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AN EVALUATION OF COLORADO STATE UNIVERSITY'S WHEAT BREEDING PROGRAM: ECONOMIC IMPACTS ON WHEAT YIELDS

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Introduction

Colorado State University's (CSU) Wheat Breeding and Genetics Program will celebrate its' 50th anniversary in 2013. 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 USDA's Colorado Agricultural Statistics Service (2012), CSU-bred wheat cultivars now account for over 60 percent of Colorado's 2.6 million acres of wheat (Figure 1).

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 (Figure 2).

The intent of this report is to analyze the economic impacts 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 Wheat Breeding and Genetics and Crop Variety Testing Programs.

This analysis assumes that the increase in yield experienced over time on the experimental plots will result in yield increases for wheat producers. Figure 3 gives a visualization of the gap that exists between the average annual yields of the variety trial locations and that of the on-farm production of wheat. Brennan (1984) argues that the trial data from variety trial locations are one of the only reliable sources for relative yields. An interesting observation in Figure 3 is the trends of 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, variety trial yields and

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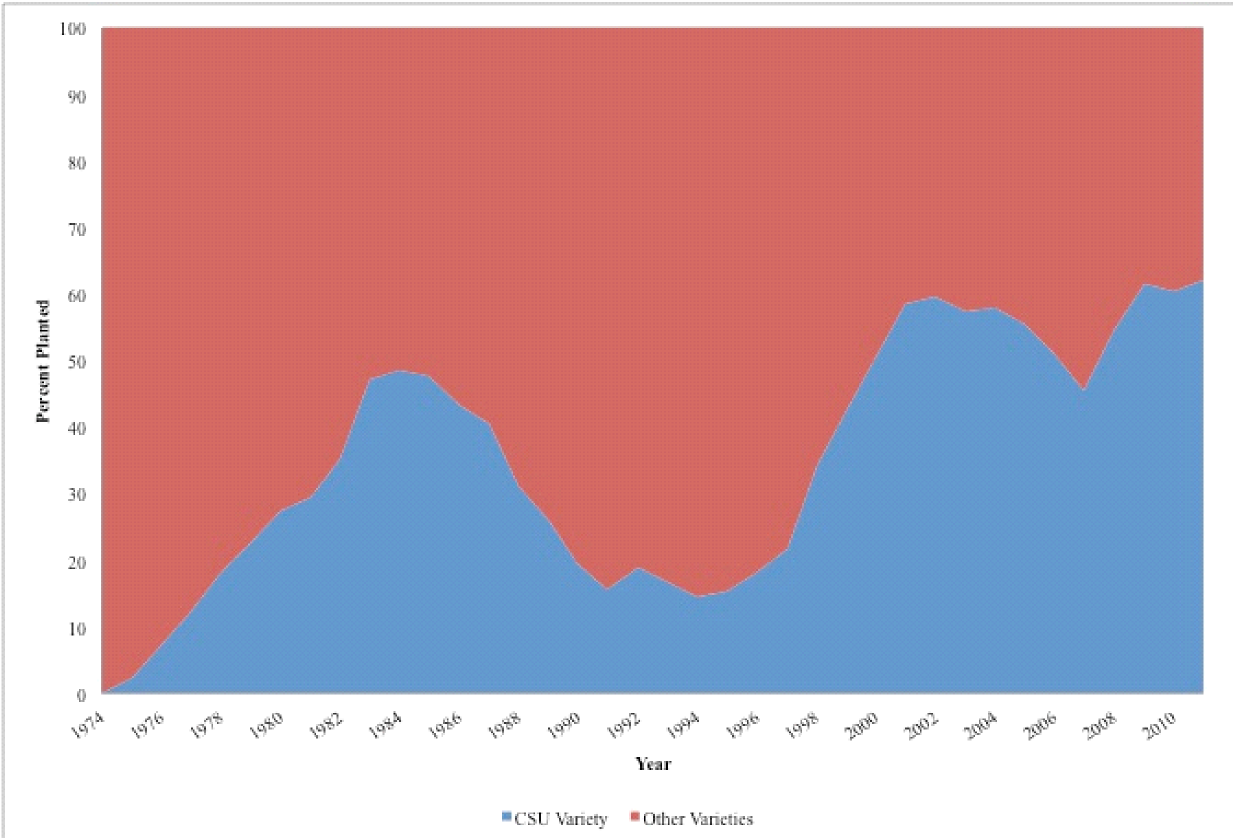

