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Risk premiums and GM traits

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An argument in favor of the development of genetically modified (GM) hybrids is that their presence is considered to be risk decreasing. On this basis, insurance premiums for corn growers in the United States who plant

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approved hybrids have been reduced. In this study we investigate, using a large dataset of experimental data compiled from reports of results from experimental field trials of corn hybrids by the State Agricultural Extension Services of ten universities over 20 years, whether the presence in a corn hybrid of a GM trait, or a combination of these traits, is likely to increase or decrease risk. The effects of input use on production uncertainty can be quantified through the specification and estimation of heteroskedastic production functions that allow for the variance of yield to change with the level of inputs, and we follow this approach in this study. We also use the flexible moments approach of Antle (1983) to estimate skewness of yield. We estimate a production function for the whole sample, and for three ERS regions represented in the dataset. For each model we use the residuals of the mean function to estimate the marginal effect of each input on variance and skewness of yield. The results show that there is not a systematic relationship between the presence of GM traits and variance and skewness of yield, and the results are not entirely consistent between ERS regions.

Key words: Production functions, yield, risk, skewness, corn, genetically modified traits.

JEL codes: C2, Q12, Q16

An important characteristic of yield risk is that its level can be influenced by the level of input use: while some inputs increase the level of yield risk, others will reduce it (Tveterås and Wan 2000). One argument in favor of the development of genetically modified (GM) hybrids is that the presence of the GM traits is considered to be risk decreasing. On this basis, the Risk Management Agency (RMA), which manages crop insurance in the United States through the Federal Crop Insurance Corporation (FCIC), has agreed to the reduction, by between 14 per cent (for yield risk programs) and 20 per cent (for revenue programs), of insurance premiums for corn growers who plant approved hybrids. The Biotech Yield Endorsement (BYE) was implemented in 2008, and followed by the Pilot Biotechnology Endorsement for the 2009-2011 crop years. The endorsement is available in counties in twelve states in which an eligible policy and plan of insurance is offered.[2] Qualifying hybrids are at least triple-stacked and are state-specific. The new endorsement was approved on the basis of actuarial reports from field trials from one company (Monsanto). We investigate (using trial data from the top ten corn-producing states in the US) the effect of the introduction of

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[2] In 2010, this reduction was in place in Colorado, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota and Wisconsin.

the GM traits over a wider area and a longer time frame. We particularly focus on the Bt corn borer and rootworm resistant traits and focus on yield in this paper, since the presence of GM traits has direct implications for yield rather than for revenue.

There is a very large literature which discusses multiple aspects of uncertainty and crop insurance. Much of this work dates from the 1990s or earlier. While there is a literature (for example, Rejesus et al. 2006) which discusses the implications of reducing premiums for producers with good records, we are not aware of any studies which investigate whether risk premium reduction is justified on the basis of the mean and variance of a particular input, in this case the GM characteristics of the corn hybrid. We use the approach developed by Just and Pope (1978) to estimate the variance of corn yield conditional on inputs, including the combinations of GM traits. Because it is likely that mean yields at the national level are skewed, since yield cannot exceed the biological potential of the plant, but can approach zero under attack by pests, or adverse weather conditions or natural disasters (Gallagher 1987), we also investigate the effect of GM traits on skewness. For this purpose we follow the approach suggested by Antle (1983), who himself builds on Just and Pope (1978), and who shows how to estimate an arbitrarily large number of conditional moments of a distribution.

Background

Production uncertainty has implications for the implementation of crop insurance, for which there is a latent demand, given the susceptibility of crop yields to weather fluctuations, and to other events such as pest infestations. The availability of crop insurance in the USA has depended on ongoing government support, at high cost. The role of the Federal Crop Insurance Corporation (FCIC), created in 1938, is to encourage the sale of crop insurance. While the crop insurance programs, administered since 1996 by the Risk Management Agency (RMA), have traditionally been based on protection and indemnities for yield alone new products designed to provide revenue insurance were introduced from 1996.

Crop insurance

Contracts are developed by the FCIC, and by private sector insurance providers. FCIC provides subsidized reinsurance to approved commercial insurers. In addition to subsidizing premiums, the FCIC also absorbs the administrative costs. Since 1998, all Multiple Peril Crop Insurance (MPCI) authorized under the Federal Crop Insurance Act has been sold by the private insurance companies (Risk Management Agency 2008).

The insurance provider agrees to indemnify the insured farmer against losses due to unavoidable perils beyond a farmer's control, such as unusual climate, insects and disease, inability to plant or excessive loss of quality due to adverse weather during the crop year. Actual Production History (APH) insurance covers between 50 and 85 per cent of the individual grower's yield history (Barnaby 2009). The producer insures between 55 and 100 per cent of the predicted price. If the harvested amount less any appraised production is less than the yield insured, the producer is paid an indemnity based on the difference (Risk Management Agency 2010). Other products pay indemnities on the basis of low prices, low yields, or both. Growers may also select catastrophic (CAT) coverage. The coverage is "free" but subject to a processing fee (Barnaby 2009). Multiple peril or all-risk agricultural insurance contracts are generally specified in terms of "result states" (eg yield) rather than the underlying state of nature (Chambers 1989). This has the practical advantage that adjusters need only determine total loss, and not loss caused by specific risk factors.

Premium rates vary according to insurance yield, and a grower with a top yield average typically pays a premium rate of about one-third that paid by a grower with a below average yield history (Barnaby 2009). In addition, the FCIC is introducing a Good Performance Refund (GPR) for producers who have demonstrated favorable crop insurance performance evidenced by a very limited number of claims over a specified number of years of participation in Federal crop insurance programs (USDA Office of Communications 2011). Its purpose is to encourage producers to use best available management practices, and rewards good performance by returning a portion of the costs paid into the program by those who have had limited or no losses (USDA Office of Communications 2011).

One of the original aims of the crop insurance program was to avoid the need to pay disaster relief. The 1994 Act made participation mandatory for farmers to be eligible for deficiency payments under price support schemes. In 1996 mandatory participation was repealed, but farmers who accepted other benefits were required to waive their eligibility for any disaster benefits that were available.

For unsubsidized insurance to be viable, loss ratios (ratio of indemnities to premium payments) need to be no more than 0.7 (Wright and Hewitt 1994). However, to encourage participation, the Federal Crop Insurance Act of 1980 authorized a subsidy of 30% of the crop insurance premium limited to the dollar amount of 65% coverage. Hence, Congress has given the RMA an objective of charging farmers a total premium (pre-subsidy) that would generate a loss ratio of 1.075 (Babcock, Hart and Hayes 2004).

Table 1. Insurance Statistics for Corn Compared with Total Crops

Total Crop Year Statistics as of 31 January 2011					**Corn Year Statistics as of 31 January 2011**			
Item	**1990**	**1999**	**2009**		**Item**	**1990**	**1999**	**2009**
	Number ('000)					Number ('000)		
Policies	895	1288	1171		Policies	295	451	504
Net acres insured	101361	196918	264621		Net acres insured	26304	52472	71893
						Percent		
					Insured acres as percentage of total acres planted to corn	35	67	83
	Billion dollars					Billion dollars		
Farmer paid premium	0.62	1.35	3.52		Farmer paid premium	0.16	0.4	1.36
Premium subsidies	0.22	0.95	3.82		Premium subsidies	0.05	0.2	2.04
Total premium	0.84	2.3	8.95		Total premium	0.21	0.6	3.4
Indemnities	0.97	2.43	5.43		Indemnities	0.12	0.36	1.18
Insurance protection	12.83	30.94	79.5		Insurance protection	4.04	8.6	31.1
	Percent					Percent		
Loss ratio	116	105	58		Loss ratio	55	60	35
Loss ratio excluding subsidy	156	180	154		Loss ratio excluding subsidy	75	90	87

Sources: USDA NASS (2011); Risk Management Agency (2011)

The actuarial performance of the program has depended on the variability of the weather and other events, and the ability of the program to control adverse selection and moral hazard problems. Over the 1980s and early 1990s the actuarial performance was poor. Since the introduction of coverage based on individual expected yields, participation rates have improved, mitigating adverse selection problems (Horowitz and Lichtenberg 1993). From 1994-2003 the aggregate loss ratio was 98% (compared with a ratio that exceeded 1.5 over 1981-

1993) (Glauber 2004), and it has continued to improve, particularly for corn. However if premiums are reduced, and risk can be shown to have increased, the loss ratio could be expected to increase.

Table 2. Insurance Statistics for Corn for Crop Years 1990-2010

Year	Number of policies ('000)	Net acres insured ('000)	Total corn acreage ('000)	% planted corn acres insured	Farmer paid premium ($m)	Premium subsidies ($m)	Total premium ($m)	Indemnities ($m)	Insurance protection ($m)	Loss ratio: Indemnities as percentage of total premiums	Loss ratio: Indemnities as percentage of farmer paid premiums
1990	296	26304	74166	35	160	54	214	117	4041	55	73
1991	231	20836	75957	27	131	45	176	211	3284	120	161
1992	218	22378	79311	28	146	50	196	159	3614	81	109
1993	218	22397	73239	31	137	48	185	604	3484	326	441
1994	290	29444	78921	37	199	70	269	52	4586	19	26
1995	609	59564	71479	83	167	205	372	350	6762	94	210
1996	501	47258	79229	60	189	218	407	216	6625	53	114
1997	463	49383	79537	62	255	206	461	152	7670	33	60
1998	441	51137	80165	64	302	233	535	357	8949	67	118
1999	451	52473	77386	68	403	200	603	364	8577	60	90
2000	488	56867	79551	71	546	194	740	403	10184	54	74
2001	480	55848	75702	74	374	492	866	566	10702	65	151
2002	475	58699	78894	74	399	511	910	1260	11424	138	316
2003	481	59494	78603	76	475	621	1096	700	12608	64	147
2004	493	62089	80929	77	614	793	1407	814	15544	58	133
2005	486	63053	81779	77	553	713	1266	698	14086	55	126
2006	486	62150	78327	79	690	871	1561	808	16774	52	117
2007	487	74969	93527	80	1371	1739	3110	1095	31444	35	80
2008	495	69325	85982	81	1688	2116	3804	3065	37534	81	182
2009	504	71893	86382	83	1358	2039	3397	1177	31073	35	87
2010	504	73514	88192	83	1106	1748	2854	1530	31665	54	138

Even though actuarial performance has become more acceptable, there is still concern about the large underwriting gains that private insurance companies earn under the program (Glauber 2004; LaFrance, Pope and Tack 2011: in press), and the average annual cost to government of the whole program which, for the crop years 2002-2010, and excluding premiums, was $4.12 billion (Risk Management Agency 2011). There has also been concern about the heavy costs of subsidies, and the distorting effects of crop insurance on production. From table 1 it can be seen that in 1990, liability (value of insurance in force) was $12.8 billion ($4.04 billion for corn), and total premium, including subsidy, was $840 million ($210 million for corn). By 2009, total liability was $79.5 billion

($31.1 billion for corn), and total premium $8.95 billion ($3.4 billion for corn). The loss ratios have historically been lower for corn than for the total crops insured. In 1990 35% of planted corn acreage was insured. In 1999 the figure was 67%, and in 2009 83% (Risk Management Agency 2011, USDA NASS 2011). More detailed statistics for corn can be found in table 2.

