AJAE Appendix for "Productivity Growth from Genetic Improvement: Evidence from Illinois Soybean Trial Data"

Jared P. Hutchins and Scott H. Irwin

A Control Variables

We include control variables in our time trend model to control for genotype-by-environment interactions, which can cause variation in Δy_{ijt} unrelated to genetic gain. Our control variables are either at the variety and location levels or are location fixed effects. At the variety level, we include the height of the plant at maturity, the week of the year that the plant matures, the lodging score of the plant,[1] whether the variety is soybean cyst nematode (SCN) resistant, and whether the seed is treated. For each location in each year, we include the planting week and the total monthly rainfall for May, June, July, August, and September. We also include that month's mean, minimum, and maximum temperature.

Each location planted soybeans in 30-inch rows and applied herbicides and fertilizer uniformly across the plants to allow for a clean comparison within each trial. By including these variety controls, we interpret yield independent of any incidental differences in height or lodging that may have led to difficulties in harvesting. During our twenty-year period, each trial used a seeding rate of 166,000 ppa.

Table A1 shows the impact of control variables on estimating the time trend. Without any controls, the rate of yield growth appears to be higher than with controls. The most significant reductions in the trend happen when variety and weather controls are included, especially for MG II. The importance of these controls in the estimation tells us that GxE effects biased yield trend estimates upward even after taking the difference between the private variety and the check variety. Location fixed-effects change the estimates a little less but do still appear to have a significant impact on the yield trend.

Tables A2 through A4 show the effects of control variables on the yields of private varieties, both unadjusted and adjusted by differencing out the check variety. In some cases, controls that significantly impact the outcome are no longer significant when the check variety's yield is subtracted. In other cases, control variables retain their significance, indicating GxE impacts. Comparatively, rainfall appears to significantly impact yields more than temperature.

Table A1: Different Levels of Controls

	(1)	(2)	(3)	(4)
Maturity Group II				
Jack Trend	40.686***	40.874***	27.129***	25.226***
	(3.519)	(3.935)	(3.524)	(3.534)
Observations	23,441	23,207	23,207	23,207
Adjusted R^2	0.269	0.319	0.427	0.449
Dwight Trend	45.034***	34.741***	28.010***	26.413***
	(5.018)	(5.294)	(3.001)	(3.069)
Observations	23,441	23,207	23,207	23,207
Adjusted R^2	0.299	0.348	0.439	0.455
Maturity Group III				
Williams 82 Trend	31.983***	22.142***	26.124***	25.664***
	(6.490)	(4.777)	(6.161)	(4.073)
Observations	27,565	27,233	27,233	27,233
Adjusted R^2	0.156	0.228	0.285	0.375
Variety Controls		X	X	X
Weather Controls			X	X
Location FE				X

Note: *p<0.1; **p<0.05; ***p<0.01

Table A2: Variety Control Variables

	Maturity Group II			*Maturity Group III*	
	Unadjusted	Adj. Jack	Adj. Dwight	Unadjusted	Adj. Williams
	(1)	(2)	(3)	(4)	(5)
Year Trend	29.735***	25.226***	26.413***	35.926***	25.664***
	(7.936)	(3.534)	(3.069)	(4.586)	(4.073)
Height	19.233**	4.778	4.810	17.050**	7.795*
	(6.205)	(3.827)	(4.491)	(7.475)	(4.084)
Lodging Score	−37.285	15.060	29.400	−64.509	−106.411***
	(58.010)	(33.331)	(37.352)	(39.020)	(25.540)
Height (Check)		−16.308**			
		(6.144)			
Lodging Score (Check)		127.896**			
		(43.039)			
Height (Check)			−4.751		
			(19.092)		
Lodging Score (Check)			53.500		
			(75.971)		
Height (Check)					−17.011**
					(7.215)
Lodging Score (Check)					145.537**
					(59.697)
SCN Resistance	−30.873	11.848	−2.338	31.602	94.564***
	(25.578)	(34.148)	(26.106)	(22.332)	(17.643)
Seed Treatment	38.069	36.278**	54.111***	−16.574	−2.605
	(20.841)	(11.778)	(12.877)	(20.968)	(12.655)
Observations	23,207	23,207	23,207	27,233	27,233
Adjusted R^2	0.534	0.449	0.455	0.622	0.375