Figure 1. Percentage of CSU Related Varieties Planted on Colorado Farms, 1974-2011

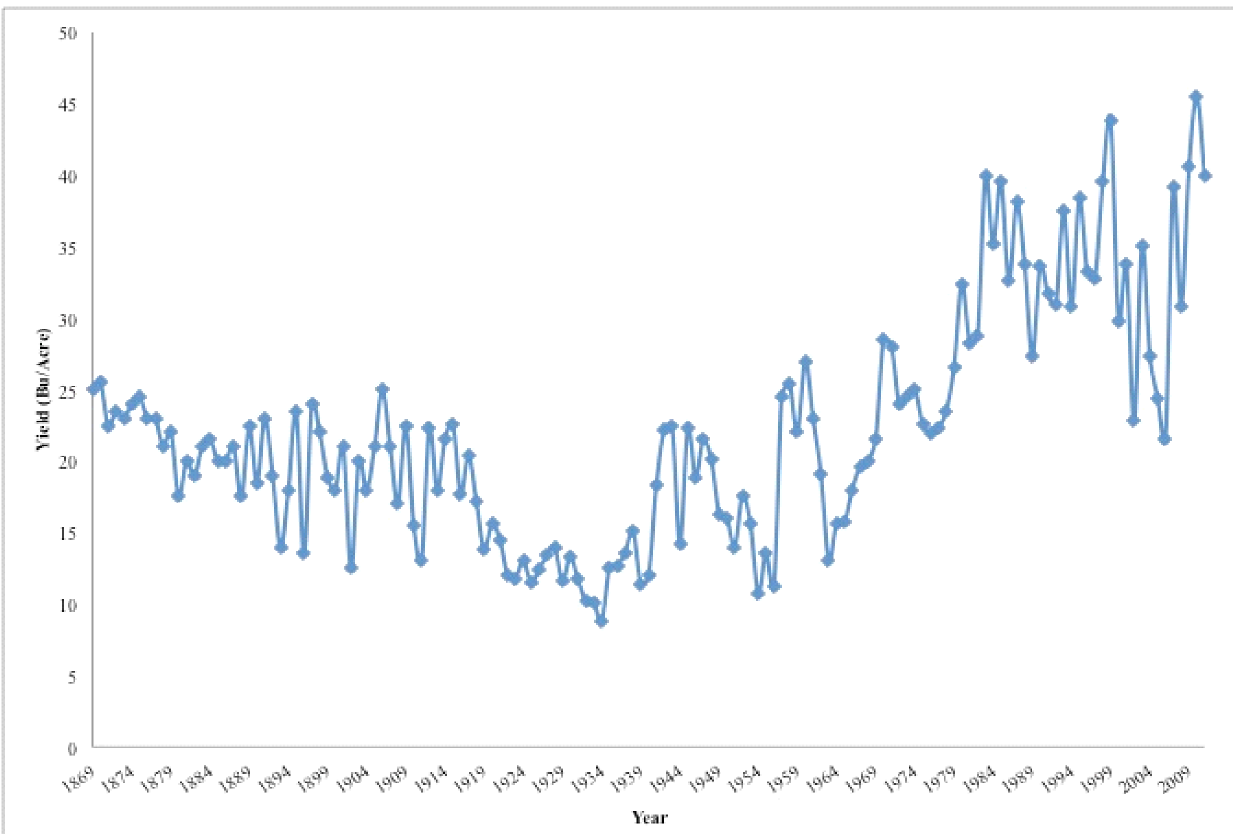

Figure 2. Colorado Historical Wheat Yields, 1869-2011

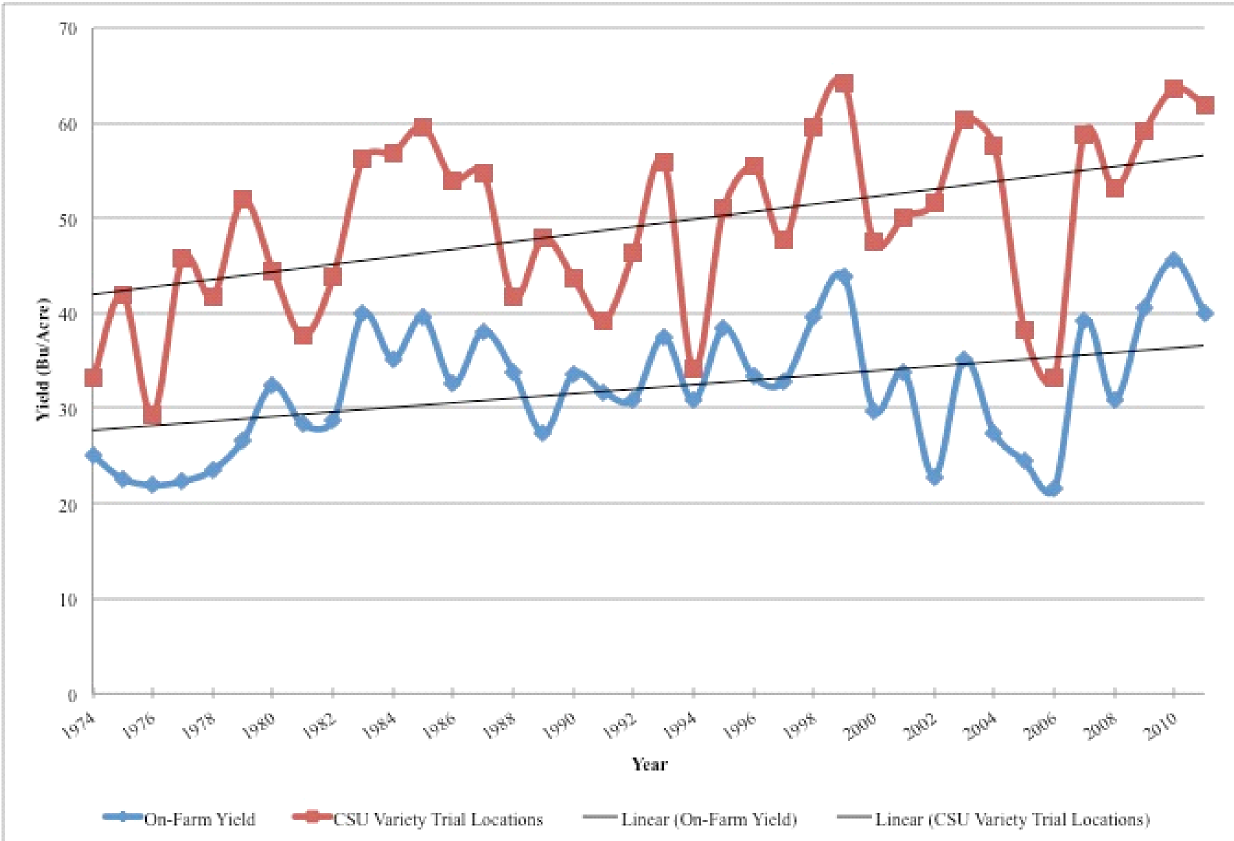

Figure 3. Average Wheat Yields for CSU Variety Trial Locations and Colorado On-Farm with Trends, 1974-2011

on-farm yields have tracked together over time. Therefore, in this paper, 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 CSU Wheat Breeding and Genetics Program.

Previous Research

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 number of in-depth procedures associated with the various approaches to estimating the gains resulting from research depending on data availability and research goals. Specifically, Alston, Norton and Pardey 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 literature reviewed demonstrated that these different applied techniques 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) applied multiple regression analysis to estimate wheat yield increases attributable to the genetic improvements from the efforts of the Kansas Agricultural Experiment Station wheat breeding program for the period 1977 - 2006. They estimated a cumulative genetic gain of 0.206 bushels per acre per year and an average annual benefit to wheat producers of nearly $79 million (2006$) during the 1977 - 2006 period of their analysis. Using the same methods, Nalley, Barkley, and Crespi (2008) analyzed the increase in quality resulting from the efforts of the 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. This study will use similar methods, including regression analysis as outlined in Nalley, Barkley and Chumley (2008), to evaluate the economic impacts resulting from the efforts of CSU's Wheat Breeding and Genetics Program.

