics Service

Summary statistics and the coefficients of variation (standard deviation divided by mean yield) are reported for Colorado as a whole, Northeast region of Colorado and Southeast region of Colorado in Tables 2.2, 2.3, and 2.4 respectively. There are distinct differences in production levels between the Northeast and Southeast of Colorado. To addresses these issues, this study begins with the development of portfolios based on data for Colorado statewide and then divides the data according to region to develop separate wheat portfolios that are appropriate for the given region.

From Table 2.2 it can be noted that Ripper has the overall highest mean yield at 48.5 bushels per acre with Bill Brown (47.8 bushels per acre) and Hatcher (47.4 bushels per acre) coming in a close second and third, respectively. Prowers 99 has the lowest variation (standard deviation), but is also the lowest yielding.

Table 2.2 Selected Variety Summary Statistics: Colorado, 2000-2011

Variety	Mean Annual Yield	Standard Deviation	Coefficient of Variation	Min	Max	Observations
Ripper	48.5	9.42	0.194	4.8	87.7	74
Bill Brown	47.8	10.50	0.220	12.3	84.3	63
Hatcher	47.4	11.09	0.234	2.2	97.6	85
Bond CL	47.0	10.89	0.232	10.9	97.3	77
TAM 111	45.4	12.28	0.271	4.2	101.3	71
Above	45.3	10.07	0.222	5.3	93.1	93
Danby	44.6	11.97	0.268	3.8	83.5	63
Prairie Red	43.7	9.31	0.213	6.0	88.5	93
Jagger	43.3	9.00	0.208	10.0	93.2	93
Jagalene	42.2	10.17	0.241	4.3	90.6	62
Yuma	42.0	9.75	0.232	6.4	93.4	78
Akron/Ankor	40.5	9.35	0.231	3.9	89.4	69
Prowers 99	38.0	7.93	0.209	6.7	83.3	72

In the Northeast region of Colorado, Ripper again had the highest average yield at 50.5 bushels per acre followed by Bill Brown with 49.6 bushels per acre and Bond CL with 49.4 bushels per acre. Prowers 99 again had the lowest variation and the lowest yield (Table 2.3).

Table 2.3 Selected Variety Summary Statistics: Northeast Region, 2000-2011

Variety	Mean Annual Yield	Standard Deviation	Coefficient of Variation	Min	Max	Observations
Ripper	50.5	11.84	0.235	4.8	87.7	48
Bill Brown	49.6	11.93	0.241	12.3	84.3	40
Bond CL	49.4	13.33	0.270	10.9	97.3	51
Hatcher	49.1	13.37	0.272	2.2	97.6	56
TAM 111	47.8	15.48	0.324	4.2	101.3	47
Above	47.7	12.52	0.263	5.3	93.1	61
Jagger	46.6	10.85	0.233	13.6	93.2	61
Danby	46.2	14.26	0.308	3.8	83.5	40
Prairie Red	46.0	11.17	0.243	6.0	88.5	61
Jagalene	44.9	12.26	0.273	4.3	90.6	42
Yuma	44.6	12.48	0.280	6.4	93.4	52
Akron/Ankor	41.9	11.78	0.281	3.9	89.4	47
Prowers 99	40.1	10.09	0.252	6.7	83.3	47

In the Southeast region of Colorado, mean yields are slightly lower than in the Northeast region and statewide, but the same varieties appeared at the top of the list as did in the statewide statistics analysis. Ripper had the highest average yield with 44.7 bushels per acre followed by Bill Brown with 44.6 bushels per acre and Hatcher with 44.2 bushels per acre. Akron/Ankor varieties had the lowest variation in the Southeast region (Table 2.4).

Table 2.4 Selected Variety Summary Statistics: Southeast Region, 2000-2011

Variety	Mean Annual Yield	Standard Deviation	Coefficient of Variation	Min	Max	Observations
Ripper	44.9	9.30	0.207	15.0	75.6	26
Bill Brown	44.6	12.12	0.272	14.7	70.5	23
Hatcher	44.2	11.31	0.256	13.4	76.7	29
Bond CL	42.2	9.43	0.223	15.4	68.1	26
Danby	41.8	10.81	0.259	13.1	68.3	23
Above	40.9	8.44	0.206	13.5	62.8	32
TAM 111	40.5	12.67	0.313	11.7	77.4	24
Prairie Red	39.2	9.10	0.232	10.4	59.5	32
Akron/Ankor	37.6	8.41	0.224	15.4	69.2	23
Jagger	37.0	10.18	0.275	10.0	68.8	32
Yuma	36.8	9.27	0.252	16.6	71.3	26
Jagalene	36.4	11.61	0.319	14.2	74.7	20
Prowers 99	34.0	8.90	0.262	12.6	58.1	25