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table A3: Rainfall Control Variables

	Maturity Group II			*Maturity Group III*	
	Unadjusted	Adj. Jack	Adj. Dwight	Unadjusted	Adj. Williams
	(1)	(2)	(3)	(4)	(5)
Rainfall (ppt)					
May	8.360	97.358	−17.259	91.075*	−36.308
	(99.569)	(64.376)	(54.546)	(44.562)	(22.587)
June	90.320	−17.346	−43.868	100.284**	60.528
	(77.069)	(38.367)	(47.683)	(41.251)	(54.780)
July	95.424	−55.125*	88.829**	172.284***	59.638*
	(88.990)	(29.201)	(29.243)	(29.877)	(31.116)
August	70.367	−8.191	12.475	90.284	50.441
	(39.132)	(29.817)	(45.402)	(56.195)	(37.799)
September	76.245*	11.521	2.950	30.041	−43.269
	(34.464)	(30.462)	(39.771)	(28.780)	(27.042)
Rainfall Squared (ppt)					
May	−1.931	−10.290	−1.965	−7.583*	1.815
	(6.992)	(6.050)	(4.432)	(3.941)	(2.703)
June	−10.342*	3.524	2.957	−7.130	−6.498
	(5.235)	(2.951)	(3.595)	(4.164)	(4.530)
July	−0.463	9.455**	−3.619	−15.282***	−4.215
	(9.862)	(3.104)	(2.671)	(2.589)	(3.063)
August	−8.977***	3.770	0.358	−4.209	−4.620
	(1.605)	(2.642)	(3.172)	(5.107)	(2.958)
September	−9.196**	0.495	−1.107	−2.335	4.232**
	(2.780)	(2.377)	(3.567)	(3.099)	(1.908)
Observations	23,207	23,207	23,207	27,233	27,233
Adjusted R^2	0.555	0.479	0.484	0.640	0.410

Note: *p<0.1; **p<0.05; ***p<0.01

Table A4: Temperature Control Variables

	Maturity Group II			Maturity Group III	
	Unadjusted	Adj. Jack	Adj. Dwight	Unadjusted	Adj. Williams
	(1)	(2)	(3)	(4)	(5)
Temp Min (degrees C)					
May	694,495.600**	−31,609.190	144,017.100	10,479.710	26,248.480
	(290,824.300)	(252,906.100)	(147,053.800)	(442,193.300)	(278,180.300)
June	−1,106,294.000*	−332,868.400	−18,518.900	551,953.300	231,437.700
	(552,660.400)	(199,589.900)	(246,840.900)	(362,210.200)	(480,462.400)
July	−100,832.100	−410,878.500	−370,752.400	−260,829.900	100,764.100
	(376,471.000)	(300,746.000)	(246,471.300)	(374,529.300)	(381,082.900)
August	676,362.700	794,879.200***	400,476.600**	93,574.400	−54,571.480
	(489,009.400)	(218,842.800)	(157,731.200)	(258,937.800)	(238,444.200)
September	−364,076.100	−305,214.500	−486,884.100	−52,041.060	−386,386.800
	(431,231.700)	(168,510.400)	(283,745.000)	(418,182.300)	(243,066.500)
Temp Max (degrees C)					
May	694,509.100**	−31,703.270	143,906.400	10,110.350	26,146.130
	(290,841.100)	(252,907.000)	(146,977.600)	(442,190.600)	(278,177.600)
June	−1,106,853.000*	−333,098.300	−18,833.350	551,801.100	231,337.400
	(552,709.600)	(199,558.200)	(246,808.200)	(362,189.700)	(480,487.800)
July	−100,646.700	−410,847.300	−370,893.900	−260,497.000	100,889.900
	(376,494.100)	(300,741.400)	(246,435.800)	(374,550.600)	(381,056.900)
August	676,358.800	795,079.900***	400,791.500**	93,478.050	−54,670.570
	(489,175.100)	(218,863.500)	(157,709.200)	(258,950.600)	(238,416.100)
September	−364,242.900	−305,209.600	−486,883.500	−52,157.320	−386,398.500
	(431,228.700)	(168,496.200)	(283,727.500)	(418,173.300)	(243,046.100)
Temp Mean (degrees C)					
May	−1,388,950.000**	63,329.890	−287,924.100	−20,574.010	−52,370.970
	(581,646.400)	(505,802.400)	(294,031.100)	(884,394.000)	(556,354.000)
June	2,213,371.000*	666,026.600	37,442.060	−1,103,657.000	−462,748.400
	(1,105,354.000)	(399,138.900)	(493,649.000)	(724,385.000)	(960,973.300)
July	201,432.400	821,745.100	741,639.900	521,343.000	−201,660.300
	(752,957.500)	(601,500.900)	(492,917.700)	(749,082.800)	(762,141.400)
August	−1,352,904.000	−1,589,970.000***	−801,266.300**	−187,228.700	109,290.000
	(978,172.000)	(437,699.100)	(315,451.200)	(517,912.600)	(476,866.300)
September	728,342.500	610,392.800	973,745.100	104,296.800	772,731.400
	(862,446.500)	(336,997.200)	(567,433.800)	(836,366.800)	(486,135.500)
Observations	23,207	23,207	23,207	27,233	27,233
Adjusted R^2	0.555	0.479	0.484	0.640	0.410