Methodology & Data

Initially, an empirical model was developed to estimate the increase in wheat yields attributable to the CSU released wheat varieties compared to other variety sources.

$$Yield_{ijt} = \beta_0 + \beta_1 White_i + \beta_2 Private_i + \beta_3 CSURL_i + \beta_4 RLYR_i + \delta_t + \theta_j + \varepsilon_{ijt}$$

Variables in this model include: $Yield_{ijt}$ is the yield in bushels per acre for variety i, at station j, in time period t; $White_i$ is a binary variable for variety i distinguishing between hard white wheat varieties ($White_i = 1$) and hard red wheat varieties ($White_i = 0$); $Private_i$ is a binary variable indicating whether or not variety i was released by a private ($Private_i = 1$) or public ($Private_i = 0$) institution; $CSURL_i$ identifies those varieties that are developed by CSU's wheat breeding program ($CSURL_i = 1$) and those that were not ($CSURL_i = 0$); $RLYR_i$ is the year that variety i is released; δ_t is a vector of binary variables (0 or 1) for each year t, from 1974 - 2011 with 2011 being the base year for the analysis; and θ_j is a vector of binary variables (0 or 1) for each of the 51 variety trial locations with Akron, Colorado, being the base location.

Data used in this analysis were obtained from the Colorado Wheat Variety Database (http://wheat.colostate.edu/vpt.html) and consisted of annual yield data from 1974 - 2011 of multiple varieties gathered from 51 variety trial locations across the state (both irrigated and non-irrigated).[2] Two hundred and twenty-five different varieties were identified by their source and the release year to the public. These experimental plots resulted in a total of 11,077 -pooled observations. Due to the nature of the data, where the years vary between variety trial locations, the analysis contains an unbalanced panel data set. 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 hard white wheat varieties are increasing in popularity mainly because of the end use advantages they may have over hard red wheat in baking, making noodles, whole grain products, etc. Two other binary variables (*Private* and *CSURL*) were 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 (δ) accounts for the changes in weather from year to year and technology changes to be held constant. The station variable (θ) is the cross-sectional portion of the panel data and allows growing conditions to be held constant based on the region of the state.

Estimation Procedures and Results

As seen in Table 1, the variable *White* suggests that hard white wheat produces on average 0.76 bushels per acre less than hard red wheat varieties, but the result is not statistically significant. This result follows logic given that very few varieties are tested and even fewer are being grown in Colorado. This finding concurs with Nalley, Barkley and Chumley (2008). They argue that despite the lower yields of some hard white wheat varieties, the end use qualities of hard white wheat, in comparison to hard red wheat, will bring a higher selling price.

The estimated coefficient for *Private* was equal to 0.92 indicating 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 (Table 1). *CSURL* indicates the

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

Table 1. Colorado Wheat Yield Regression Results[a]

Variable	Mean	Estimated Coefficient	Standard Error
Intercept		-331.45***	28.02
White	0.09	-0.76	0.51
Private	0.30	0.92***	0.38
CSURL	0.29	0.74**	0.35
RLYR	1987.76	0.193***	0.01
Chi-square	12,005.88		
Log-likelihood	-46,078		
Number of Observations	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. *** and ** indicates the level of statistical significance at the 1% and 5% levels, respectively.

[a] The estimated coefficients used in this analysis are from an iterated general least squares regression, which is used to address heteroskedasticity issues.

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 yield 0.74 more bushels per acre than the varieties released by other public and private institutions. 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 varieties 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 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 0.19 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 and Genetics 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.[3] The remaining 51.16% can be attributed to increases in technology, production management and agronomic practices.

Table 2 and table 3 provide insight as to the production differences across the years and location. 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 2 demonstrates the differences in yield between Akron (base location) and all other variety trial locations. As expected, the locations that have irrigation have much higher yields. For example, Fort Collins has 25.6 bu/ac higher yields when compared to Akron. Another item of particular interest can be observed when comparing the stations by region. It can be seen that those stations located north of I-70, on average, have higher yields compared to those south of I-70 (with the exception of Cortez which is located in the southwest region). The δ_t term allows the variation across the years to be held constant.

Table 3 shows the difference in yield when compared to 2011 (the base year). As expected, across time the average yields have increased. For example, the increase in yield over the previous 10, 20, and 30 years is 6.1 bu/ac, 7.9 bu/ac, and 13.7 bu/ac, respectively.

[3] 7.33 is a result of the cumulative genetic improvement of 0.193 over the 38 time periods.

Table 2. Fixed Effects Regression Results: Yield Difference between Locations (bu./ac.)