Given the already high costs of operating the MPCI scheme, it would appear that care should be taken in any move to reduce premiums. Since Goodwin, Vandeveer and Deal (2004) find a negative relationship between premium rates and level of participation, lower premiums are likely to lead to increased participation. In that context, an understanding of the marginal effects of input use on output variability is crucial to the understanding of the relationship between input use, including the use of GM traits, risk and the decision to participate in insurance programs. If GM traits have led to an increase, rather than a decrease, in variability of corn yield, it is possible that the already substantial costs of the program may increase.

Inputs, yield variability and skewness

Production risk is a well documented aspect of most types of biological production. Because stochastic production shocks are realized after input quantities have been chosen, the input choice also influences the level of risk to which producers are exposed, as some inputs increase the level of risk, while others reduce it. A producer's choice of variable inputs affects not only the mean level of output but also the shape of the statistical distribution of output (Babcock, Chalfant and Collender 1987).

Input use is also dependent on preferences towards risk. Risk averse producers choose input levels which differ from optimal input choices of risk-neutral producers (Tveterås and Wan 2000). A risk averse firm will use more (less) of a production factor than will a risk-neutral firm if the input decreases (increases) output variance (Babcock, Chalfant and Collender 1987). Ramaswami (1992) has shown that for all risk averse producers, the marginal risk premium is positive (negative) if and only if the input is risk increasing (decreasing). This implies that it is sufficient to obtain information on the marginal risk of an input in order to determine whether a risk averse producer uses less of the input than a risk neutral producer (Tveterås and Wan 2000).

Empirical studies have found evidence of risk reducing inputs. Some inputs (e.g. investment in improving environmental conditions, irrigation, frost protection, disease-resistant seed varieties, and over-capitalization) may be negatively related to the variance of crop outputs attributable to weather, insects and crop diseases, whereas it has been suggested that a positive relationship may exist between other inputs (such as land size and fertilizer) and output variability (Just and Pope 1978; Wan, Griffiths and Anderson 1992). In some cases the effect on yield variability is reasonably clear. Feder, Just and Zilberman (1985) found that irrigation both increases average production and reduces variability of output, agreeing with the arguments advanced earlier by Just and Pope (1979).[3] An input such as frost protection is also likely to reduce variability since survival of the crop becomes more probable and marginal product tends in probability towards zero as input use increases.

However the effect on variability is less certain for some other inputs, particularly agrochemical inputs such as fertilizer and pesticides. Interestingly for the objective of this paper, this question has been analysed in an indirect way by a number of authors, including Ramaswami (1993), who analyse the effect of insurance on input use and interpret any change as a result of input characteristics. Ramaswami found that if an input is risk-decreasing the effect of actuarially fair crop insurance is to reduce input use, however the effect on use of a risk-increasing input could not be theoretically established.

Various studies have used the positive (negative) relationship between use of an input and participation in MPCI as an indication of whether an input is risk-increasing (decreasing) for a risk-averse farmer. However, even this approach has not produced unanimous results. For example, while Horowitz and Lichtenberg (1993) conclude that MPCI participation induces increased use of fertilizer, insecticides, herbicides and total pesticides implicitly suggesting that these inputs are risk increasing, Babcock and Hennessy (1996) concluded that farmers who took out insurance reduced spending on nitrogen fertilizer, that is, used less

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[3] Irrigation may also reduce the skewness of a distribution, in that it provides a means of mitigating the effects of severe climatic variation. Harri et al. (2009), using 50 years of continuous data from 1956-2005 found that yield data for corn in counties in Corn Belt states, which are less subject to severe weather fluctuations, were non-normally distributed and consistently negatively skewed, while counties where normality is not rejected are mostly found in the predominantly irrigated plains region of Kansas and Nebraska, and parts of Mississippi, Pennsylvania and New York.

fertilizer than those who did not insure, suggesting that increased inputs reduced risk. Quiggin, Karagiannis and Stanton (1993) found that MPCI participation meant lower expenditures on inputs such as fertilizer, pesticides, labor and energy. They found that fertilizer and chemical expenditures exhibit a negative effect on yield variability for corn.

An interesting study is that of Smith and Goodwin (1996) who found that MPCI participation had a significant negative effect on total chemical input but argue that this result should not be taken as evidence that growers think that the inputs are risk reducing. Instead, they interpret their result as evidence for the presence of moral hazard: producers with insurance have different production practices from those who do not insure and growers who insure use less of some inputs because they will get payouts if their yield is lower[4]. An additional consequence of the presence of moral hazard may be that, as Smith and Goodwin (1996) also suggest, producers respond to increased yield variability by buying more insurance (holding expected returns constant).

The role of pesticides in increasing or decreasing yield variability is also unclear. Where the mean and variance have the same sign, a reduction in pesticide use would imply a reduction in variability of output, whereas, in reality, a reduction in pesticide use may or may not lead to more variable production. Pannell (1991) notes that there is general consensus in the literature that risk considerations influence pesticide use. Feder (1979) is considered to have established the theoretical relationship for the presumed negative relationship between degree of risk and level of pesticide usage. The farmer can affect the number of pests (or its distribution) within a given time period by using pesticides, thus eliminating a proportion of the pest population. A major motivation for pesticide application is the provision of some insurance against damage: that is the existence of uncertainty in the pest-pesticide system by itself leads to a higher and more frequent use of chemicals (Feder 1979). An increase in the degree of uncertainty regarding the damage per pest will cause an increase in the volume of pesticide application for any given degree of pest numbers and cost, even though the mean value of the average rate of damage is unchanged. By increasing the pesticide level farmers will reduce the level of risk at the margin

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[4] See also Goodwin, Vandeveer and Deal (2004)

(Feder 1979). Turpin and Maxwell (1976) show that farmers use soil pesticides as insurance against production uncertainty, suggesting that they perceive that that increasing input does not increase risk. Smith and Goodwin (1996) find that crop insurance and pesticides are substitutes, so that an increase in the use of pesticides reduces the requirement for crop insurance.

While Pannell (1991) agrees that uncertainty about some variables, such as pest density and pest mortality, does lead to higher pesticide use under risk aversion, he suggests that the reputation of pesticides as risk reducing inputs appears to be mainly based on analyses which only consider uncertainty about the level of pest infestation or chemical efficacy, and does not consider the many other sources, such as uncertainty about output price and yield, in the pest/pesticide/crop system which may or may not result in reduced risk as pesticide use is increased. The conclusions of Pannell (1991) and Horowitz and Lichtenberg (1993) differ from the conventional wisdom because they consider output uncertainty rather than concentrating solely on pest infestation. Pesticides are likely to be risk increasing rather than decreasing when output uncertainty is the dominant source of randomness (Pannell 1991). Specific pesticides only have a major effect on output when there is an incidence of the pest.

Horowitz and Lichtenberg (1993) argue that, intuitively, an input reduces risk if it adds more to output in bad states of nature than in good states of nature, since this makes output in each state of nature more uniform and decreases yield variability. An input increases risk if it adds relatively more to output in good states than in bad ones, since that increases the discrepancy between states of nature. In crops where high pest infestations occur primarily when crop growth conditions are good, pesticides work by increasing output in good states of nature and marginal variance is likely to be positive (Horowitz and Lichtenberg 1993).

Finally, and also related to the topic of this paper, Traxler et al. (1995) concluded that early varietal research emphasized increasing mean yield, while the emphasis later shifted to the reduction of yield variance. We now turn to a discussion of the literature on the effect of the latest generation of varietal changes and yield variability.

Pesticides, GM traits and variability

Bt corn is genetically engineered to produce a protein found in the soil bacterium *Bacillus thuringiensis*. The protein is toxic to lepidopterous insects (Hurley, Mitchell and Rice 2004). The Bt traits offer nearly complete protection against the European corn borer (Ortman et al. 2001) and the western rootworm, and are much more effective than conventional chemical controls.

Applications of foliar insecticide used to control corn borer infestations in non Bt corn are less effective than Bt traits because of the difficulty in scouting and timing treatments to control the larvae before they bore into the plant (Ortman et al. 2001). Corn rootworm is probably the most economically important pest in the United States, and was managed historically by rotating crops or with soil insecticide. Some species of rootworm have evolved to reduce the effectiveness of crop rotation in some areas, and if rotation is not effective, soil insecticide is the only form of control available. However, as insecticide is applied in the soil, it is difficult to ensure that each plant is protected, while with rootworm resistant Bt seed technology each individual plant is protected. Yields will increase relative to non-Bt fields where infestations occur (Payne, Fernandez-Cornejo and Daberkow 2003).

A non-zero pest infestation causes some pest damage. Maximal potential supply adjusts downward. However if the GM trait is present, the control of the pest could be considered to be close to 100%. The Bt traits in corn hybrids can therefore be classified as a kind of “super pesticide”, and are likely to have a positive effect on expected yield. They may also have an effect on variability, and according to the differing views expressed by, for example, Feder (1979) and others on one hand and Horowitz and Lichtenberg (1993) and Pannell (1991) on the other, the marginal effect on yield variability for these inputs (the traits incorporated in the seeds) could be expected to be negative or positive, respectively. The present policy of reducing premiums is based on an implicit assumption that triple-stacked corn hybrids have a negative effect on yield variability – which, as is clear from the literature, is not *a priori* unanimously accepted. If pesticides (or GM traits) increase variance, then premium reductions may not be justifiable.

Theoretical framework

An understanding of the marginal effects of input use on the distribution of output is crucial to the understanding of the relationship between input use, risk and insurance uptake under the assumption of risk aversion. Just and Pope (1978, 1979) suggest that popular formulations of stochastic production functions are limited in this analysis, in that the functions impose a risk-increasing effect because the error term interacts multiplicatively with the deterministic part, whereas, as discussed above, there are cases where increasing inputs may have a risk reducing effect on output. They show (Just and Pope 1978) that these different relationships cannot be correctly handled by the commonly used functions, no matter whether the function has an additive or multiplicative error, and no matter whether the function is linear or non-linear (Wan, Griffiths and Anderson 1992).