Through the application of portfolio theory to Colorado varietal selection, wheat producers can potentially increase yield and reduce variability by combining wheat varieties that respond differently to growing environments. Through the calculation of standard deviations, covariates, and means, it can be mathematically determined as to how each variety's yield responds to different environmental factors relative to each of the other varieties. The variance/covariance matrices can be found in the Appendix. Ideally, varieties that have a negative covariate would be integrated into the planting plans to reduce the risk resulting from environmental fluctuations.

2.5 Estimation Procedures and Results

Complete data on wheat variety yield means, standard deviations, and covariances are used to estimate wheat portfolios along the efficiency frontier. Standard deviations are estimated across years. Pairwise covariates of the selected wheat varieties are estimated. By varying the target yield (λ) while minimizing the standard deviation for the given target yield, the efficiency frontier is drawn for the three data sets (Colorado – Table 2.5, Figure 2.1; Northeast Region – Table 2.6, Figure 2.2; and Southeast Region – Table 2.7, Figure 2.3).

Economic Impact of 2011 Actual Portfolio vs. 2011 Potential Portfolio

The wheat varieties Above, Akron/Ankor, Bill Brown, Bond CL, Hatcher, Jagalene, Jagger, Prairie Red, Ripper, and TAM 111 all had recorded percentages of acres planted in the NASS "Winter Wheat Seedings by Variety Survey, 2011" and account for 75.2% of total acres planted. By proportioning the varieties' percentage planted to equal 100%, it allowed the estimation of the variation (V) and mean yield (E) for 2011 Actual Portfolio (V = 10.79 bu./acre, E = 46.7 bu./acre, respectively). The variation was then held constant at the 2011 Actual Portfolio level (10.79 bu./acre) and quadratic programming was used to maximize the mean yield providing an estimate of the 2011 Potential Portfolio. The mean yield (E) was increased by one bu./acre to E = 47.7 bu./acre. The opportunity cost is the forgone yield caused by producing below the efficiency frontier. This is calculated by simply taking the difference between the 2011 Potential Portfolio mean yield and the 2011 Actual Portfolio mean yield and is approximately one bushel per acre. Using 2011 Colorado wheat prices ($6.65 per bushel) and 2011 acres planted (2,345,000) reported by NASS, the potential gain by moving to the efficiency frontier is an estimated $15,451,925 (1 bushel per acre*2.35 million planted acres*$6.65 per bushel). This amounts to a potential increase in total revenue by 2.12% from wheat production in Colorado without an increase in risk as measured by yield variation.

There is additional potential of reducing variation through the application of portfolio theory. The 2011 Actual Portfolio has an estimated standard deviation of 10.79 bu./acre and a mean yield of 46.7 bu./acre. By holding the mean yield constant and minimizing the variance, there is potential to get the same yield but reduce the variation to a standard deviation of 9.23 bu./acre or a 14.5% decrease in variation.

Colorado Efficiency Frontier Portfolio Results

For the 2000 – 2011 time period, Ripper had the highest mean yield at 48.5 bu./acre (Table 2.2) and constitutes the highest point on the efficiency frontier (Figure 2.1). Meanwhile Prowers 99 has the lowest variation with a standard deviation equal to 7.93 bu./acre (Table 2.2) and is the left most and lowest point on the efficiency frontier (Figure 2.1). Using these two points as the extremes, an efficiency frontier was drawn between the two points by varying the target mean yield and then minimizing the portfolio variance for the given varied yield. Several portfolios were developed representing the points along the efficiency frontier between the two extremes and can be found in column 1 of Table 2.5. The portfolios in column 1 of Table 2.5 contain the percentage of a variety that could be planted in order to obtain certain levels of yield and variation.