Location #	Variety Trial Location Name[a]	Location Region	Regression Model Difference
1	Akron (base)	Northeast	--
2	Amherst	Northeast	-0.6
3	Anton	Northeast	7.4
4	Arapahoe	Southeast	-10.5
5	Bennett	Northeast	-2.9
6	Briggsdale	Northeast	-24.0
7	Burlington (I)	Northeast	17.0
8	Burlington (NI)	Northeast	-4.8
9	Cheyenne Wells	Southeast	-12.0
10	Clarkville	Northeast	5.6
11	Cortez	Southwest	2.8
12	Dailey (I)	Northeast	24.8
13	Eads	Southeast	-7.2
14	Fort Collins (I)	Northeast	25.6
15	Fort Morgan	Northeast	4.6
16	Genoa	Northeast	-2.3
17	Haxtun (I)	Northeast	52.6
18	Holly (I)	Southeast	3.2
19	Holyoke (I)	Northeast	3.4
20	Hoyt	Northeast	5.2
21	Julesburg (I)	Northeast	18.8
22	Julesburg (NI)	Northeast	0.7
23	Karval	Southeast	2.7
24	Kim	Southeast	-1.2
25	Lamar	Southeast	-8.6
26	Matheson	Southeast	4.3
27	New Raymer	Northeast	6.0
28	Nunn	Northeast	-8.8
29	Orchard	Northeast	-3.2
30	Ovid (I)	Northeast	21.2
31	Ovid (NI)	Northeast	-1.6
32	Paoli (I)	Northeast	10.5
33	Peetz	Northeast	-4.0
34	Platner	Northeast	-3.0
35	Proctor (I)	Northeast	11.6
36	Punkin Center	Southeast	-2.8
37	Rocky Ford (I)	Southeast	25.9
38	Roggen	Northeast	-1.0
39	Sheridan Lake	Southeast	-5.4
40	Springfield	Southeast	4.4
41	Sterling	Northeast	-0.7
42	Stratton (I)	Northeast	41.4

Table 2. Fixed Effects Regression Results: Yield Difference between Locations (bu./ac.), cont.

Location #	Variety Trial Location Name[a]	Location Region	Regression Model Difference
43	Vernon (I)	Northeast	16.2
44	Walsh (I)	Southeast	8.2
45	Walsh (NI)	Southeast	-9.7
46	Wiggins (I)	Northeast	42.8
47	Wiggins (NI)	Northeast	1.5
48	Willard	Northeast	0.4
49	Wray (I)	Northeast	13.4
50	Yuma (I)	Northeast	30.5
51	Yuma (NI)	Northeast	-2.7

[a] I imples irrigation and NI implies no irrigation. Several trial locations have changed from irrigated to non-irrigated.

Table 3. Fixed Effects Regression Results: Yield Difference between Years (bu./ac.)

Year	Regression Model Difference
1974	-12.7
1975	-7.0
1976	-17.2
1977	-6.9
1978	-12.5
1979	-3.6
1980	-7.3
1981	-13.7
1982	-9.5
1983	1.2
1984	0.9
1985	5.0
1986	-1.9
1987	-1.7
1988	-11.6
1989	-7.8
1990	-10.7
1991	-7.9
1992	-7.4
1993	5.5
1994	-16.8
1995	-2.1

Table 3. Fixed Effects Regression Results: Yield Difference between Years (bu./ac.), cont.

1996	0.8
1997	-6.1
1998	6.0
1999	11.7
2000	-8.1
2001	-6.1
2002	-16.9
2003	3.8
2004	-2.8
2005	-17.0
2006	-23.4
2007	4.3
2008	-6.9
2009	2.5
2010	4.7
2011 (base)	--

Based on the *RLYR* coefficient, an estimation of the average increase in yield (0.193 bu./ac./yr.) 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 estimated regression, 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 4). The annual costs of the CSU Wheat Breeding and Genetics Program were estimated at $2.22 million and $3.22 million between 2006 and 2011, respectively (Sommers, 2012).

Comparing estimated benefits to estimated costs to calculate a benefit/cost ratio is a bit difficult to complete given the accessible data. For example, for 2011, benefits of $61.49 million vs. $3.22 million in costs suggest that the benefits outweigh the costs by a ratio of 19:1. However, the $61.49 million in 2011 benefits is a cumulative effect from 38 years of research while the $3.22 million in 2011 costs is a one-year research program expense with future benefits yet to be realized. Therefore, we suggest using 19:1 as an upper bound on the benefit cost ratio for the CSU Wheat Breeding and Genetics Program.