Just and Pope (1978, 1979) propose that a useful production function should have sufficient flexibility so that the effect of inputs on the deterministic component of production is different from the effect of inputs on the stochastic component, and suggest the introduction of some function of the inputs, $h(X)$, which perturbs the effects of the disturbances in such a way that the relationships of the inputs with risk are not determined solely by the relationships of inputs with expected output. Their model, with interdependent heteroskedastic disturbances that condition the mean and variance of the dependent variable on independent variables, uses the heteroskedastic error structure proposed by Harvey (1976). In the proposed production functions, the disturbance $h(X)\varepsilon$ could be multiplicative, or additive. The multiplicative case, $y=f(X)h(X)\varepsilon$ constrains the sign of the change in variance of marginal product with respect to a factor change without consideration of the nature of the input. The general additive case, which does not constrain the sign, and allows the possibility of increasing, decreasing or constant marginal risk (Just and Pope 1978), can be expressed as follows:

$$Y_{it} = f(X_{it}) + u_{it} = f(X_{it}) + h^{1/2}(Z_{it})\ \varepsilon_{it}$$

where Y_{it} is output and we assume that $E(\varepsilon_{it})=0$, $var(\varepsilon_{it}) = 1$. The functions $f(X_{it})$ and $h(Z_{it})$ determine the conditional mean and variance, respectively, of Y. The component f(.) is the deterministic component of production (representing the mean of production) as a function of the independent variables and u_{it} is the stochastic component (representing its variance). The variance of yield from the non-measurable inputs (that is the variance of the stochastic disturbance term from the expected yield function) is then also estimated as a function of the independent variables (Rosegrant and Roumasset 1985). The suggested approach is quite flexible in that the set of inputs used to estimate the stochastic component of the production function (Z_{it}), need not be the same as the set of inputs in the deterministic part of the production function (X_{it}), and the functional form of h(.), may or may not be identical to that of f(.).

In addition to concerns about variance, empirical evidence suggests that farmers exhibit decreasing absolute risk aversion, which implies that farmers are averse to ‘downside risk’ (Antle 1987; Kim and Chavas 2003), in that they are especially averse to being exposed to unexpectedly low returns, and that their welfare is positively (negatively) affected by an increase (decrease) in skewness of returns (Kim and Chavas 2003). Such considerations may matter both with regard to input use and insurance uptake, raising the need to estimate the impact of input use on the skewness of the conditional distribution.

It is likely that mean yields at the national level are skewed. Yield on individual farms may also be skewed, and skewness may, for example, be affected by chemical applications which may reduce a farmer’s risk of extremely low yields (Gallagher 1987). While the Just and Pope (1978) production function allows input levels to affect risk, defined by the variance of output, independently of their effect on the expected level of output, later studies have suggested other methods of linking higher moments of output distributions to variable inputs (Babcock, Chalfant and Collender 1987). There is empirical evidence (for example, Anderson 1973; Antle and Goodger 1984; Day 1965; Just and Pope 1979) that second, third and fourth moments of output may be functions of inputs (Antle 1983). Nelson and Preckel (1989) identified the need for a flexible approach to estimating yield distributions when skewness is important, and Antle and Goodger (1984) found that input-conditioned mean and variance are not sufficient for a description of a stochastic production. Gallagher (1987) among others has observed negative skewness for crop yields.

Hence, Antle (1983) suggested the need for an econometric production model which would provide a general representation of the probability distribution of output without imposing arbitrary restriction on the moments. He proposed a model which expresses the moments of the probability distribution, including skewness, as explicit functions of inputs, and showed that consistent estimates of all central moments can be obtained econometrically. His method allows the investigation of the mean, variance, and the skewness associated with downside risk exposure (Kim and Chavas 2003).

Following Kim and Chavas (2003), $E[y_{it} - E(y_{it})]^{j}$ is the *j*th central moment of $y_{it..}$ If $\varepsilon_{yit}(X,t)=E_{yit}\ (X,t,e)$ denotes the mean, or first moment, of yield per acre, $\varepsilon_{yit}(X,t) = E[(y_{it}(X,t,e) - \varepsilon y_{it}(X,t)^{j}]$ is the *j*th moment of y_{it}, $j=2........m$, conditional on input decisions X, and a time trend, t. The skewness is therefore the cube of the residuals of yield, and the marginal skewness conditional on the input is the cube of the residuals regressed on the inputs, and, because of the presence of heteroskedasticity, the functions for the moments need to be estimated so that the standard errors of the parameters are consistent.

Data

In this study we use a large dataset of results from experimental field trials to investigate the effects on yield variability due to the presence in a corn hybrid of a GM trait, or a combination of GM traits.

Our data was compiled from reports of actual yield results from experimental field trials of corn hybrids submitted by corn breeders to the State Agricultural Extension Services of ten universities over 20 years, in the ten most important corn-producing states in the United States (Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, South Dakota and Wisconsin), largely corresponding to ERS Farm Resource Region 1, the “Heartland”. Wisconsin and Minnesota belong largely to Farm Resource Region 2, the “Northern Crescent”, and Kansas and parts of Nebraska to Region 4, the “Prairie Gateway”.

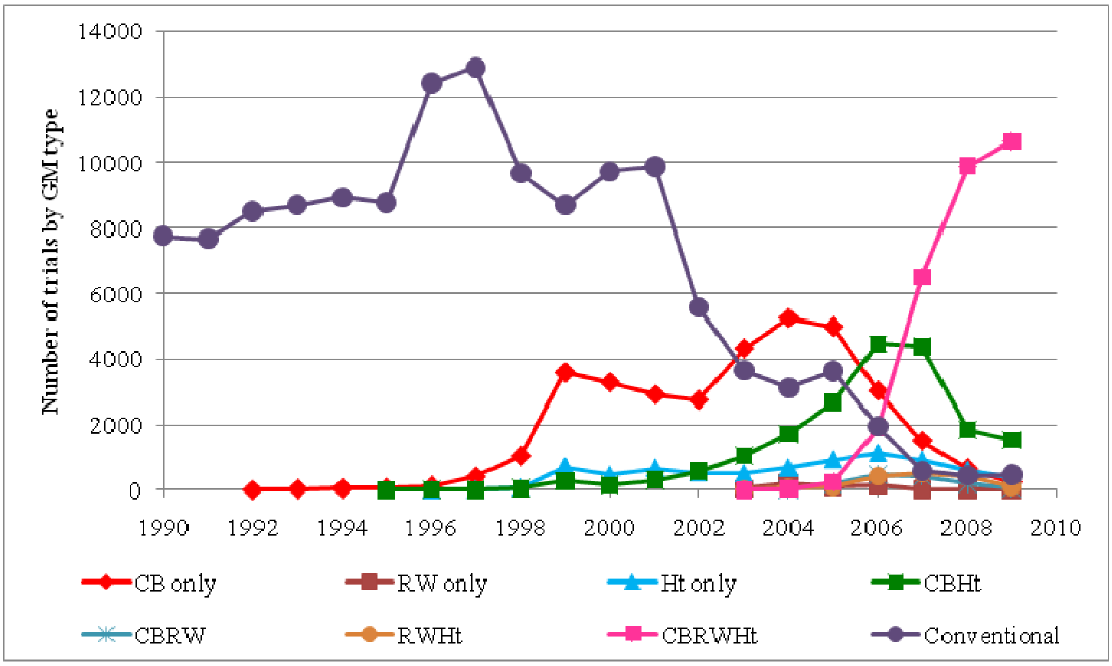

Figure 1. Number of trials by year and GM category

The dataset reports on yield in bushels per acre for 226,918 individual trials, of 20,508 hybrids, at 335 locations, submitted by 430 companies and, in addition to the genetic make-up of the hybrid (including the traits present in each hybrid and the degree of stacking), the dataset includes rich detail on agronomic practices (yield, seeding rate, nitrogen application), climatic conditions (rainfall and average minimum and maximum temperatures for each of the months April to September) as well as other variables that potentially influence yield and its variability (soil type, cultivation type, previous crop, whether the trial is early or late, and whether or not irrigation water was applied). We only included observations for hybrids for which we have at least seven trials, leaving us with a sample of 189,840 observations. We have followed this practice in the separate regions; hence the sum of the number of observations in the regions is less than the number in the total sample.

A detailed description of the data, its sources and the way we have dealt with missing data can be found in the Appendix. Summary statistics are provided in table 3. Figure 1 summarizes the relative importance of GM versus non GM varieties under trial. The breakdown of data by year and state of trial, and by year and GM attributes, can also be found in tables 5 and 6 in the Appendix.

Table 3. Summary Statistics

Variable	Definition	Mean	Std. Dev.	Min	Max
Yield	Bushels per acre of shelled grain (56lb/bu)adjusted to a moisture content of 15.5%	174.28	41.57	1.00	317
Seeding rate	Seeding rate in thousands of kernels per acre	28.52	38.22	10.14	43.5
No or min till	Dummy variable indicating no or minimum till	0.09	0.28	0.00	1
Conventional	Conventional soil preparation methods (base case)	0.91	0.28	0.00	1
Irrigated	Dummy variable indicating crop grown with irrigation	0.16	0.36	0.00	1
Dryland	Crop grown without irrigation (base case)	0.84	0.36	0.00	1
Early	Dummy variable indicating an early trial	0.21	0.41	0.00	1
Late	Dummy variable indicating a late trial (base case)	0.79	0.41	0.00	1
Soybean	Dummy variable indicating that soybean was the previous crop in the rotation (base case)	0.78	0.42	0.00	1
Corn	Dummy variable to indicating that corn was the previous crop in the rotation	0.11	0.32	0.00	1
Wheat	Dummy variable to indicating that wheat was the previous crop in the rotation	0.06	0.23	0.00	1
Alfalfa	Dummy variable to indicating that alfalfa was the previous crop in the rotation	0.02	0.13	0.00	1
Other	Dummy variable to indicating that a crop other than those mentioned above was the previous crop in the rotation	0.04	0.19	0.00	1
Silt loam	Dummy variable indicating silt loam soil (base case)	0.59	0.49	0.00	1
Clay	Dummy variable indicating clay soil	0.02	0.15	0.00	1
Silty clay loam	Dummy variable indicating Silty clay loam soil	0.16	0.37	0.00	1
Clay loam	Dummy variable indicating Clay loam soil	0.09	0.29	0.00	1
Loam	Dummy variable indicating Loam	0.06	0.25	0.00	1
Sandy loam	Dummy variable indicating Sandy loam soil	0.06	0.24	0.00	1
Sand	Dummy variable indicating Sand	0.004	0.06	0.00	1
N in lbs/ac	Nitrogen application in lbs per acre	136.48	80.72	0.00	380
N not reported	Dummy variable indicating that nitrogen use was not reported	0.18	0.38	0.00	1
IL	Dummy variable indicating Illinois trial	0.14	0.35	0.00	1
IN	Dummy variable indicating Indiana trial	0.08	0.27	0.00	1
IA	Dummy variable indicating Iowa trial	0.16	0.37	0.00	1
KS	Dummy variable indicating Kansas trial	0.06	0.24	0.00	1
MN	Dummy variable indicating Minnesota trial	0.06	0.23	0.00	1
MO	Dummy variable indicating Missouri trial (base case)	0.11	0.31	0.00	1
NE	Dummy variable indicating Nebraska trial	0.11	0.31	0.00	1
OH	Dummy variable indicating Ohio trial	0.09	0.29	0.00	1
SD	Dummy variable indicating South Dakota trial	0.04	0.20	0.00	1
WI	Dummy variable indicating Wisconsin trial	0.15	0.36	0.00	1
No GM	Dummy variable indicating conventional hybrids (base case)	0.58	0.49	0.00	1
CB	Dummy variable indicating hybrid has corn borer resistant trait only	0.16	0.37	0.00	1
RW	Dummy variable indicating hybrid has corn rootworm resistant trait only	0.002	0.04	0.00	1
Ht	Dummy variable indicating hybrid has herbicide tolerant trait only	0.03	0.16	0.00	1
CB and Ht	Dummy variable indicating hybrid has both corn borer resistant and herbicide tolerant traits	0.08	0.27	0.00	1
RW and Ht	Dummy variable indicating hybrid has both corn rootworm resistant and herbicide tolerant traits	0.01	0.09	0.00	1
CB and RW	Dummy variable indicating hybrid has both corn borer resistant and corn rootworm resistant traits	0.01	0.08	0.00	1
CB, RW and Ht	Dummy variable indicating hybrid is at least triple stacked with corn borer resistant, corn rootworm resistant and herbicide tolerant traits	0.14	0.34	0.00	1

