Wheat Yield Response: On-farm Management versus Breeder Contributions

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ABSTRACT

Data from the WSU wheat variety test program along with spatially interpolated historic weather records present a unique opportunity to compare wheat variety performance across time and Washington State geography. A key assumption in this analysis takes wheat variety to be genetically constant year-over-year. This assumption allows us to separate breeding versus farm-level productivity gains. Furthermore, across the wide variety of climate regions within Washington State, productivity gains can be measured for different climate regions, allowing a unique contribution to the body of literature attempting to differentiate the various technology contributions to farm productivity.

Analysis of breeder contributions to wheat productivity gains are then applied to state-wide USDA productivity data and determine the economic benefit provided by the wheat variety improvements to average $1.8M per year (2010 dollars).

OVERVIEW

Data from the Washington State University (WSU) wheat variety test program along with spatially and temporally interpolated historic weather records present a unique opportunity to compare wheat variety performance across time and geography. A key assumption in this analysis takes a wheat variety to be genetically constant year-over-year. If the same variety is observed improving in yield year-over-year, that measurable improvement, controlled for location and weather conditions, is attributable to on farm management improvements. Likewise, a difference in yield between varieties, controlling for location and weather conditions, allows a measure a performance between varieties. Using both of these measures we compare contributions to year-over-year gains in yield from breeder selection versus on farm management. Furthermore, these productivity gains and comparisons are estimated for each of the four major precipitation zones within Washington State.

DATA

Wheat variety yield data is sourced from the WSU Uniform Cereal Variety Testing Program. The WSU variety test program's stated mission is to provide growers with *"comprehensive information on the adaptation and performance of winter and spring wheat varieties across the different climate regions and management practices in eastern Washington."* Digitized data records covering harvest years 1979-2010 include 4,000-6,000 yearly experimental test plots in specific locations and coded by experimental category, including plots that were planted specifically to mimic standard farming practices. From over 340,000 available test plots over 70,000 meet the requirements characterized as standard farming practices.

This wheat variety data was matched with a spatially and temporally interpolated weather and temperature data set that includes hourly temperatures, daily precipitation, daily average wind, daily average solar insolation and daily soil moisture. This data is derived from a unique combination of North American Land Data Assimilation System Phase-2 (NLDAS-2) and Parameter-elevation Regressions on Independent Slopes Model (PRISM) data sets.

METHOD

Three different linear regression models were used to estimate gains in yield due to improved on-farm management and improved varieties. The regression models are titled, "Heat Index Model", "Evapotranspiration Model" and "Modified Thompson Model" and emphasize different methodological ways of measuring the effects on yield from moisture, temperature, wind, snow coverage, location, time and other factors. The basic analysis for each of the three models is described in general here:

On farm management contribution to gains in yield were estimated by regressing yield for each wheat variety i, at location j, and harvest year t, using some combination of temperature, location and weather variables represented by the matrix $\mathbf{W}_{jt}$ while also including a continuous time variable represented by the harvest year, YR_t and dummy variables V_i for each unique variety plus an interaction term between year and variety dummies . The model allows each variety a unique slope representing the year-over-year gain (or loss) in yield as a result of on farm management. The example model follows:

$$yield_{ijt} = a + b_1 YR_t + b_2 V_i + b_3 \left(V_i \times YR_t \right) + \mathbf{W}_{jt} + e_{ijt}$$

Differentiating variety yield with respect to year results in a unique year-over-year change in yield for each variety. Because we assume each unique variety's genetics to remain constant the derivative describes year-over-year changes in yield resulting from on-farm management only.

$$\frac{\partial yield_i}{\partial YR} = b_1 + b_3 V_i$$

In order to measure *breeder contributions to yield* a modified version of the model excludes the variety*year, , interaction term. In this case each variety is forced to share the same slope while the variety dummy variables describe intercept differences and as such, compare average yield differences between varieties. Ordering variety yield by release year allows a trend estimate on breeder contributions to gains in yield. The basic variety comparison model follows:

$$yield_{ijt} = a + b_1 YR_t + b_2 V_i + \mathbf{W}_{jt} + e_{ijt}$$

Climate predictions for Eastern Washington suggest a modest increase in average annual rainfall of 4% for the thirty year period 2020-2050 compared to the period 1971-2000. To account for modest increases in moisture a quadratic model is developed to estimate optimal annual rainfall totals for each wheat class. An example quadratic model follows:

$$Yield_{ijt} = a + b_1 YR_t + b_2 Rain_t + b_3 Rain_t^2 + b_x \mathbf{W}_{jt} + e_{ijt}$$

Furthermore, two models based on the heat index and modified Thompson approaches are developed to estimate variety response to marginal increases in moisture. An example of these models follow:

$$Yield_{ijt} = a + b_1 YR_t + b_2 Rain_t + b_3 Rain_t^2 + b_x \mathbf{W}_{jt} + e_{ijt}$$

METHOD (continued)

The model can be differentiated with respect to rainfall to determine each variety's response to an additional inch of rain:

$$\frac{\partial Yield_i}{\partial Rain} = b_2 + b_4 V_i$$

The models and their derivative are applied to each precipitation zone as well as the aggregate of all zones in Eastern Washington.