Note: *p<0.1; **p<0.05; ***p<0.01

B Alternative Models

B.1 Varying Coefficient of Check Variety

In our main specification, we point out that our approach is the same as using the check variety's yield in the same year and location as a control variable but with the coefficient fixed to be 1. To allow more flexibility in the model, we can allow the coefficient to vary by estimating a model like this:

$$y_{ijt} = \tau YoR_i + \gamma y_{0jt} + \mu_j + \delta X_{ijt} + \upsilon Z_{jt} + \Delta\epsilon_{ijt}. \tag{1}$$

where γ may or may not be equal to 1.

In Table B1, we show our year trend estimates either with the coefficient fixed to being 1 or allowed to vary and the estimated coefficient. The coefficient on the check variety yield is between 0.7 and 0.8 for all of the maturity groups. It does not appear to make a significant difference in calculating the linear rate of yield gain from genetics. Figure B1 shows the year fixed effects calculation for MG II using the check variety Jack to adjust, with and without the varying coefficient. In addition to the linear rates of change being statistically indistinguishable, the year-of-release fixed effects are also similar in both models.

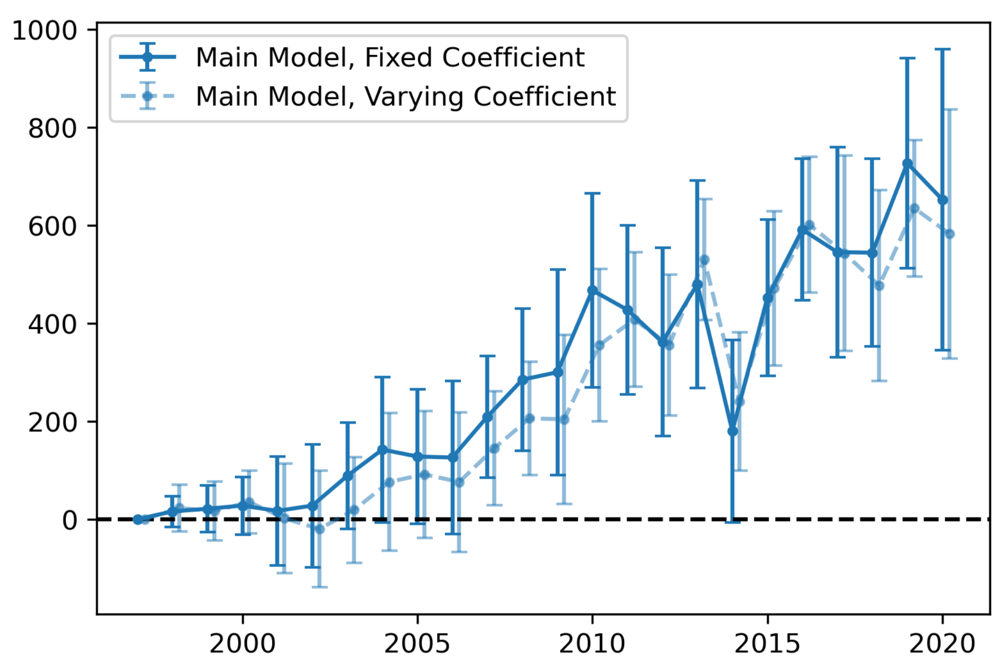
B.2 Variety Fixed Effects with Parsing

In Table B3, we examine some alternative specifications for the VFE. In case the VFE produces too volatile intercepts, we first show the time trends when only intercepts that are statistically different from zero at the 90% level are used. Second, we restrict the sample only to varieties that have been tested for at least two years to determine whether temporal variation significantly impacts the estimates. The yield trend is not significantly