Empirical procedures

Using the methods proposed by Just and Pope (1978) and Antle (1983) we investigate the effect of the presence of GM traits on the distribution of corn yield through the specification and estimation of a heteroskedastic production function that allows for the variance and skewness of yield to change with the presence of the traits and their various combinations (Anderson and Griffiths 1981; Just and Pope 1978; Just and Pope 1979). Additionally, we want to explore the possibility that there are regional differences in the impact of the traits, as suggested by Goodwin, Vandeveer and Deal (2004) and following evidence of non-normal distributions for corn yield and their geographical nature (Harri et al. 2009)[5]. For this reason we estimate our model for the ten most important corn-producing states of the US, and then for the ERS Farm Resource Regions for which we have data. Although we have some data for five regions, regions 3 and 5 represent only 2% and 0.3% respectively, of the total. We therefore estimate a production function for the whole sample, and for three of the ERS farm resource regions represented in the dataset: regions 1 ("Heartland"), 2 ("Northern Crescent") and 4 ("Prairie Gateway").We estimate the mean function for corn yield in bushels per acre, while controlling for a wide variety of agronomic practices, location characteristics and climatic conditions. Because we have multiple observations for the same hybrids, we are also able to control for varietal differences. For each model we use the residuals of the mean function to estimate the variance and skewness of yield and the effect of each input on these moments.

We estimate the residuals using both a fixed effects model and a random effects model. The fixed effect model allows us to avoid problems of correlation between the hybrids which make up the cross sectional element, and the independent variables. However, when we use a fixed effects estimator the mean contribution of the GM traits associated with each hybrid is absorbed into the

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[5] Using data for 1488 counties, with 50 years of continuous data from 1956-2005, Harri et al. (2009) found that yield data for corn in counties in Corn Belt states were non-normally distributed and consistently negatively skewed and that this would be expected since this region has generally favorable conditions for corn production, with infrequent disasters. Counties where normality is not rejected are mostly found in the predominantly irrigated plains region of Kansas and Nebraska, along the southern portions of the Mississippi River, and in Pennsylvania and New York. Positive skewness tends to be found in marginal areas such as south Texas and the Carolinas where unfavorable conditions are more frequent.

fixed effects. A random effects model would allow us to identify the average contribution to yield of the GM traits in their various combinations.

There was no difference in the value of the residuals from each method suggesting that, due both to the experimental nature of this data and the wealth of the dataset that allows us to control for non-random inputs to the production process (namely, site characteristics and weather), the possibility of correlation between production inputs and the error term is not important. As a consequence, the estimates of the higher moments are unaffected by the choice of estimator and we have chosen to estimate our model using a random effects GLS regression as our first step.

In the empirical part of this paper we use the flexible Just and Pope (1978) specification to estimate variance. We extend our analysis to estimate skewness using the flexible moments approach of Antle (1983). The expected yield is estimated as a function of the independent variables, using a random effects GLS regression.

The residuals for this estimation are predicted (using $[y_{it}(X,t,e)\text{-}\varepsilon y_{it}(X,t)]$, and squared (cubed) to give the variance (skewness) of yield. The variance (skewness) is then explained as a function of the independent variables using Ordinary Least Squares (OLS) to find the marginal effect of each input on the variance (skewness) of yield related to each of the inputs. In the presence of heteroscedasticity, which was identified using a White test, the standard errors of the parameters need to be corrected so that they are consistent. The results reported are therefore corrected for heteroskedasticity.

Results

The empirical results relating to trend and GM traits are shown in table 4. The full results for the whole sample and the regions 1, 2 and 4 are provided in tables 7-10 in the appendix. Our results for the whole sample are generally consistent with those reported in previous work.

From the mean function, a positive coefficient for the trend variable indicates that expected yield is increasing over time. Irrigation and nitrogen application also have a positive sign, as would be expected from earlier work mentioned above. Most of the various combinations of GM trait have a positive sign, indicating that the traits are on average yield increasing. The exceptions are rootworm resistance, which has a negative coefficient, although this effect is imprecisely estimated, and herbicide tolerance by itself which has a negative sign, but at the 10% level o f significance.

The results of the regressions for the second and third moments show that variance of corn yield is increasing over time. However, the positive sign of the coefficient of skewness for the trend variable implies a reduced exposure to downside risk over time. Nitrogen application decreases variance and reduces downside risk, as is demonstrated by a positive marginal skewness. The negative coefficient for marginal variance indicates an effect on risk which is consistent with some studies and inconsistent with others. Where variance is taken as the sole measure of risk, nitrogen application has typically been considered to increase the variance of risk (Babcock 1992). However when nitrogen is grouped with other agricultural chemicals it has been considered to be risk decreasing. Irrigation is strongly risk decreasing, and strongly reduces the downside risk. This is consistent with the findings of Harri et al. (2009).

The results for the higher moments show that there is not a systematic relation between GM traits and yield risk, both between traits and within traits: for example, the presence of the rootworm resistant trait by itself has no statistically significant effect on mean or skewness, but reduces variance. The effect of the presence of most of the other traits and combinations of traits is to increase variance. The exceptions are the combination of corn borer and rootworm resistance, whose coefficient has a negative sign, but is statistically insignificant. The triple stacking combination does not have a statistically significant effect on variance. All combinations of GM traits, with the exception of the non-significant rootworm by itself, have a negative coefficient for skewness, implying that their presence increases downside risk. Most importantly in the context of this paper, the presence of triple stacking has no statistically significant effect on variance for the whole sample, and also appears to increase downside risk, suggesting that in general the assumptions underlying the insurance discount policies do not have generalized empirical support.

Table 4. Relevant Results for Whole Sample and Farm Resource Regions 1, 2 and 4

Whole sample	**Mean function**			**Variance function**			**Skewness function**		
Dep. Var.	Yield in bushels per acre			Residuals squared			Residuals cubed		
yield	Coef.	z	P>|z|	Coef.	t	P>|t|	Coef.	t	P>|t|
trend	1.29	26.62	0.00	2.67	1.81	0.07	1320.60	7.75	0.00
cbo	6.07	12.80	0.00	83.29	6.28	0.00	-6137.60	-4.24	0.00
rwo	-2.77	-1.02	0.31	-231.32	-4.11	0.00	5778.24	1.27	0.20
hto	-1.70	-1.70	0.09	110.19	4.16	0.00	-1068.28	-0.38	0.70
cbht	2.35	3.24	0.00	186.85	9.62	0.00	-7007.11	-3.32	0.00
rwht	10.53	5.45	0.00	88.25	1.72	0.09	-13755.47	-2.22	0.03
cbrw	9.32	4.79	0.00	-26.25	-0.53	0.60	-10534.56	-1.95	0.05
cbrwht	10.63	15.01	0.00	26.14	1.45	0.15	-7339.27	-3.94	0.00
Obs	189840								
Groups	8731			F(51,189788)	272.50		F(51,189788)	39.19	
Wald chi^2(51)	47271.88			Prob > F	0.00		Prob > F	0.00	
Prob >chi^2	0.00			R-squared	0.07		R-squared	0.02	
Region 1									
trend	1.42	24.78	0.00	9.27	5.23	0.00	452.35	2.63	0.01
cbo	5.34	11.19	0.00	65.08	4.40	0.00	-2949.39	-1.86	0.06
rwo	-2.70	-1.04	0.30	-167.76	-2.86	0.00	1029.97	0.22	0.82
hto	3.37	3.64	0.00	28.06	0.99	0.32	-1957.15	-0.70	0.49
cbht	6.42	9.09	0.00	120.93	5.18	0.00	-3398.14	-1.36	0.17
rwht	12.84	9.67	0.00	-11.25	-0.25	0.80	-7623.94	-1.76	0.08
cbrw	10.37	5.36	0.00	-13.79	-0.29	0.78	-546.83	-0.14	0.89
cbrwht	11.45	15.81	0.00	63.90	3.13	0.00	-4541.13	-2.28	0.02
Obs	116768								
Groups	5965			F(49,116718)	178.32		F(49,116718)	24.14	
Wald chi^2(49)	38098.94			Prob > F	0.00		Prob > F	0.00	
Prob >chi^2	0.00			R-squared	0.09		R-squared	0.02	
Region 2									
trend	1.77	15.92	0.00	15.70	4.41	0.00	198.70	0.56	0.58
cbo	11.35	9.00	0.00	117.88	3.62	0.00	-15124.88	-4.80	0.00
rwo	-7.81	-6.22	0.00	-549.15	-4.27	0.00	-9826.68	-1.32	0.19
hto	1.56	0.66	0.51	38.22	0.65	0.51	-2919.82	-0.52	0.60
cbht	1.96	1.10	0.27	182.20	3.86	0.00	-2052.04	-0.44	0.66
rwht	5.26	0.69	0.49	475.40	2.20	0.03	-37577.87	-1.40	0.16
cbrw	-23.93	-2.33	0.02	-23.70	-0.07	0.95	-2093.40	-0.06	0.95
cbrwht	11.89	6.88	0.00	-493.51	-9.62	0.00	-3482.57	-0.67	0.50
Obs	28037								
Groups	1989			F(41, 27995)	56.65		F(41,27995)	9.97	
Wald chi^2(41)	13680.10			Prob > F	0.00		Prob>F	0.00	
Prob > chi^2	0.00			R-squared	0.10		R-squared	0.03	
Region 4									
trend	0.91	7.94	0.00	31.57	5.92	0.00	-937.87	-1.34	0.18
cbo	1.42	1.09	0.28	201.29	3.45	0.00	634.63	0.08	0.94
rwo	5.79	4.00	0.00	-80.66	-0.23	0.82	1266.24	0.05	0.96
hto	-12.47	-5.60	0.00	199.51	1.30	0.19	-22954.85	-1.22	0.22
cbht	-0.17	-0.11	0.91	206.02	2.78	0.01	-8886.45	-0.97	0.33
rwht	10.37	5.35	0.00	95.11	0.54	0.59	15174.51	0.97	0.33
cbrw	4.72	1.96	0.05	-110.55	-0.78	0.44	3963.28	0.31	0.76
cbrwht	0.08	0.05	0.96	175.46	2.38	0.02	-15741.93	-1.70	0.09
Obs	19122								
Groups	1212			F(38, 19083)	30.37		F(38, 19083)	4.2	
Wald chi^2(38)	27053.01			Prob > F	0.00		Prob > F	0.00	
Prob > chi^2	0.00			R-squared	0.08		R-squared	0.01	