Table 2.5 Portfolio Analysis of Colorado Wheat Varieties, 2000-2011

Portfolio	Target Mean Yield (Bu./Acre)	Standard Deviation (Bu./Acre)	Coefficient of Variation
100% Prowers 99	38.0	7.93	0.209
17.5% Jagger 4.1% Prairie Red 78.3% Prowers 99	39.2	8.21	0.210
32.6% Jagger 10.6% Prairie Red 56.8% Prowers 99	40.3	8.46	0.210
47.7% Jagger 17% Prairie Red 35.3% Prowers 99	41.5	8.68	0.209
62.7% Jagger 23.5% Prairie 13.8% Prowers 99	42.7	8.87	0.208
72.1% Jagger 3.8% Prairie Red 7.1% Prowers 99 17% Ripper	43.8	9.01	0.206
67.5% Jagger 32.5% Ripper	45.0	9.09	0.202
45% Jagger 55% Ripper	46.2	9.18	0.199
22.5% Jagger 77.5% Ripper	47.3	9.29	0.196
100% Ripper	48.5	9.42	0.194
2011 Actual Portfolio of Planted Varieties in Colorado[a]	46.7	10.79	0.231
2011 Potential Portfolio[b] 54.5% Bill Brown 37.3% Hatcher 8.3% Ripper	47.7	10.79	0.226

[a] The "2011 Actual Portfolio" defined here is based on the percentage planted from the NASS 2011 publication and those varieties found in the CSU Trials, proportioned to equal 100%
[b] The "2011 Potential Portfolio" is estimated by maximizing the target yield while holding the variance at the 2011 Actual Portfolio variance (Standard Deviation = 10.79)

The variety Ripper by itself offers the lowest variation to yield ratio as seen in the coefficient of variation (CV = 0.192). This helps explain the reason for the steepness of the efficiency frontier as seen in Figure 2.1. Note the distance between the frontier and both the 2011 Actual Portfolio and 2011 Potential Portfolio in Figure 2.1. By maximizing yield at the 2011 Actual Portfolio level of variation, the expected wheat yield moves to that of the 2011 Potential Portfolio. By then moving to the left from the 2011 Potential Portfolio towards the efficiency frontier, a large reduction in variation is expected to occur while maintaining the higher yield.

Furthermore, there is a remarkable difference in yields between the Northeast and Southeast regions of Colorado and it is logical to develop unique variety portfolios for those regions. The statewide results provide an interesting overall result but it would be of more use to producers to have a portfolio for each region.