Table B1: Main Specification, Varying or Fixed Coefficients on Check Variety Yield

	MG II				MG III	
	Jack		Dwight		Williams 82	
	Fixed	Varying	Fixed	Varying	Fixed	Varying
	(1)	(2)	(3)	(4)	(5)	(6)
Year Trend	25.225***	24.475***	26.413***	25.623***	25.664***	26.156***
	(3.534)	(2.836)	(3.069)	(3.011)	(4.073)	(3.544)
Check Variety Yield		0.800***		0.747***		0.691***
		(0.028)		(0.023)		(0.060)
Observations	23,207	23,207	23,207	23,207	27,233	27,233
Adjusted R^2	0.449	0.757	0.455	0.745	0.375	0.747
Note:				*p<0.1; **p<0.05; ***p<0.01		

Figure B1: MG II Change using Jack, Varying and Fixed Coefficient



different in either of these alternative specifications. However, when using Dwight as the base category, the effects more closely match the Jack results when using all of the coefficients instead of just the significant ones. Thus, it is likely that the differences in the VFE method between these two check variety comparisons is explained by some coefficients becoming insignificant when the check variety is changed.

Table B2: Variety Fixed Effects Method

	MG II				MG III	
	Jack		Dwight		Williams 82	
Year Trend	31.114***	13.745***	23.302***	13.054***	28.048***	18.608***
	(1.087)	(2.145)	(0.868)	(1.739)	(0.871)	(1.529)
Year Trend X GE		30.672***		18.593***		11.116***
		(2.530)		(2.052)		(1.908)
Observations	2,914	2,914	2,915	2,915	3,379	3,379
Adjusted R^2	0.219	0.281	0.198	0.238	0.235	0.254

Note: *p<0.1; **p<0.05; ***p<0.01
Variety FEs are set equal to zero when $p > .1$

B.3 Random Effects

Fixed effects can be easily influenced by outlier observations which can skew the average of the effects in each release year. As we explain in the methodology section, another approach to estimating a variety's yield contribution is to model its intercept as random instead of fixed. Random effects will produce estimates for varieties with even a few data points by essentially borrowing variation from other varieties (Ramsey and Rejesus 2021). This produces a "shrinking" effect whereby a variety's intercept is skewed towards the average since they are assumed to be drawn from a distribution, often assumed to be normal. This approach has other advantages in a Bayesian framework, such as modeling heterogeneous slopes, examining the standard deviation of the intercepts, and getting the

Table B3: Variety FE Model, Alternative Specifications

	Only Significant	All Estimates	At Least Two Years
Maturity Group II			
Jack	31.114***	29.472***	27.718***
	(1.087)	(0.956)	(1.452)
Observations	2,914	2,914	1,127
Adjusted R^2	0.219	0.246	0.244
Dwight	23.302***	29.535***	22.322***
	(0.868)	(0.956)	(1.148)
Observations	2,915	2,915	1,128
Adjusted R^2	0.198	0.247	0.251
Maturity Group III			
Williams 82	28.048***	27.176***	29.994***
	(0.871)	(0.790)	(1.056)
Observations	3,379	3,379	1,375
Adjusted R^2	0.235	0.259	0.369

Note: *p<0.1; **p<0.05; ***p<0.01

most efficient estimates from a variance perspective. The disadvantages of this approach are that it imposes a distributional assumption that may not be correct and must assume that the variety's intercept is independent of the other covariates (Antonakis, Bastardoz and Rönkkö 2021; Wooldridge 2010).