The results for farm resource region 1 (the "Heartland") are similar to those for the whole sample for trend, nitrogen application and irrigation, although the effect of irrigation on decreasing variance is stronger, and on improving downside risk is much stronger, than for the whole sample. Most of the GM combinations are risk increasing, or not significant, with the exception of rootworm resistance by itself, which decreases risk and also has a positive effect on downside risk. The other combinations have a negative effect on downside risk. The other combinations are not statistically significant in the skewness function.

In farm resource region 2 (the "Northern Crescent"), irrigation has a stronger effect on decreasing variance and improving downside risk than is seen in the whole sample. A number of the combinations do not significantly affect mean yield. Corn borer resistance by itself increases mean yield, increases variance and has a negative effect on downside risk. In this region, rootworm resistance has a statistically significant negative effect on mean yield, but also a significant risk reducing effect. Its effect on downside risk is not significant. The presence of the triple combination of corn borer and rootworm resistance and herbicide tolerance implies an increase in mean yield, a decrease in risk, and has no significant effect on downside risk, suggesting that in this region a reduction in insurance premiums for triple stacked hybrids could be justified.

In region 4 (the "Prairie Gateway") for which we have data for Kansas and parts of Nebraska, the mean yield and variance are, in common with the whole sample and other regions, increasing over time, but in this region, skewness is negative, but not statistically significant. Irrigation has a positive effect on mean yield, a strong effect on reducing variance, and a much stronger effect in improving downside risk compared with the whole sample and the other regions. These irrigation effects could be expected given the importance of irrigation in these states. The effect of the GM traits in this region is mixed. Only the triple stack combination has a significant (and negative) effect on downside risk, and then only at the 10% level of significance. Corn borer resistance by itself has no significant effect on mean yield, but increases risk. Rootworm resistance increases yield but has no significant effect on variance. Herbicide tolerance decreases yield but has no effect on risk. Rootworm combined with both corn borer resistance and herbicide tolerance increases yield but has no effect on risk. The triple stack combination has no significant effect on mean yield, increases variance, and has a negative effect on downside risk at the 10% level of significance.

It is clear from the above that the effects of different combinations will differ between regions, although corn borer resistance by itself is generally consistent in having a positive effect on yield, increasing risk, and having a negative effect on downside risk. This also applies overall, with the exception of region 2, for the combination of most interest to us, the triple-stacking which qualifies those growing hybrids with this combination for premium reductions. The other combinations show more mixed results.

Conclusion

The results of this study are important because, apart from updating previous findings regarding conventional inputs and the corn borer resistant trait, they report on the effect on risk, and downside risk of various combinations of GM traits, and this is relevant given the current policies with regard to reductions in insurance premiums. The results show that only in the "Northern Crescent" does the triple stacked combination both increase mean yield and reduce variability of yield, suggesting that the policy of premium reduction requires more detailed scrutiny, and should be tailored according to location.

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Appendix.

Data

Summary statistics for the variables included in the analysis are provided in table 3 in the text. The number of observations by year and state is shown in table 5. Number of trials by GM category is shown in table 6.

a. ***Missing data:*** We have relied on the cooperation of the various extension services to obtain copies of those reports which are not available online, and some records are not complete.
    i. Iowa has the longest history of testing but records are incomplete. Records are complete from 2005. Professor Joe Lauer of UW Madison was able to provide us with data for individual locations for 1996-2001. The years 2002-2004 are lost. Even though we only have ten years of Iowa data the number of trials is substantial.
    ii. Cultivation type and rotation were not reported by Ohio for 1998-2002 but the locations and agronomic practices for other years are consistent so that we have assumed that the same cultivation methods and rotation decisions were made.
    iii. Indiana in some years reports only regional average yields, so we have omitted those years and those locations where individual site results are not reported. This means that we have no entries for 1990-1993, and 1998-1999, and limited results for 1994-1997.
    iv. Minnesota trial results for 1990 and for 1995-96 are missing and cannot be traced.
    v. The University of Missouri is missing reports for 1998 and 2000, but some of the 1998 and 2000 results are reported in the following years' reports and we have included those results.

b. ***Dependent variable***: Grain yields are reported as bushels per acre of shelled grain (56 lb/bu) adjusted to a moisture content of 15.5%. As expected, the average annual yield for each state for these trials is consistently above the average annual yield for each state published by the National Agricultural Statistics Service of the USDA.

c. *Agronomic variables*

i. ***Early or late:*** Most states conduct early and late maturity trials, but in some cases the distinction was not made until the late 1990s or early 2000s. Some states still do not make a distinction. If there is not a specific statement that the trial is early season we have assumed that it is late. Nebraska reports on mid trials in some years – we have classified these as late. A dummy variable is used to indicate an early trial.

ii. ***Irrigated or dryland***: Missouri, Nebraska, Kansas, and Wisconsin conduct irrigated trials, and a dummy variable is included to indicate whether a trial is irrigated. Type of cultivation is reported in some detail and it has been impossible to account for all of the variations.

iii. ***Minimum or no till compared with conventional tillage***: A dummy variable has been used to indicate minimum or no till preparation, but only where this is explicitly stated. The default variable is conventional and everything other type of cultivation is included in this category.

iv. ***Soil type***: Seven soil types are identified by dummy variables, with silt loam as the default soil. The only state that does not report soil type is Minnesota and we have used the coordinates for each trial site and the Soil Web Survey of the USDA Natural Resources Conservation Service (*S1*) to identify the predominant soil type in that location.

v. ***Rotation:*** previous crop is also reported for most locations. However, Illinois does not report on rotation, and, in a small number of other locations, the rotation is omitted. As soybean is the usual rotation crop, we have assumed that this is the previous crop where it was missing. Dummy variables have been included for corn, wheat, alfalfa, and other, with soybean as the base case.

vi. ***Seeding rate***: Generally a seeding rate is reported, although in some states final plant population is given instead. We have used seeding rate (in thousands of kernels) where possible, but if this was not available we have substituted plants per acre. This is not exactly comparable, but the order of magnitude is in general similar.

vii. ***Fertilizer***: We have nitrogen fertilizer application in lbs per acre for most states. However, Illinois started reporting fertilizer application rates only in 2000. Iowa does not report fertilizer rates. We included a zero value for the missing observations. To differentiate between cases where nitrogen use was reported as zero, and the missing observations, we have introduced a dummy variable with a value of 1 indicating "Nitrogen not reported". To accommodate the estimation of a log-log transformation as a comparison for the linear functional form we have assigned a value of 0.01 rather than zero where applicable. Although some states do report phosphorus and potassium application, this is not always the case, and we have not included these fertilizers in our analysis.

viii. **Pesticides and herbicides:** It would have been useful to include pesticide and herbicide application rates. However the variety of different combinations that are possible and that have been used over the past 20 years is immense. We have assumed that the trials are conducted so as to eliminate pest and weed infestations.

d. ***Climatic variables - rainfall and average maximum and minimum temperatures:***

In most cases the trial reports include rainfall for the growing months. If not, for example for Ohio and Iowa, there is generally a very good network of weather stations and it has been possible to extract monthly rainfall from their databases (*S2, S3*). For those states which do not report specific rainfall figures (Nebraska includes column charts, and Minnesota does not report rainfall) we have used the database provided by the PRISM Climate Group at the University of Oregon (*S4*) This allows monthly rainfall, minimum and maximum temperatures to be extracted based on latitude and longitude coordinates. Some universities have reported rainfall May-September, others April-August and others April-September. We have filled the gaps for the months April-September from the PRISM database. As temperature is likely to be less local than rainfall, we have extracted minimum and maximum monthly temperatures April-September from the PRISM database. We have also followed Alston and Venner (*S5*) in including a cross term for rainfall and average maximum monthly temperature for the growing season.

e. ***Other dummy variables***

i. ***State where trial conducted***: We have included dummy variables to indicate the state where the trial was conducted. This is to allow for differences in method in each state where the differences have not been identified by the other included variables.

ii. ***Year of trial***: We have also included dummy variables or year of trial to account for other factors that may have influenced the trial results, including technical changes other than varietal change, and unusual weather occurrences not reflected in the rainfall and temperature data.

f. *GM traits and stacking of traits*

We have details of the GM traits associated with each hybrid. We have identified the presence of these traits using dummy variables, and have also created dummy variables to indicate the combinations of traits where traits are stacked. The base case is no GM traits. The number of trials by year and by category of GM traits for the whole dataset can be found in table S3.

g. *Hybrid identifiers*

The trial reports provide the name of the company submitting the hybrid for trial, the name of the hybrid, and, since the introduction of genetically modified hybrids, the GM traits associated with each hybrid. Since some quite different hybrids have the same number, we have identified each separate hybrid by combining the name of the submitting company and the name of the hybrid. It is this variable that we have used to create dummy variables for our cross section. Where the hybrid number is the same, and the submitting company has changed, but is known to be affiliated with the previous submitting company, we have considered the hybrids to be identical. In some cases a hybrid will have the same name, but a different submitting company in consecutive years. For example, Keltgen, Lynks and Mycogen all submitted a hybrid with the same name in different years. Mycogen took over Keltgen and Lynks in the early to mid 1990s, so we have assumed that these varieties are in fact the same, and have renamed the hybrid identifier accordingly. Kruger Seed Company has at times submitted seed under the company names Kruger, KSC/Challenger, Circle and Desoy. We have based our decision on the ownership groups shown in table S4. This table was collated from numerous sources, including company reports, company websites, media releases and newspaper articles. It is accurate, to the best of our knowledge, as at June 2010.