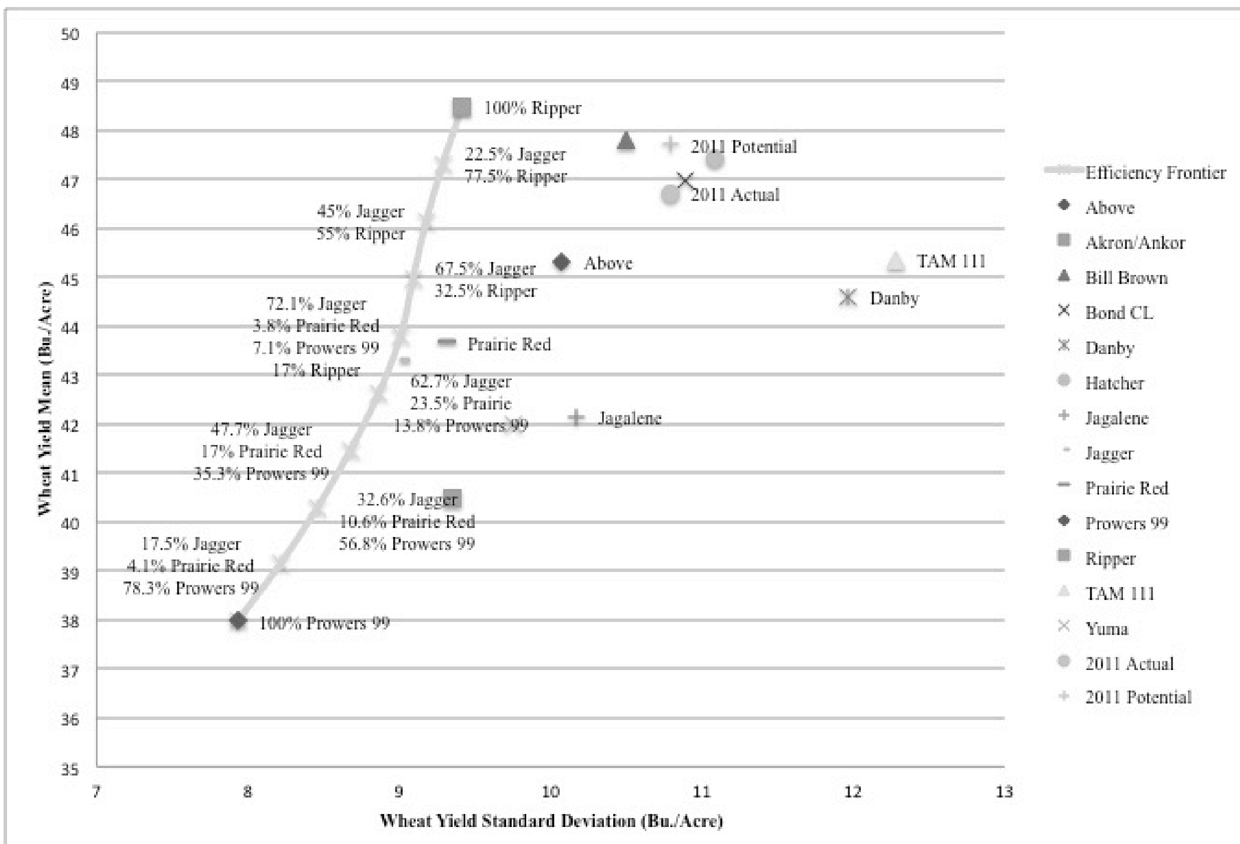

Figure 2.1 Colorado Wheat Efficiency Frontier, 2011

Northeast Region Efficiency Frontier Portfolio Results

The 2011 Actual Portfolio for Northeast Colorado was estimated by using the 2011 percentages planted found in the 2011 survey of Colorado Winter Wheat Varieties published by NASS for the Northeast region. The standard deviation of the Actual Portfolio (12.91 bu./acre) was then held constant and the expected yield was maximized using quadratic programing, allowing for the estimation of the 2011 Potential Portfolio for the Northeast region. The estimated yield difference between the two portfolios was nearly 0.5 bu./acre.

Similar to the statewide portfolio analysis, Ripper was the highest yielding variety at 50.5 bu./acre (Table 2.6) and Prowers 99 was the variety with the lowest variation with a standard deviation of 10.09 bu./acre (Table 2.6). The efficiency frontier was drawn using the same methods as discussed above. The resulting portfolios are shown in Table 2.6 and the efficiency frontier in Figure 2.2.

Table 2.6 Portfolio Analysis of Northeast Region Wheat Varieties, 2000-2011

Portfolio	Target Mean Yield (Bu./Acre)	Standard Deviation (Bu./Acre)	Coefficient of Variation
100% Prowers 99	40.1	10.09	0.252
17.8% Jagger 82.2% Prowers 99	41.2	10.27	0.249
35.5% Jagger 64.5% Prowers 99	42.4	10.44	0.246
53.3% Jagger 46.7% Prowers 99	43.6	10.58	0.243
71% Jagger 29% Prowers 99	44.7	10.69	0.239
87.1% Jagger 1.8% Prairie Red 11.1% Prowers 99	45.9	10.79	0.235
89% Jagger 11% Ripper	47.0	10.94	0.233
59.1% Jagger 40.9 Ripper	48.2	11.22	0.233
29.2% Jagger 70.8% Ripper	49.4	11.52	0.234
100%Ripper	50.5	11.84	0.235
2011 Actual Portfolio of Planted Varieties in Northeast Colorado[a]	49.1	12.91	0.263
2011Potential Portfolio[b] 82% Bond CL 17.7% Ripper	49.6	12.91	0.261

[a] The "2011 Actual Portfolio" defined here is based on the percentage planted from the NASS 2011 publication and those varieties found in the CSU Trials, proportioned to equal 100%
[b] The "2011 Potential Portfolio" is estimated by maximizing the target yield while holding the variance at the 2011 Actual Portfolio variance (Standard Deviation = 12.91)

The portfolio that offers the lowest coefficient of variation consists of 89% Jagger and 11% Ripper (CV = 0.233). A portfolio of 59.1% Jagger and 40.9% Ripper offers a similar coefficient of variation equal to 0.233 with a higher projected yield. Both portfolios could be suggested to those farmers looking to minimize risk while keeping expected yields relatively high. Figure 2.2 shows the steepness of the efficiency frontier drawn by the portfolios found in Table 2.6.