Ideally, we would calculate a benefit cost ratio for the program using 1974 - 2011 benefit/cost data. However, we are restricted to only having cost data for 2006 - 2011. Therefore, the best we can do is to assume that 2006 - 2011 cost data is reflective of previous years minus inflation. If we assume a 3% discount rate, the average annual benefits from the CSU Wheat Breeding and Genetics Program from 1974 - 2011 is $19.76 million. Compared to the average costs from 2006 - 2011 of $2.77 million, this suggests a benefit/cost ratio of 7:1. We suggest this as a lower bound on the benefit cost ratio for the CSU Wheat Breeding and Genetics Program.

Table 4. Annual Benefits and Costs of the Colorado State University Wheat Breeding Program

Year	Colorado Harvested Acres (in millions)	% Acres Using CSU Varieties	Nominal Colorado Wheat Price Received (bu./ac.)	Cumulative Genetic Improvement (bu./ac.)	Benefits	Costs[a]
1974	2.90	0.00	$3.81	0.193	$0	NA
1975	2.50	2.40	$3.24	0.386	$74,901	NA
1976	2.44	7.30	$2.36	0.578	$243,804	NA
1977	2.58	12.20	$2.12	0.771	$515,502	NA
1978	2.52	18.00	$2.81	0.964	$1,230,193	NA
1979	2.64	22.40	$3.53	1.157	$2,415,736	NA
1980	3.40	27.60	$3.70	1.350	$4,685,919	NA
1981	3.11	29.50	$3.58	1.542	$5,062,710	NA
1982	2.96	35.30	$3.35	1.735	$6,069,700	NA
1983	3.06	47.20	$3.24	1.928	$9,031,108	NA
1984	3.27	48.50	$3.19	2.121	$10,729,510	NA
1985	3.52	47.70	$2.77	2.314	$10,766,531	NA
1986	2.96	43.30	$2.26	2.506	$7,247,767	NA
1987	2.56	40.50	$2.51	2.699	$7,010,592	NA
1988	2.35	31.00	$3.69	2.892	$7,780,789	NA
1989	2.27	26.20	$3.66	3.085	$6,714,833	NA
1990	2.59	19.60	$2.46	3.278	$4,093,049	NA
1991	2.34	15.60	$3.07	3.470	$3,882,535	NA
1992	2.40	18.90	$3.15	3.663	$5,227,584	NA
1993	2.58	16.80	$3.21	3.856	$5,371,255	NA
1994	2.59	14.40	$3.48	4.049	$5,258,999	NA
1995	2.74	15.40	$4.64	4.242	$8,298,543	NA
1996	2.27	18.00	$4.26	4.434	$7,711,876	NA
1997	2.75	21.60	$3.17	4.627	$8,715,596	NA
1998	2.61	34.20	$2.49	4.820	$10,713,047	NA
1999	2.45	42.50	$2.22	5.013	$11,587,463	NA

Table 4. Annual Benefits and Costs of the Colorado State University Wheat Breeding Program, cont.

2000	2.40	50.60	$2.70	5.206	$17,040,090	NA
2001	2.04	58.50	$2.72	5.398	$17,557,825	NA
2002	1.67	59.70	$3.63	5.591	$20,234,965	NA
2003	2.23	57.50	$3.32	5.784	$24,611,851	NA
2004	1.71	57.90	$3.25	5.977	$19,277,090	NA
2005	2.22	55.40	$3.43	6.170	$26,014,662	NA
2006	1.92	51.00	$4.54	6.362	$28,269,750	$2,215,497
2007	2.37	45.60	$6.01	6.555	$42,560,618	$2,469,048
2008	1.94	54.40	$6.62	6.748	$47,047,583	$2,782,005
2009	2.48	61.40	$4.57	6.941	$48,280,374	$2,850,045
2010	2.38	60.50	$5.54	7.134	$56,833,326	$3,109,322
2011	2.03	62.20	$6.65	7.326	$61,487,198	$3,215,054
Mean	2.52	35.00	$3.55	3.760	$14,727,760	$2,773,495

[a] NA - Not available.

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. 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 over the past 38 years. Adjusting for inflation, we estimate that every $1 in costs attributed to the CSU Wheat Breeding and Genetics Program over the last 38 years has resulted in approximately $7 in yield benefits for Colorado producers. As suggested by the 19:1 ratio of 2011 benefits to 2011 costs, the overall benefit/cost ratio for the program will continue to increase for some time into the future.

Some limitations to this study include the exclusion of experimental lines of wheat that were not released as improved varieties. 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. As pointed out by Nalley, Barkley and Chumley this analysis is a "crude" estimate of the cumulative economic benefits due to its' limitations.

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