Table 5. Number of Trials by Year and State

Year	Illinois	Indiana	Iowa	Kansas	Minnesota	Missouri	Nebraska	Ohio	South Dakota	Wisconsin	Total
1990	1692			620		869	1356	1194	511	1515	7757
1991	1547			482	822	768	1209	1165	460	1222	7675
1992	1712			631	632	967	1191	949	541	1886	8509
1993	1819			762	561	937	1243	1365	573	1480	8740
1994	1749	113		614	566	1093	1429	1018	629	1779	8990
1995	1717	422		598		1319	1142	1067	593	1988	8846
1996	1444	1096	3732	529		1022	844	1332	513	2083	12595
1997	1189	981	3693	642	823	1190	1139	1004	535	2146	13342
1998	1069		3245	668	789	308	1169	955	590	2063	10856
1999	2095		3409	621	993	1223	1149	967	634	2159	13250
2000	1810	1626	3575	555	985	334	1333	853	556	1997	13624
2001	1739	1710	3321	671	859	1168	1087	844	593	1767	13759
2002	1302	1629		505	697	1201	1010	844	481	1765	9434
2003	1630	1155		466	735	1389	996	888	522	1797	9578
2004	2005	1341		672	931	1468	1149	1010	731	1818	11125
2005	1925	1471	2214	679	836	1479	1043	941	494	1803	12885
2006	1816	1196	2607	702	1190	1825	1023	838	640	1682	13519
2007	1778	1160	2810	932	1296	1529	1352	1215	588	2205	14865
2008	2020	1470	2587	1029	1039	1585	1201	1053	472	1645	14101
2009	1565	1241	2397	1028	940	1589	1184	1435	420	1669	13468
Total	33623	16611	33590	13406	14694	23263	23249	20937	11076	36469	226918

Table 6. Number of Trials by Year and GM Category

Year	Number of trials	CB only	RW only	Ht only	CBHt	CBRW	RWHt	CBRWHt	Total GM	Total conventional
1990	7757								0	7757
1991	7675								0	7675
1992	8509	7							7	8502
1993	8740	39							39	8701
1994	8990	56							56	8934
1995	8846	69			2				71	8775
1996	12595	131		6	25				162	12433
1997	13342	408		20	8				436	12906
1998	10856	1042		78	53				1173	9683
1999	13250	3582		705	269				4556	8694
2000	13624	3286		456	151				3893	9731
2001	13759	2910		668	301				3879	9880
2002	9434	2750		533	572				3855	5579
2003	9578	4319	47	497	1047		8	7	5925	3653
2004	11125	5242	219	672	1713	25	77	44	7992	3133
2005	12885	4979	122	925	2678	194	107	247	9252	3633
2006	13519	3030	149	1,123	4467	462	421	1912	11564	1955
2007	14865	1517	24	916	4387	433	501	6498	14276	589
2008	14101	661	9	599	1856	200	423	9908	13656	445
2009	13468	246	2	384	1544	58	114	10645	12993	475
Total	226918	34274	572	7582	19073	1372	1651	29261	93785	133133

Table 7. Full Results for Whole Sample

Whole sample	**Mean function**				**Variance function**				**Skewness function**			
Dep. Var.	Yield in bushels per acre				Residuals squared				Residuals cubed			
Obs	189840				Obs	189840			Obs	189840		
Groups	8731				F(51,189788)	272.50			F(51,189788)	39.19		
R-sq:					Prob > F	0.00			Prob > F	0.00		
within	0.26				R-squared	0.07			R-squared	0.02		
between	0.64											
overall	0.39											
Wald chi^2(51)	47271.88											
Prob >chi^2	0.00											
yield	Coef.	Robust Std. Err.	z	P>|z|	Coef.	Robust HC Std. Err.	t	P>|t|	Coef.	Robust HC Std. Err.	t	P>|t|
trend	1.29	0.05	26.62	0.00	2.67	1.47	1.81	0.07	1320.60	170.40	7.75	0.00
seedingrat~u	2.80	0.05	59.93	0.00	7.15	2.22	3.23	0.00	-2240.01	260.93	-8.58	0.00
nomintill	-6.64	0.36	-18.31	0.00	84.38	18.46	4.57	0.00	-2502.50	2232.65	-1.12	0.26
irrigated	22.87	0.54	42.11	0.00	-148.66	25.22	-5.89	0.00	13481.59	3007.57	4.48	0.00
early	-2.92	0.35	-8.43	0.00	75.13	12.47	6.02	0.00	-16209.34	1412.24	-11.48	0.00
corn	-7.05	0.31	-22.62	0.00	-12.43	14.55	-0.85	0.39	3944.25	1569.23	2.51	0.01
wheat	-5.01	0.41	-12.14	0.00	90.95	23.75	3.83	0.00	-7704.99	2664.56	-2.89	0.00
alfalfa	2.98	0.61	4.86	0.00	-100.25	36.39	-2.76	0.01	21551.12	3565.74	6.04	0.00
other	-9.81	0.55	-17.87	0.00	246.95	33.60	7.35	0.00	-14638.59	4084.54	-3.58	0.00
clay	-18.07	0.58	-31.13	0.00	254.00	29.86	8.51	0.00	-16057.84	2840.19	-5.65	0.00
siltyclayloam	-2.59	0.24	-10.64	0.00	-102.22	12.63	-8.10	0.00	2067.53	1312.50	1.58	0.12
clayloam	-2.09	0.31	-6.71	0.00	-125.91	14.64	-8.60	0.00	82.39	1504.17	0.05	0.96
loam	-8.02	0.36	-22.58	0.00	-10.05	19.24	-0.52	0.60	-7705.04	2204.13	-3.50	0.00
sandyloam	-4.01	0.40	-10.12	0.00	-139.61	21.68	-6.44	0.00	-5531.74	2483.18	-2.23	0.03
sand	-23.10	1.55	-14.92	0.00	773.88	104.93	7.38	0.00	-90350.80	12083.87	-7.48	0.00
nlbs	0.12	0.00	45.00	0.00	-2.40	0.13	-17.89	0.00	191.82	15.38	12.48	0.00
nitnotreported	18.94	0.59	31.93	0.00	-58.49	25.73	-2.27	0.02	30669.27	2792.32	10.98	0.00
aprrain	-0.40	0.06	-6.31	0.00	1.05	2.77	0.38	0.70	1978.73	300.87	6.58	0.00
mayrain	-0.89	0.04	-20.64	0.00	6.01	1.99	3.03	0.00	-423.67	205.35	-2.06	0.04
junrain	0.25	0.04	5.76	0.00	-9.81	1.76	-5.56	0.00	1341.99	183.05	7.33	0.00
julrain	1.58	0.04	38.53	0.00	-33.91	1.86	-18.21	0.00	1704.62	185.76	9.18	0.00
augrain	0.67	0.05	13.31	0.00	-33.65	2.04	-16.50	0.00	1796.04	215.75	8.32	0.00
septrain	-0.46	0.06	-8.31	0.00	16.27	2.38	6.85	0.00	-2088.87	260.10	-8.03	0.00

Whole sample	**Mean function**				**Variance function**				**Skewness function**			
minapr	-0.61	0.07	-8.77	0.00	43.76	2.97	14.74	0.00	-3097.26	324.78	-9.54	0.00
minmay	0.96	0.06	15.45	0.00	-13.05	2.90	-4.50	0.00	1858.44	346.29	5.37	0.00
minjune	1.17	0.07	17.16	0.00	-49.73	2.68	-18.55	0.00	-181.30	288.84	-0.63	0.53
minjuly	-0.71	0.08	-8.68	0.00	-68.00	3.64	-18.68	0.00	2503.51	337.29	7.42	0.00
minaug	-0.18	0.07	-2.44	0.02	-49.51	3.15	-15.74	0.00	1165.43	351.78	3.31	0.00
minsept	0.04	0.04	0.96	0.34	10.34	2.07	4.99	0.00	717.00	225.54	3.18	0.00
maxapr	1.60	0.05	30.19	0.00	-30.10	2.02	-14.88	0.00	1560.17	216.50	7.21	0.00
maxmay	-0.07	0.06	-1.21	0.23	29.43	2.83	10.39	0.00	-2187.22	343.23	-6.37	0.00
maxjune	-0.61	0.05	-12.84	0.00	18.27	1.80	10.15	0.00	-85.89	188.00	-0.46	0.65
maxjuly	0.26	0.07	3.58	0.00	44.18	3.67	12.05	0.00	-2067.55	320.69	-6.45	0.00
maxaug	-2.75	0.08	-35.77	0.00	56.68	3.22	17.59	0.00	-439.59	335.53	-1.31	0.19
maxsept	1.14	0.05	24.42	0.00	0.40	2.07	0.19	0.85	-247.94	230.33	-1.08	0.28
IL	19.77	0.66	29.92	0.00	-841.43	21.93	-38.37	0.00	21439.22	2399.50	8.93	0.00
IND	15.06	0.72	20.79	0.00	-669.45	25.36	-26.40	0.00	29875.49	2795.12	10.69	0.00
IA	0.65	0.71	0.92	0.36	-1376.12	26.98	-51.01	0.00	35745.60	2984.50	11.98	0.00
KS	14.77	0.62	23.98	0.00	-590.49	26.68	-22.13	0.00	27892.35	2862.51	9.74	0.00
MN	19.82	0.88	22.45	0.00	-774.00	34.47	-22.46	0.00	36899.58	3877.74	9.52	0.00
NE	19.43	0.69	28.11	0.00	-849.45	30.29	-28.05	0.00	18166.78	3555.80	5.11	0.00
OH	11.51	0.74	15.46	0.00	-914.06	25.67	-35.61	0.00	33601.16	2852.77	11.78	0.00
SD	29.87	1.01	29.46	0.00	-877.83	42.12	-20.84	0.00	20840.80	4864.12	4.28	0.00
WI	27.49	0.81	33.79	0.00	-809.46	26.59	-30.44	0.00	12813.51	2955.66	4.34	0.00
cbo	6.07	0.47	12.80	0.00	83.29	13.25	6.28	0.00	-6137.60	1448.52	-4.24	0.00
rwo	-2.77	2.73	-1.02	0.31	-231.32	56.28	-4.11	0.00	5778.24	4552.71	1.27	0.20
hto	-1.70	1.00	-1.70	0.09	110.19	26.46	4.16	0.00	-1068.28	2799.85	-0.38	0.70
cbht	2.35	0.72	3.24	0.00	186.85	19.43	9.62	0.00	-7007.11	2108.33	-3.32	0.00
rwht	10.53	1.93	5.45	0.00	88.25	51.34	1.72	0.09	-13755.47	6204.95	-2.22	0.03
cbrw	9.32	1.95	4.79	0.00	-26.25	49.86	-0.53	0.60	-10534.56	5389.27	-1.95	0.05
cbrwht	10.63	0.71	15.01	0.00	26.14	17.97	1.45	0.15	-7339.27	1862.53	-3.94	0.00
Constant	75.72	5.79	13.08	0.00	620.10	218.36	2.84	0.01	37494.31	23893.25	1.57	0.12