The movement from the 2011 Actual Portfolio point to the 2011 Potential Portfolio point (see Figure 2.2) provides a small increase in expected yield. In addition, by moving left from the 2011 Potential Portfolio for the Northeast region towards a portfolio that lies on the efficiency frontier allows for a sizeable reduction in risk without having to give up potential yield. In fact, some of the estimated portfolios would both increase expected yield and reduce the variation (standard deviation) when compared with the 2011 Potential Portfolio for the Northeast region.

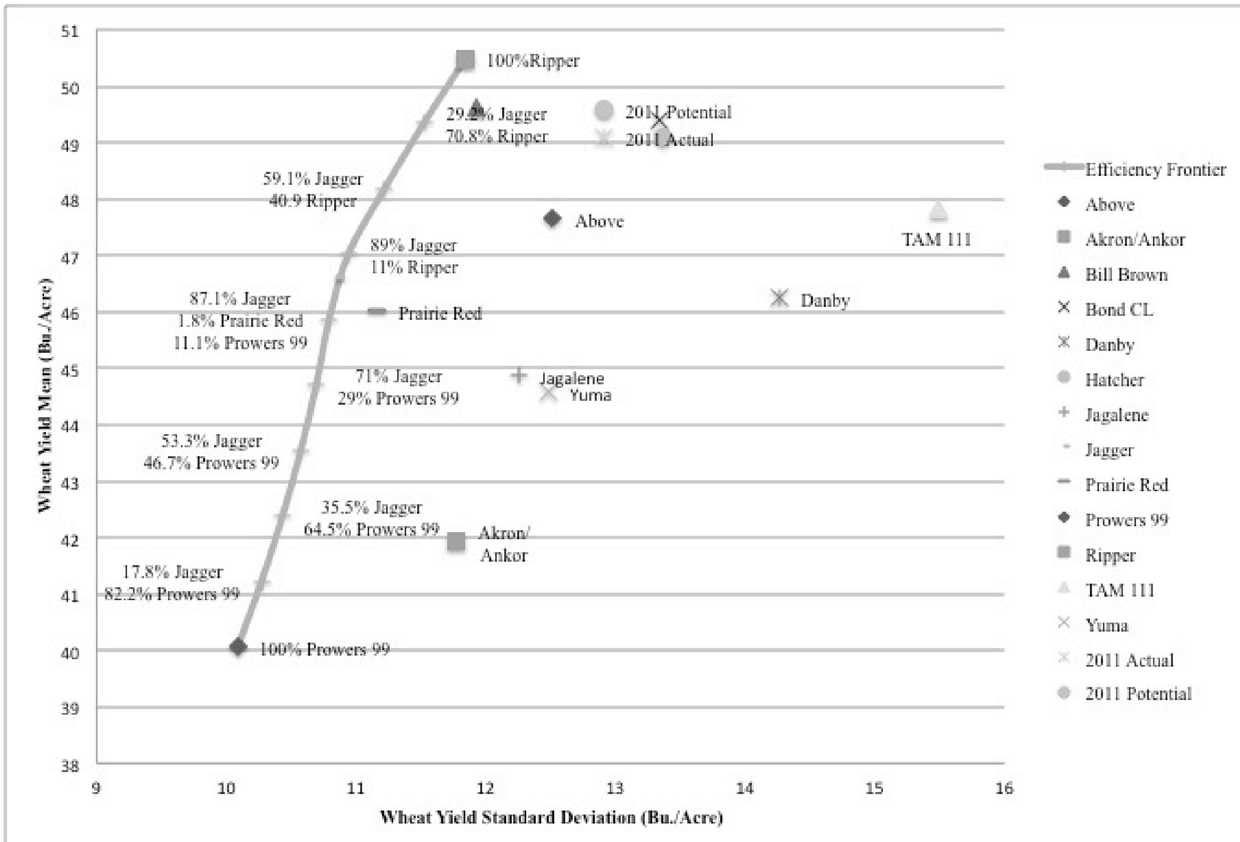

Figure 2.2 Northeast Region Wheat Efficiency Frontier, 2011

Southeast Region Efficiency Frontier Portfolio Results

The 2011 Actual Portfolio for Southeast Colorado was estimated again by using the 2011 percentages planted found in the 2011 survey of Colorado Winter Wheat Varieties published by NASS for the Southeast region. The standard deviation of the Actual Portfolio (11.24 bu./acre) was then held constant and the expected yield was maximized allowing for the estimation of the 2011 Potential Portfolio for the Southeast region. The estimated yield difference between the two portfolios was nearly one bu./acre.