Since many of our varieties have only a few data points in each year, it is worth understanding the contribution of random effects to studying yield gain from genetics in this data. The validity of the random effects assumption rests on whether or not the appearance of varieties in locations is unrelated to the covariates. For example, if a company selects a variety to appear in a certain location because of that location's climate, this might violate the random effects assumption. In Table B4, we show the estimates of yield gain from genetics each year using the main method, the variety fixed effects method, and the variety random effects method. The variety random effects method assumes that the variety impacts are from a normal distribution. In both maturity groups, the random effects estimates are much smaller than the other approaches. In Figure B2, we can see that the random effects are much more modest than the other approaches. The random effects in maturity group II predict no yield gain before 2010. The random effects in maturity group III are positive but still much smaller than the other models.

This particular estimation does not provide evidence of the validity of the random effects or mixed model approach in general. Instead, it shows that random effects, in their simplest, most naive form, give very different estimates from these data. This approach could be bolstered by estimating more heterogeneous slopes to weaken the assumption that the variety intercepts are unrelated to the covariates. Indeed, the mixed model/Bayesian approach could be used to bolster the main approach in this paper and the variety fixed effects method. Understanding how these methods might complement each other is a fruitful area for future research.

C Robustness Checks

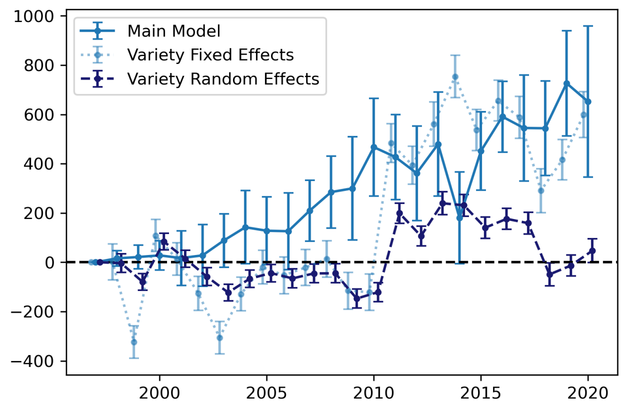
C.1 Company Panel

According to Figure 3, there is significant company attrition in this data. For this reason, it is difficult to understand to what extent the time trends we see in the data are impacted by companies dropping out of the University of Illinois soybean trials. After 2008, we also see a small decrease in the percent of variety submissions that are GE (Figure 4). This might lead us to suspect that the genetic gain we calculate in this data is influenced by certain companies participating in the trials instead of others.

The robustness check we perform here forms a panel of companies that participated in at least 95% of the years in the sample. Figure C1 shows the GE adoption rates for the

Figure B2: Year Fixed Effects, Comparison to Random Effects

(a) Maturity Group II (Jack)



(b) Maturity Group III (Williams 82)

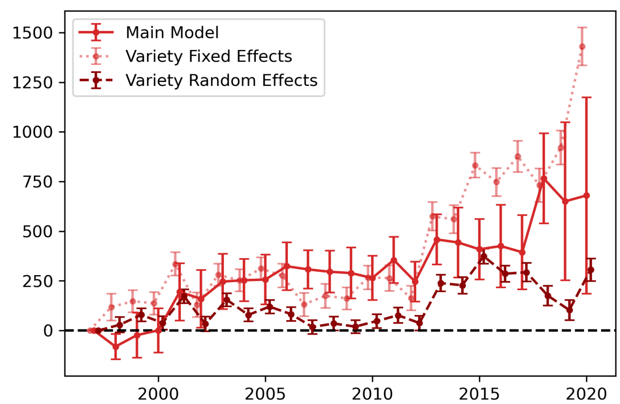
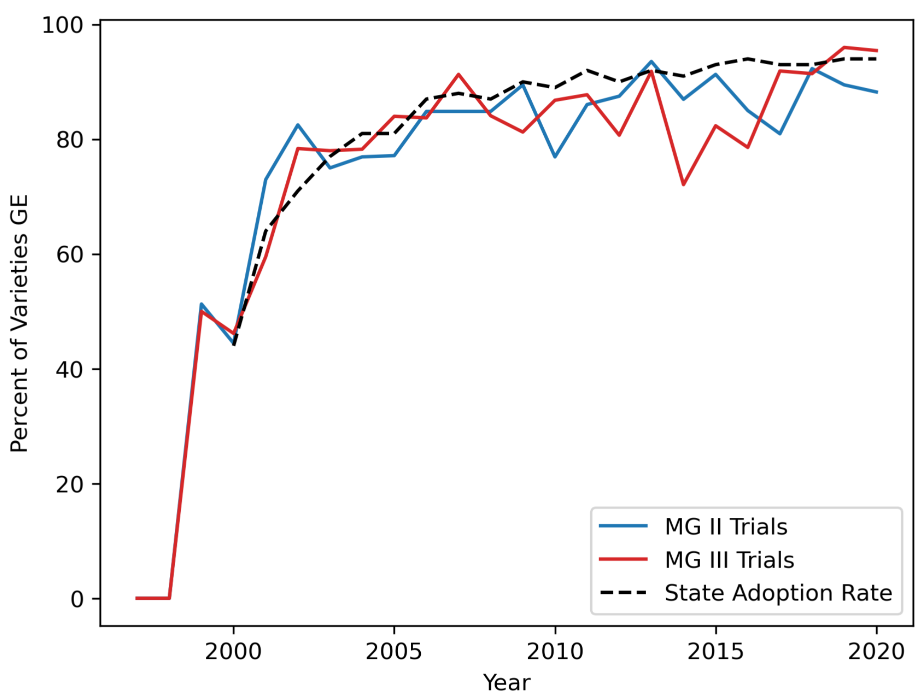