Table 8. Full Results Region 1 (Heartland)

Region 1	**Mean function**				**Variance function**				**Skewness function**			
Dep. Var.	Yield in bushels per acre				Residuals squared				Residuals cubed			
Obs	116768				Obs	116768.00			Obs	116768.00		
Groups	5965				F(49,116718)	178.32			F(49,116718)	24.14		
R-sq:					Prob > F	0.00			Prob > F	0.00		
within	0.23				R-squared	0.09			R-squared	0.02		
between	0.72											
overall	0.40											
Wald chi^2(49)	38098.94											
Prob >chi^2	0.00											
yield	Coef.	Robust Std. Err.	z	P>z	Coef.	Robust HC Std. Err.	t	P>t	Coef.	Robust HC Std. Err.	t	P>t
trend	1.42	0.06	24.78	0.00	9.27	1.77	5.23	0.00	452.35	172.15	2.63	0.01
seedingrathou	2.38	0.07	32.14	0.00	-14.65	2.76	-5.31	0.00	141.41	264.94	0.53	0.59
nomintill	-8.86	0.50	-17.71	0.00	3.06	22.92	0.13	0.89	6707.02	2389.65	2.81	0.01
irrigated	23.33	0.82	28.42	0.00	-211.48	31.35	-6.75	0.00	24485.69	3137.67	7.80	0.00
early	-1.27	0.38	-3.33	0.00	-45.49	14.64	-3.11	0.00	-3722.55	1319.34	-2.82	0.01
corn	-5.33	0.50	-10.65	0.00	61.63	24.52	2.51	0.01	7090.11	2432.90	2.91	0.00
wheat	-5.04	0.56	-9.03	0.00	208.08	30.21	6.89	0.00	-2464.67	2945.04	-0.84	0.40
alfalfa	36.24	1.45	24.91	0.00	-895.48	51.13	-17.51	0.00	18379.23	3829.05	4.80	0.00
other	-3.48	1.25	-2.79	0.01	198.09	66.36	2.99	0.00	-31853.00	6644.99	-4.79	0.00
clay	-19.89	0.65	-30.68	0.00	319.72	30.79	10.38	0.00	-7891.71	2844.91	-2.77	0.01
siltyclayloam	-2.20	0.28	-7.82	0.00	-98.09	13.80	-7.11	0.00	5661.05	1271.53	4.45	0.00
clayloam	-4.28	0.37	-11.46	0.00	28.14	18.33	1.54	0.13	-1862.58	1788.53	-1.04	0.30
loam	-8.86	0.40	-21.97	0.00	72.52	17.96	4.04	0.00	769.45	1644.28	0.47	0.64
sandyloam	-0.38	0.52	-0.73	0.47	-377.57	24.15	-15.63	0.00	21014.52	2043.96	10.28	0.00
sand	-9.42	1.43	-6.58	0.00	-94.50	57.51	-1.64	0.10	-8725.74	4437.32	-1.97	0.05
nlbs	0.08	0.00	23.27	0.00	-2.24	0.15	-14.56	0.00	113.16	15.61	7.25	0.00
nitnotreported	12.64	0.72	17.60	0.00	-51.06	29.43	-1.74	0.08	13233.85	2900.72	4.56	0.00
aprrain	-0.68	0.07	-9.20	0.00	21.72	2.98	7.30	0.00	180.61	300.38	0.60	0.55
mayrain	-0.68	0.05	-13.74	0.00	7.77	2.45	3.18	0.00	497.99	243.03	2.05	0.04
junrain	0.04	0.05	0.84	0.40	-11.16	2.03	-5.51	0.00	1740.04	203.93	8.53	0.00
julrain	1.47	0.05	30.00	0.00	-35.63	2.28	-15.66	0.00	1331.81	230.85	5.77	0.00
augrain	0.53	0.05	10.34	0.00	-27.83	2.13	-13.04	0.00	1319.78	203.78	6.48	0.00
septrain	-0.21	0.06	-3.63	0.00	7.60	2.35	3.24	0.00	-1566.59	238.86	-6.56	0.00

Region 1	Mean function					Variance function					Skewness function			
minapr	-0.28	0.08	-3.58	0.00		32.96	3.26	10.11	0.00		-4073.94	310.13	-13.14	0.00
minmay	0.65	0.07	9.77	0.00		4.80	2.73	1.76	0.08		-996.59	275.10	-3.62	0.00
minjune	1.01	0.08	13.27	0.00		-22.42	2.95	-7.60	0.00		-157.65	289.71	-0.54	0.59
minjuly	-0.54	0.08	-6.83	0.00		-48.43	3.29	-14.73	0.00		3486.29	326.43	10.68	0.00
minaug	0.03	0.09	0.39	0.70		-59.77	3.38	-17.70	0.00		2160.41	351.21	6.15	0.00
minsept	0.31	0.05	6.73	0.00		10.68	2.20	4.85	0.00		661.85	214.72	3.08	0.00
maxapr	1.57	0.06	25.40	0.00		-37.39	2.30	-16.28	0.00		2712.77	221.25	12.26	0.00
maxmay	0.19	0.07	2.59	0.01		-4.29	2.81	-1.53	0.13		1451.47	273.74	5.30	0.00
maxjune	-0.72	0.04	-17.36	0.00		6.79	1.53	4.44	0.00		193.50	131.95	1.47	0.14
maxjuly	-0.64	0.07	-9.81	0.00		39.38	2.88	13.66	0.00		-2956.86	317.88	-9.30	0.00
maxaug	-3.08	0.09	-33.52	0.00		80.29	3.68	21.79	0.00		-1371.21	378.91	-3.62	0.00
maxsept	0.73	0.05	13.68	0.00		16.88	2.17	7.78	0.00		-1831.75	213.94	-8.56	0.00
IL	13.53	0.70	19.42	0.00		-680.53	24.84	-27.39	0.00		29016.18	2737.53	10.60	0.00
IN	9.51	0.72	13.17	0.00		-515.46	27.16	-18.98	0.00		25721.26	2847.09	9.03	0.00
IA	-4.02	0.77	-5.25	0.00		-1152.11	29.98	-38.43	0.00		31467.36	3173.71	9.92	0.00
MN	10.95	1.01	10.83	0.00		-445.41	38.12	-11.68	0.00		21165.97	3952.14	5.36	0.00
NE	13.57	1.00	13.63	0.00		-772.67	36.88	-20.95	0.00		18217.34	3562.60	5.11	0.00
OH	9.79	0.79	12.43	0.00		-832.01	28.64	-29.05	0.00		25621.89	3007.15	8.52	0.00
SD	21.87	1.22	17.97	0.00		-758.49	49.08	-15.46	0.00		25180.48	5110.28	4.93	0.00
cbo	5.34	0.48	11.19	0.00		65.08	14.80	4.40	0.00		-2949.39	1583.43	-1.86	0.06
rwo	-2.70	2.61	-1.04	0.30		-167.76	58.76	-2.86	0.00		1029.97	4635.86	0.22	0.82
hto	3.37	0.93	3.64	0.00		28.06	28.48	0.99	0.32		-1957.15	2805.28	-0.70	0.49
cbht	6.42	0.71	9.09	0.00		120.93	23.36	5.18	0.00		-3398.14	2497.02	-1.36	0.17
rwht	12.84	1.33	9.67	0.00		-11.25	44.45	-0.25	0.80		-7623.94	4326.08	-1.76	0.08
cbrw	10.37	1.94	5.36	0.00		-13.79	48.29	-0.29	0.78		-546.83	3983.03	-0.14	0.89
cbrwht	11.45	0.72	15.81	0.00		63.90	20.43	3.13	0.00		-4541.13	1990.20	-2.28	0.02
Constant	200.49	6.41	31.28	0.00		-839.59	246.03	-3.41	0.00		-35756.70	24988.41	-1.43	0.15

Table 9. Full Results Region 2 (Northern Crescent)

Region 2	**Mean function**				**Variance function**				**Skewness function**			
Dep. Var.	Yield in bushels per acre				Residuals squared				Residuals cubed			
Obs	28037				Obs	28037			Obs	28037		
Groups	1989				F(41, 27995)	56.65			F(41,27995)	9.97		
R-sq:					Prob > F	0.00			Prob>F	0.00		
within	0.23				R-squared	0.10			R-squared	0.03		
between	0.73											
overall	0.47											
Wald chi^2(41)	13680.10											
Prob > chi^2	0.00											
yield	Coef.	bust Std.	z	P>|z|	Coef.	Robust HC Std. Err.	t	P>|t|	Coef.	Robust H	t	P>|t|
trend	1.77	0.11	15.92	0.00	15.70	3.56	4.41	0.00	198.70	356.40	0.56	0.58
seedingrathou	0.77	0.12	6.53	0.00	55.14	4.50	12.26	0.00	-2562.53	468.69	-5.47	0.00
nomintill	0.29	0.89	0.32	0.75	115.25	38.98	2.96	0.00	-10779.03	3997.27	-2.70	0.01
irrigated	22.68	1.08	20.95	0.00	-453.18	50.54	-8.97	0.00	22570.47	5339.46	4.23	0.00
early	-1.04	0.62	-1.68	0.09	-79.28	16.85	-4.71	0.00	-4099.40	1623.68	-2.52	0.01
corn	-8.48	0.54	-15.63	0.00	-19.82	22.18	-0.89	0.37	-2751.93	2180.64	-1.26	0.21
wheat	6.79	1.59	4.27	0.00	420.62	78.18	5.38	0.00	5646.78	8052.32	0.70	0.48
alfalfa	3.45	0.74	4.69	0.00	-124.81	35.68	-3.50	0.00	16267.00	3258.99	4.99	0.00
other	-8.06	0.88	-9.18	0.00	50.36	42.31	1.19	0.23	-11817.41	4513.01	-2.62	0.01
clay	(omitted)				(omitted)				(omitted)			
siltyclayloam	-13.11	2.58	-5.07	0.00	-663.98	124.25	-5.34	0.00	-4813.63	6400.25	-0.75	0.45
clayloam	6.62	0.67	9.90	0.00	-250.55	29.81	-8.41	0.00	928.22	2856.94	0.32	0.75
loam	-15.50	2.77	-5.59	0.00	-576.22	97.69	-5.90	0.00	24689.22	8126.23	3.04	0.00
sandyloam	3.89	0.90	4.34	0.00	475.82	44.84	10.61	0.00	-21972.68	4643.55	-4.73	0.00
sand	-24.55	2.05	-11.97	0.00	587.40	88.67	6.62	0.00	-54746.76	7867.62	-6.96	0.00
nlbs	0.09	0.01	16.67	0.00	-2.45	0.27	-9.23	0.00	197.28	28.50	6.92	0.00
nitnotreported	-11.36	2.38	-4.78	0.00	-546.10	104.27	-5.24	0.00	38742.65	10467.72	3.70	0.00
aprrain	1.78	0.18	10.08	0.00	-41.18	7.50	-5.49	0.00	5471.54	726.66	7.53	0.00
mayrain	-0.54	0.12	-4.52	0.00	0.26	5.27	0.05	0.96	828.92	493.20	1.68	0.09
junrain	1.89	0.11	17.98	0.00	12.71	5.65	2.25	0.02	-1379.21	597.16	-2.31	0.02
julrain	0.89	0.11	7.79	0.00	-45.05	5.29	-8.52	0.00	1985.45	527.91	3.76	0.00
augrain	0.95	0.12	8.03	0.00	-50.52	4.79	-10.56	0.00	3344.26	460.10	7.27	0.00
septrain	1.18	0.14	8.41	0.00	-25.35	6.94	-3.65	0.00	1662.13	722.01	2.30	0.02