The Southeast region analysis offered some interesting results. A single variety did not have the lowest variation, but rather a portfolio produced the lowest variation. This gives evidence towards the discussion of Hazell and Norton (1986) that by creating a portfolio of varieties that have negatively related covariates, a more stable yield or lower variation can be obtained. A portfolio of 43.4% Akron/Ankor, 23.9% Prairie Red and 32.9% Prowers 99 would result in a standard deviation of 8.08 bu./acre (Table 2.7), whereas a portfolio of 100% Akron/Ankor would result in a standard deviation of 8.41 bu./acre (Table 2.4).

Table 2.7 Portfolio Analysis of Southeast Region Wheat Varieties, 2000-2011

Portfolio	Target Mean Yield (Bu./Acre)	Standard Deviation (Bu./Acre)	Coefficient of Variation
43.4% Akron/Ankor 23.9% Prairie Red 32.9% Prowers 99	36.8	8.08	0.220
22.5% Above 32.4% Akron/Ankor 18.8 % Prairie Red 26.3% Prowers 99	37.7	8.11	0.215
48.3% Above 18.8% Akron/Ankor 11.2% Prairie Red 21.7% Prowers 99	38.6	8.17	0.212
74.2% Above 5.1% Akron/Ankor 3.5% Prairie Red 17.2% Prowers 99	39.5	8.25	0.209
92.6% Above 7.4% Prowers 99	40.4	8.36	0.207
90.1% Above 9.9% Ripper	41.3	8.55	0.207
67.4% Above 32.6% Ripper	42.2	8.77	0.208
44.6% Above 55.4% Ripper	43.1	8.97	0.208
0.2% Above 32.4% Bond CL 67.4% Ripper	44.0	9.11	0.207
100% Ripper	44.9	9.30	0.207
2011 Actual Portfolio of Planted Varieties in Southeast Colorado[a]	43.8	11.24	0.256
2011 Potential Portfolio[b] 28.1% Bill Brown 71.9% Ripper	44.8	11.24	0.251

[a] The "2011 Actual Portfolio" defined here is based on the percentage planted from the NASS 2011 publication and those varieties found in the CSU Trials, proportioned to equal 100%
[b] The "2011 Potential Portfolio" is estimated by maximizing the target yield while holding the variance at the 2011 Actual Portfolio variance (Standard Deviation = 11.24)

Several portfolios were used to draw the efficiency frontier for the Southeast Region. Using the portfolio discussed above which had the smallest variation and a portfolio of 100% Ripper, which boasted the highest yield, a frontier was drawn using the portfolios found in Table 2.7 and can be seen in Figure 2.3. Three of those portfolios offer equal coefficients of variation and could be good recommendations to growers. Portfolios made up of 92.6% Above, 7.4% Prowers 99 or

90.1% Above, 9.9% Ripper or 0.2% Above, 32.4% Bond CL and 67.4% Ripper all have the smallest coefficient of variation of 0.207 for the Southeast region.

As seen in the previous discussions, a move from the 2011 Actual Portfolio for the Southeast region provides a small increase in expected yield while maintaining the same level of variation. A leftward movement from the 2011 Actual Portfolio point to an estimated portfolio that lies on the efficiency frontier would not only has the potential of reducing risk but also offers a slight increase in expected wheat yield (see Figure 2.2).