Table B4: Methods Comparison, Fixed and Random Effects

	Main Model	Fixed Effects	Random Effects
		Maturity Group II (Jack)	
Year Trend	24.475***	31.424***	5.555***
	(2.836)	(0.989)	(0.494)
Observations	23,207	2,814	2,816
Adjusted R^2	0.757	0.264	0.043
		Maturity Group III (Williams 82)	
Year Trend	26.156***	31.240***	8.213***
	(3.544)	(0.864)	(0.484)
Observations	27,233	3,257	3,259
Adjusted R^2	0.747	0.286	0.081
Note:			*p<0.1; **p<0.05; ***p<0.01

Figure C1: GE Adoption Rate, Company Panel



trials when we only consider these companies. Compared to Figure ??, these companies have a portfolio of varieties much closer to the state average. This suggests either that the companies that entered after 2008 are testing more conventional varieties or that companies that have dropped out of the trials are testing more GE varieties.

Table C1 shows the time trend for the whole sample versus the balanced panel of companies. The point estimates are essentially unchanged for the time trend for all the varieties (upper panel of Table C1). Given the size of the standard errors, it is unlikely that the estimates of the time trend are statistically distinguishable between samples.

However, the company panel does have significant impacts on the GE component of the trend. In the lower panel of Table C1, we compare the trend with the GE interaction on the full sample versus the company panel. The GE coefficient is statistically insignificant in the company panel results, meaning that GE varieties grow at the same rate as conventional varieties in this subsample. The point estimates are also a bit smaller, indicating that the statistical insignificance is not solely the result of bigger standard errors due to a smaller sample size. These results suggest that the boost from GE varieties to the time trend is driven mainly by companies that enter or exit the data.

C.2 Balanced Regions

Figure 2 shows that our three check varieties, Jack, Dwight, and Williams 82, are only consistently planted in Regions 2 and 3. If locations fail to plant the check varieties for any reason related to the varieties submitted there, using the full sample could cause problems in the estimation. For example, if Williams 82 stopped being planted in a certain location because of the company submissions to that location then there might be bias in our time trends.

In Table C2 we compare our main results on the full sample to the time trend using only Regions 2 and 3 for MG II and only Region 3 for MG III. In these regions, the check variety was consistently planted. The trends are slightly different when only using Re-

Table C1: All Companies versus Panel of Companies

	MG II, Adj. Jack		*MG II, Adj. Dwight*		*MG III, Adj. Williams*	
	All	Panel	All	Panel	All	Panel
	(1)	(2)	(3)	(4)	(5)	(6)
Year Trend	25.225***	23.829***	26.413***	28.509***	25.664***	23.162***
	(3.534)	(4.574)	(3.069)	(5.119)	(4.073)	(4.059)
Observations	23,207	3,629	23,207	3,629	27,233	3,870
Adjusted R^2	0.449	0.503	0.455	0.500	0.375	0.413
Year Trend	20.692***	20.020***	13.650***	22.618***	26.345**	20.701***
	(3.886)	(4.796)	(3.757)	(5.145)	(6.881)	(5.650)
Year Trend X GE	15.409***	6.667	24.346***	10.196	15.195**	8.015
	(4.419)	(6.854)	(5.700)	(7.725)	(4.642)	(5.051)
Observations	23,207	3,485	23,207	3,485	20,420	3,704
Adjusted R^2	0.487	0.508	0.496	0.503	0.458	0.434