RESULTS

For the wheat class *winter white common*, the most widely cultivated wheat class in Washington State covering 60-70% of all wheat acreage, aggregate results estimate 25% of average year-over-year gains in yield derive from improved wheat varieties. Analysis by precipitation zone shows breeder contribution to gains are proportionally higher in dry regions (30-40% of all year-over-year gains attributable to variety improvements) and proportionally less for the wettest region (only 12% of all year-over-year gains attributable to variety improvements). Results for other wheat classes are also estimated.

Results from the analyses of breeder contributions to wheat productivity gains are applied to state-wide USDA annual wheat yield records to determine the economic gains attributable to wheat variety improvements. Annual economic gains are estimated to average about $1.4M for winter wheat and $0.4M for spring wheat. Combining all wheat classes the aggregated state-wide annual average economic gain from improved wheat varieties is about $1.8M (2010 dollars). These value estimates are gross monetary returns on the price per bushel received on the average increase in yield attributed to improved varieties. This value does not include costs associated with harvesting, storing and managing the additional yield nor does it account for any increase in seed price that may be associated with higher performing varieties.

WINTER WHEAT RESULTS (tabulated)

Winter Wheat Varieties
On-farm vs. Breeding Contributions to Yield

Winter Wheat Type	On-Farm / Breeder / % Breeder by Regression Model	dbush /dyr Dry	dbush /dyr Med-Dry	dbush /dyr Medium	dbush /dyr Wet	dbush /dyr All
Winter White Common	On-Farm, Heat Index Model	0.13	0.53	1.29	1.98	0.83
	On-Farm, Evapotranspiration Model	0.24	0.87	1.14	1.99	0.91
	On-Farm, Modified Thompson Model	0.33	0.40	1.45	1.68	0.87
	Breeder, Heat Index Model	0.17	0.27	0.27	0.28	0.36
	Breeder, Evapotranspiration Model	0.14	0.29	0.26	0.28	0.25
	Breeder, Modified Thompson Model	0.17	0.27	0.27	0.28	0.25
	% Breeding, Heat Index Model	0.56	0.34	0.17	0.12	0.30
	% Breeding, Evapotranspiration Model	0.37	0.25	0.19	0.12	0.22
	% Breeding, Modified Thompson Model	0.34	0.40	0.16	0.14	0.22
Winter White Club	On-Farm, Heat Index Model	0.04	0.31	0.55	2.30	0.62
	On-Farm, Evapotranspiration Model	0.06	0.15	0.08	1.62	0.23
	On-Farm, Modified Thompson Model	0.11	0.24	1.23	1.39	0.70
	Breeder, Heat Index Model	0.27	0.12	0.70	0.32	0.43
	Breeder, Evapotranspiration Model	0.25	0.15	0.45	0.14	0.38
	Breeder, Modified Thompson Model	0.55	0.12	0.46	0.20	0.46
	% Breeding, Heat Index Model	0.86	0.28	0.56	0.12	0.41
	% Breeding, Evapotranspiration Model	0.82	0.51	0.85	0.08	0.63
	% Breeding, Modified Thompson Model	0.83	0.33	0.27	0.13	0.40
Winter Red Common	On-Farm, Heat Index Model	0.37	0.21	†	1.66	0.29
	On-Farm, Evapotranspiration Model	0.31	0.76	†	1.84	0.95
	On-Farm, Modified Thompson Model	0.19	-0.48	†	2.05	0.39
	Breeder, Heat Index Model	0.16	0.31	†	0.64	0.31
	Breeder, Evapotranspiration Model	0.16	0.26	†	0.62	0.29
	Breeder, Modified Thompson Model	0.16	0.31	†	0.64	0.31
	% Breeding, Heat Index Model	0.30	0.59	†	0.28	0.52
	% Breeding, Evapotranspiration Model	0.34	0.25	†	0.25	0.23
	% Breeding, Modified Thompson Model	0.45	N/A	†	0.24	0.44

† Too few observations