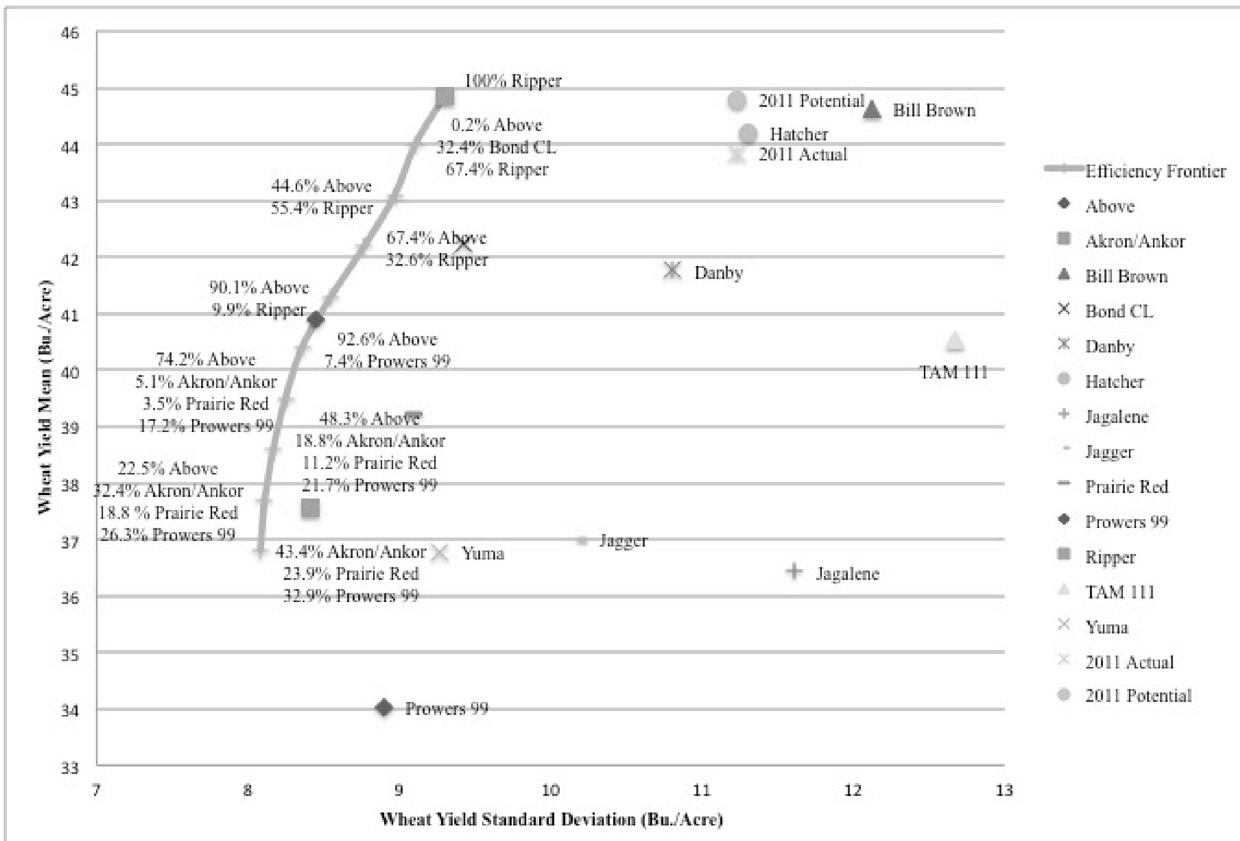

Figure 2.1 Southeast Region Wheat Efficiency Frontier, 2011

2.6 Conclusions and Implications

As an addition to the many tools already available to wheat growers in Colorado, the creation of variety portfolios offers a statistical method to help minimize risk and stabilize yields.

This initial application of portfolio theory to Colorado wheat offers a quantitative look at the relationship among wheat varieties. By analyzing the covariates of wheat varieties, growers can take advantage of the ways in which the varieties react to different growing conditions. This analysis also provides evidence of the great work that Colorado State University Wheat Breeding and Genetics Program has done in developing varieties that are appropriate for Colorado growers by offering increased yields and reduced variation.

One potential limitation to this analysis is the bias created by the methods used to select the varieties. The number of observations for each variety is not equal due to new varieties entering the variety trials and the older varieties being phased out. This does create a problem as growing conditions change on an annual basis and can create a bias towards those varieties that were planted during relatively good years. Another limitation could be the criteria itself used for selecting the varieties. This analysis requires at least three years of comparable data between the different varieties. This immediately excludes the newly released varieties that only have a couple of years of trial data.

Wheat production can be enhanced in Colorado through the application of portfolio theory by offering wheat growers a new tool to help in planting decisions. In addition to the currently available information such as the wheat variety yield data released annually by Colorado State University, it is suggested that a “user-friendly” computer tool be developed using similar processes as applied in this study. This tool can be used in extension and education applications to derive optimal portfolios to help increase yield stability and wheat producer profits.