Note: *** p<0.01, ** p<0.05, * p<0.1.
Standard errors are clustered at the location level.
Variety Controls: height of base and private variety, lodging score of base and private variety, maturity week of base and private variety, seed treatment, planting week, and SCN resistance.
Weather Controls: monthly rainfall, monthly rainfall squared, mean monthly temperature, max monthly temperature, min monthly temperature (May, June, July, August, September)

gions 2 and 3 but not in any consistent direction. When using Dwight or Williams 82 as the check variety, the linear time trend increases when using only regions 2 and 3.

Table C2: Yield Trends, Regions 2 and 3 Only

	MG II				*MG III*	
	Jack		Dwight		Williams 82	
	All	Region 2/3	All	Region 2/3	All	Region 3
	(1)	(2)	(3)	(4)	(5)	(6)
Year Trend	25.226***	24.528***	26.413***	32.414***	25.664***	30.365**
	(3.534)	(4.879)	(3.069)	(6.764)	(4.073)	(6.507)
Observations	23,207	12,305	23,207	12,305	27,233	13,799
Adjusted R^2	0.449	0.545	0.455	0.597	0.375	0.512

Note: *** p<0.01, ** p<0.05, * p<0.1.
Standard errors are clustered at the location level.
Variety Controls: height of base and private variety, lodging score of base and private variety, maturity week of base and private variety, seed treatment, planting week, and SCN resistance.
Weather Controls: monthly rainfall, monthly rainfall squared, mean monthly temperature, max monthly temperature, min monthly temperature (May, June, July, August, September)

C.3 Year of Trial Versus First Year Tested

In our main results, we use the first year a variety is tested in the trial as the "year of release" to estimate the linear time trend and year fixed effects. Since some of these varieties are never released, we use the first year that it appeared in the trial as a good approximation of the year that the variety was developed. The year of release is the variable most often used when studying genetic improvement in seed genetics (Rincker et al. 2014; Tack, Lingenfelser and Jagadish 2017).

An alternative variable for the time trend is the year the trial occurred ("year of trial"). Using this measure differs from the first approach because it will attribute the performance of a variety first introduced in one year to every year it is tested. For example, if a variety is tested in both 2000 and 2001, the "year of release" will only attribute its performance in both years to the year 2000. The "year of trial" will instead attribute its performance in each of those years to that year. Otherwise, using the year of the trial treats each variety tested in each year as essentially a new variety. The results should only differ when a sufficient number of varieties are tested in more than one year and their performance is significantly different between years.