Region 2	Mean function				Variance function				Skewness function			
minapr	1.33	0.21	6.38	0.00	34.46	8.94	3.85	0.00	-1275.79	964.80	-1.32	0.19
minmay	1.26	0.18	6.85	0.00	43.91	8.31	5.28	0.00	-1753.23	858.70	-2.04	0.04
minjune	-0.52	0.24	-2.21	0.03	-85.19	11.18	-7.62	0.00	358.06	1186.42	0.30	0.76
minjuly	2.61	0.22	12.10	0.00	-58.39	9.60	-6.08	0.00	5266.92	1014.35	5.19	0.00
minaug	1.33	0.19	6.99	0.00	-62.41	7.98	-7.82	0.00	3367.36	814.52	4.13	0.00
minsept	-1.11	0.16	-7.08	0.00	81.03	8.14	9.95	0.00	-2324.34	835.63	-2.78	0.01
maxapr	1.00	0.13	7.71	0.00	-16.23	5.04	-3.22	0.00	596.30	520.07	1.15	0.25
maxmay	-0.43	0.15	-2.91	0.00	25.76	6.84	3.76	0.00	-1805.10	673.74	-2.68	0.01
maxjune	2.95	0.19	15.20	0.00	60.34	10.07	5.99	0.00	-3047.12	1082.69	-2.81	0.01
maxjuly	-3.45	0.20	-17.22	0.00	49.26	10.27	4.80	0.00	-6723.78	1114.36	-6.03	0.00
maxaug	-2.91	0.16	-18.38	0.00	85.84	7.20	11.93	0.00	-1554.57	793.68	-1.96	0.05
maxsept	2.30	0.14	15.97	0.00	-64.48	7.08	-9.11	0.00	3190.30	751.17	4.25	0.00
cbo	11.35	1.26	9.00	0.00	117.88	32.55	3.62	0.00	-15124.88	3149.31	-4.80	0.00
rwo	-7.81	1.26	-6.22	0.00	-549.15	128.49	-4.27	0.00	-9826.68	7443.55	-1.32	0.19
hto	1.56	2.37	0.66	0.51	38.22	58.48	0.65	0.51	-2919.82	5588.39	-0.52	0.60
cbht	1.96	1.79	1.10	0.27	182.20	47.22	3.86	0.00	-2052.04	4703.51	-0.44	0.66
rwht	5.26	7.65	0.69	0.49	475.40	216.30	2.20	0.03	-37577.87	26776.70	-1.40	0.16
cbrw	-23.93	10.27	-2.33	0.02	-23.70	344.24	-0.07	0.95	-2093.40	34188.51	-0.06	0.95
cbrwht	11.89	1.73	6.88	0.00	-493.51	51.33	-9.62	0.00	-3482.57	5185.85	-0.67	0.50
Constant	-71.50	13.57	-5.27	0.00	-6964.85	565.52	-12.32	0.00	474345.60	65954.24	7.19	0.00

Table 10. Full Results Region 4 (Prairie Gateway)

Region 4	**Mean function**				**Variance function**				**Skewness function**			
Dep. Var.	Yield in bushels per acre				Residuals squared				Residuals cubed			
Obs	19122				Obs	19122			Obs	19122		
Groups	1212				F(38, 19083)	30.37			F(38, 19083)	4.2		
R-sq:					Prob > F	0.00			Prob > F	0.00		
within	0.4812				R-squared	0.08			R-squared	0.01		
between	0.7536											
overall	0.5384											
Wald chi^2(38)	27053.01											
Prob > chi^2	0.00											
yield	Coef.	Robust Std. Err.	z	P>|z|	Coef.	Robust HC Std. Err.	t	P>|t|	Coef.	Robust HC Std. Err.	t	P>|t|
trend	0.91	0.11	7.94	0.00	31.57	5.33	5.92	0.00	-937.87	697.46	-1.34	0.18
seedingrat~u	3.52	0.11	31.86	0.00	29.25	6.28	4.66	0.00	-2643.86	777.37	-3.40	0.00
nomintill	-7.88	0.81	-9.71	0.00	94.85	41.28	2.30	0.02	6661.30	4490.30	1.48	0.14
irrigated	17.10	1.21	14.12	0.00	-404.60	58.07	-6.97	0.00	33058.62	6882.15	4.80	0.00
early	-15.91	1.99	-8.00	0.00	-342.97	65.82	-5.21	0.00	10521.00	5876.67	1.79	0.07
corn	-9.24	0.73	-12.70	0.00	77.57	41.15	1.89	0.06	-17229.22	5237.63	-3.29	0.00
wheat	-10.20	1.15	-8.86	0.00	358.89	60.29	5.95	0.00	1613.53	6989.71	0.23	0.82
alfalfa	-6.88	2.68	-2.57	0.01	-1271.50	123.37	-10.31	0.00	36240.15	10013.16	3.62	0.00
other	-10.55	1.40	-7.54	0.00	555.60	73.79	7.53	0.00	-22669.54	8570.38	-2.65	0.01
siltyclayloam	1.60	0.82	1.94	0.05	-173.31	38.39	-4.51	0.00	-4919.46	3917.24	-1.26	0.21
clayloam	-4.72	4.61	-1.02	0.31	-1969.32	190.61	-10.33	0.00	9453.72	19443.16	0.49	0.63
sandyloam	-12.97	1.09	-11.93	0.00	242.97	56.80	4.28	0.00	-7522.61	7154.94	-1.05	0.29
nlbs	0.19	0.01	23.74	0.00	-4.92	0.43	-11.31	0.00	84.74	53.63	1.58	0.11
aprrain	-0.29	0.20	-1.49	0.14	-110.53	11.62	-9.51	0.00	5186.05	1509.01	3.44	0.00
mayrain	-0.18	0.14	-1.30	0.19	-40.91	6.44	-6.36	0.00	-709.51	696.32	-1.02	0.31
junrain	0.80	0.16	5.04	0.00	-14.44	8.65	-1.67	0.10	1999.66	1097.52	1.82	0.07
julrain	0.64	0.11	5.91	0.00	33.79	5.38	6.28	0.00	-1473.77	568.24	-2.59	0.01
augrain	-0.86	0.21	-4.19	0.00	20.96	9.89	2.12	0.03	-3949.46	1132.18	-3.49	0.00
septrain	-0.60	0.16	-3.80	0.00	-39.98	8.38	-4.77	0.00	21.05	941.34	0.02	0.98

Region 4	**Mean function**					**Variance function**					**Skewness function**			
minapr	-2.09	0.20	-10.67	0.00		74.63	11.60	6.43	0.00		-404.71	1407.92	-0.29	0.77
minmay	1.65	0.20	8.31	0.00		49.56	9.71	5.11	0.00		-4479.31	1171.36	-3.82	0.00
minjune	2.27	0.21	11.01	0.00		-100.69	11.34	-8.88	0.00		1346.59	1322.39	1.02	0.31
minjuly	-1.29	0.25	-5.08	0.00		3.53	13.77	0.26	0.80		-882.98	1769.61	-0.50	0.62
minaug	-2.70	0.26	-10.54	0.00		-66.40	15.00	-4.43	0.00		6529.19	2040.64	3.20	0.00
minsept	-0.21	0.12	-1.80	0.07		6.41	5.20	1.23	0.22		1366.80	609.82	2.24	0.03
maxapr	1.24	0.14	8.75	0.00		-31.70	8.10	-3.91	0.00		544.92	1018.65	0.53	0.59
maxmay	0.54	0.17	3.21	0.00		-69.87	8.26	-8.46	0.00		4388.36	1067.56	4.11	0.00
maxjune	-2.24	0.18	-12.52	0.00		105.70	9.57	11.04	0.00		-3712.10	1144.79	-3.24	0.00
maxjuly	1.66	0.22	7.63	0.00		38.01	10.52	3.61	0.00		-2827.06	1247.11	-2.27	0.02
maxaug	-1.87	0.23	-8.19	0.00		33.30	11.67	2.85	0.00		-1346.62	1401.99	-0.96	0.34
maxsept	1.15	0.13	8.58	0.00		-6.52	6.92	-0.94	0.35		-2944.42	772.12	-3.81	0.00
cbo	1.42	1.30	1.09	0.28		201.29	58.37	3.45	0.00		634.63	7724.36	0.08	0.94
rwo	5.79	1.45	4.00	0.00		-80.66	348.68	-0.23	0.82		1266.24	24540.43	0.05	0.96
hto	-12.47	2.23	-5.60	0.00		199.51	152.90	1.30	0.19		-22954.85	18889.86	-1.22	0.22
cbht	-0.17	1.56	-0.11	0.91		206.02	74.18	2.78	0.01		-8886.45	9120.37	-0.97	0.33
rwht	10.37	1.94	5.35	0.00		95.11	174.71	0.54	0.59		15174.51	15600.81	0.97	0.33
cbrw	4.72	2.41	1.96	0.05		-110.55	141.64	-0.78	0.44		3963.28	12884.24	0.31	0.76
cbrwht	0.08	1.65	0.05	0.96		175.46	73.87	2.38	0.02		-15741.93	9257.89	-1.70	0.09
Constant	159.31	10.61	15.01	0.00		-1748.08	560.62	-3.12	0.00		321801.30	60254.98	5.34	0.00