2.7 References

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2.8 Appendix

Table 2.8 Colorado Variance/Covariance Matrix

	Above	Akron/ Ankor	Bill Brown	Bond CL	Danby	Hatcher	Jagalene	Jagger	Prairie Red	Prowers 99	Ripper	TAM 111	Yuma
Above	101.48												
Akron/ Ankor	91.32	87.40											
Bill Brown	119.82	116.63	110.21										
Bond CL	112.98	111.18	115.16	118.55									
Danby	138.75	141.01	121.67	129.27	143.24								
Hatcher	111.56	105.07	123.48	122.99	142.97	122.89							
Jagalene	107.62	100.43	116.94	103.95	134.50	110.01	103.43						
Jagger	85.44	80.42	103.80	99.73	120.73	96.66	96.24	81.08					
Prairie Red	93.40	84.36	113.73	105.47	130.72	102.64	98.87	78.63	86.72				
Prowers 99	80.57	75.58	121.01	102.06	138.09	93.14	89.85	73.72	74.75	62.90			
Ripper	98.75	100.07	108.48	92.49	121.70	98.76	97.82	82.85	92.82	93.85	88.70		
TAM 111	136.16	123.97	149.42	134.77	175.93	142.36	116.68	120.32	126.78	109.58	120.31	150.83	
Yuma	94.07	89.08	114.28	117.62	135.80	112.22	103.30	85.35	85.74	78.33	98.42	126.29	95.10

Table 2.9 Northeast Colorado Variance/Covariance Matrix

	Above	Akron/ Ankor	Bill Brown	Bond CL	Danby	Hatcher	Jagalene	Jagger	Prairie Red	Prowers 99	Ripper	TAM 111	Yuma
Above	156.73												
Akron/ Ankor	145.35	138.69											
Bill Brown	181.22	166.16	142.37										
Bond CL	174.30	176.10	154.81	177.80									
Danby	200.20	200.90	166.88	183.42	203.40								
Hatcher	170.41	167.50	162.43	182.31	198.55	178.74							
Jagalene	168.93	156.37	163.14	164.01	192.09	170.94	150.23						
Jagger	130.27	125.85	136.94	151.78	167.60	143.89	144.12	117.64					
Prairie Red	139.02	131.35	149.35	156.05	177.63	151.36	152.08	115.86	124.66				
Prowers 99	133.06	120.76	169.42	163.64	195.68	149.86	143.62	112.94	121.28	101.76			
Ripper	155.73	169.94	147.85	143.89	176.53	155.62	157.54	126.98	138.99	156.91	140.22		
TAM 111	155.73	198.19	147.85	209.69	256.03	155.62	180.36	184.15	191.70	178.36	192.50	239.75	
Yuma	154.31	154.31	161.11	189.39	193.60	178.06	163.50	135.28	139.33	129.73	170.52	205.16	155.79

Table 2.10 Southeast Colorado Variance/Covariance Matrix

	Above	Akron/ Ankor	Bill Brown	Bond CL	Danby	Hatcher	Jagalene	Jagger	Prairie Red	Prowers 99	Ripper	TAM 111	Yuma
Above	71.32												
Akron/ Ankor	67.75	70.75											
Bill Brown	112.11	119.47	146.92										
Bond CL	80.21	79.21	123.12	88.84									
Danby	103.34	114.93	123.45	108.21	116.77								
Hatcher	92.73	91.69	153.39	107.75	135.53	127.88							
Jagalene	96.56	100.89	142.06	89.68	127.77	125.23	134.80						
Jagger	79.54	82.94	125.23	92.51	110.89	108.53	122.00	103.69					
Prairie Red	70.19	62.81	119.38	85.95	111.20	93.85	100.63	73.86	82.77				
Prowers 99	60.36	59.91	143.45	90.02	129.99	93.85	82.90	84.46	55.87	79.22			
Ripper	80.38	76.81	109.92	77.86	90.49	97.21	86.90	95.89	76.40	73.94	86.45		
TAM 111	115.63	116.32	169.09	115.95	155.08	148.65	143.25	140.94	122.33	107.68	108.16	160.47	
Yuma	71.27	72.41	142.58	91.24	131.97	110.10	108.56	94.30	63.93	72.39	84.30	128.85	85.94