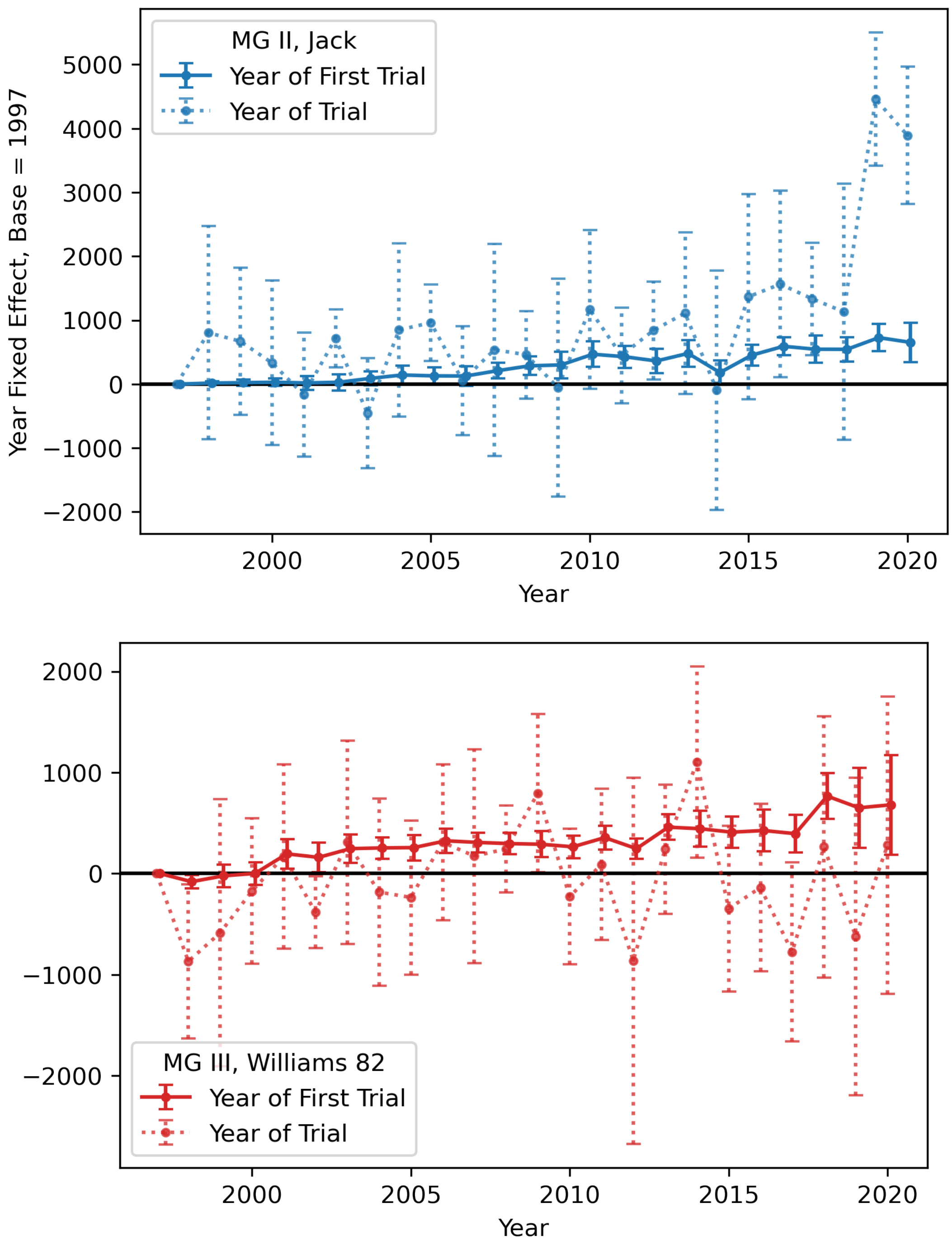
Table C3: Year of First Test Versus Year of Trial

	MG II, Adj. Jack		*MG II, Adj. Dwight*		*MG III, Adj. Williams*	
	First Year	Year of Trial	First Year	Year of Trial	First Year	Year of Trial
	(1)	(2)	(3)	(4)	(5)	(6)
Year Trend	25.226***	32.769***	26.413***	33.687***	25.664***	29.896***
	(3.534)	(4.606)	(3.069)	(3.910)	(4.073)	(5.158)
Observations	23,207	23,207	23,207	23,207	27,233	27,233
Adjusted R^2	0.449	0.455	0.455	0.460	0.375	0.378

Note: *** p<0.01, ** p<0.05, * p<0.1.
Standard errors are clustered at the location level.
Variety Controls: height of base and private variety, lodging score of base and private variety, maturity week of base and private variety, seed treatment, planting week, and SCN resistance.
Weather Controls: monthly rainfall, monthly rainfall squared, mean monthly temperature, max monthly temperature, min monthly temperature (May, June, July, August, September)

Table C3 compares two time trends: one estimated with the year of the first test and one with the year of the trial. Our estimates with the year of the first test were 25-26 kh/ha per year but the rate increases to 30-32 kg/ha per year when year of the trial is used instead. This estimate agrees with both Rincker et al. (2014) and Xu et al. (2013) who both find a rate of growth around 30 kg/ha per year. Figure C2, however, shows that the year fixed effects using the year of the trial are much more volatile than the estimates using the year of first trial. These results suggest that while our estimates using the year of the first trial are more conservative they are likely more stable.

Figure C2: Year of First Trial and Year of Trial, Year FE



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