

# Choosing Between Increased Means and Reduced Variance: Implications for Genetically Modified Crops

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Plant genetic modifications can affect farm profitability through two pathways—the reduction in risk or variation in production or shifts in the relative productivity of inputs. This analysis examines the potential effect of each of these pathways for hard red winter wheat production in Oklahoma. Specifically, the analysis examines the potential impact of a genetic innovation that increases the drought tolerance of winter wheat compared with an innovation that increases the efficiency of nitrogen use. Given these individual results, the study then analyzes the potential effect of stacking these traits. The possibility of stacked traits may enable breeders to tailor varieties to specific drought regions.

**Key words:** state dependent production functions, drought tolerance, nitrogen efficiency.

## Introduction

The adoption of genetically modified (GM) crops has been dramatic. Ninety percent of corn and upland cotton and 93% of soybeans planted in the United States in 2013 contains some form of genetic modification (US Department of Agriculture [USDA], Economics Research Service [ERS], 2013). Hence, producers receive benefits from these innovations that exceed their costs (including the cost of seeds and licensing fees). These genetic events have contributed to the increased agricultural productivity observed in the United States (Schmitz, Moss, Schmitz, Furtan, & Schmitz, 2010). However, the plethora of evidence supporting the benefits of GM crops to some extent hides several relevant economic questions posed by these advances. Specifically, how much is actually known about the effect of innovations on the production surface itself. In terms of production functions, conceptually we are interested in comparing genetic events that reduce the relative risk of production versus innovations that shift the entire distribution of yields upward. One could argue that several of the existing events reduce the risk. For example, the genetic events for corn reduce the plant's susceptibility to pests—such as the European corn borer—or make the plant tolerant to an herbicide—such as RoundUp™. In either case, the innovation eliminates the lower tail of the yield distribution or reduces the cost of treating an adverse outcome. Currently, we cannot identify an event that increases the entire distribution of production functions. One such event on the horizon is an innovation that increases the efficiency of nitrogen use in cereal crops, and another is the introduction of drought-tolerant varieties. The current study analyzes the potential tradeoff between these two “pathways” for hard red winter wheat production in Oklahoma. Specifically, we

consider the potential gains for a drought-tolerant innovation compared to the gains from increasing the effectiveness of nitrogen.

## Modeling Drought Tolerance

Two popular approaches to modeling the risk in production surfaces are the stochastic production function approach introduced by Just and Pope (1978) and the state-contingent production function based on the risk model developed by Chambers and Quiggin (2000). Given our interest in the linkage between risk or state outcomes and economic decisions, we adopt the state-contingent production function approach. As depicted in Figure 1, the production decision is characterized by three different production functions dependent on the outcome of a random (state) variable  $\varepsilon = (\varepsilon_1 \ \varepsilon_2 \ \varepsilon_3)$ . For example, let  $\varepsilon_1$  be the outcome where the Modified Palmer Drought Severity Index has a high, positive value (i.e., the growing season is wet). This wet outcome implies a certain level of soil moisture that interacts with the choice variable  $x$  (e.g., the level of nitrogen applied per acre). Figure 2 presents three state-contingent production functions for hard red wheat production in Oklahoma using the Modified Palmer Drought Severity Index to define the high, average, and low states of nature using the empirical estimates of the production function for hard red winter wheat from Moss (2013). The decision maker then chooses the input level that maximizes expected profit across states of nature (i.e., assuming risk neutrality) as

$$\max_x p_y [\pi_1 f_1(x) + \pi_2 f_2(x) + \pi_3 f_3(x)] - w x, \quad (1)$$

where  $p_y$  is the price of the output and  $w$  is the cost of the input (i.e., cost of nitrogen in dollars per pound).

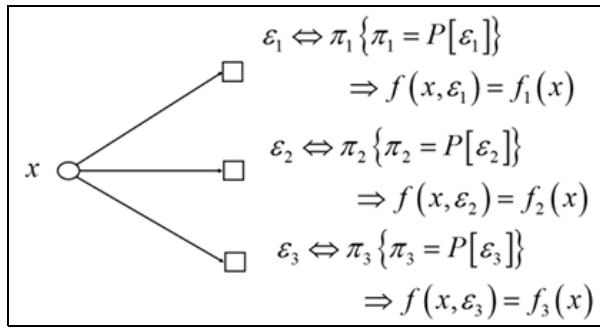


Figure 1. State contingent production functions.

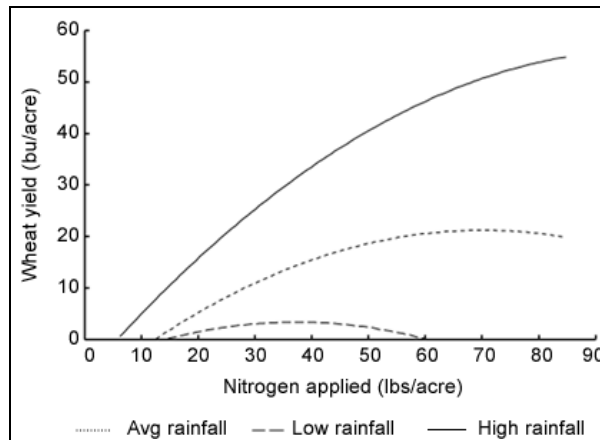


Figure 2. State contingent production functions for wheat in Oklahoma.

In order to consider the economic impact of a drought-tolerant variety, we consider a new state-dependent production function of

$$\max_x p_y [\pi_1 f_1(x) + \pi_2 f_2(x) + \pi_3 \tilde{f}_3(x, \tau)] - w x, \quad (2)$$

where  $\tilde{f}_3(x, \tau)$  is a new (higher) production function in the low rainfall state ( $\tau$  controls how close the lower function is to the average rainfall state). Table 1 presents the optimal level of nitrogen for different wheat prices, assuming a nitrogen price of \$544/ton. The second column depicts the nitrogen choice for the original state-contingent production function (i.e.,  $\tau = 0.00$ ). The third column represents a shift such that the original state-contingent function for the low rainfall state is given 75% of the weight, and a weight of 25% is given to the average rainfall function (i.e.,  $\tau = 0.25$ ). From left to right, each column represents a smaller effect of drought (i.e., Column 2 is the original production function and Column 3 is a new production function [ $\tilde{f}_3(x, 0.25) = 0.25 \times f_2(x) + 0.75 \times f_3(x)$ ]). As the downside risk declines, the producer chooses to increase the level of

Table 1. Optimal nitrogen use given an increase in drought tolerance.

Wheat price	Weight of average rainfall				Percent change from non-GM		
	0.00 <sup>a</sup>	0.25	0.50	0.75	0.25	0.50	0.75
4.00	65.95	66.95	67.95	68.96	1.51	3.04	4.56
4.50	66.54	67.54	68.55	69.55	1.50	3.01	4.52
5.00	67.02	68.01	69.02	70.02	1.49	2.99	4.49
5.50	67.40	68.40	69.41	70.41	1.48	2.97	4.46
6.00	67.73	68.73	69.73	70.74	1.47	2.96	4.44
6.50	68.00	69.00	70.00	71.01	1.47	2.95	4.42
7.00	68.24	69.23	70.24	71.24	1.46	2.94	4.41

<sup>a</sup> These values represent the change in reduction of drought damage from the introduction of the GMO ( $\tau = 0.25$  implies that the drought event is 25% of the original difference between the average and low rainfall yield).

Table 2. Average wheat yields (bushels/acre) from increased drought tolerance.

Wheat price	Nitrogen constant <sup>a</sup>	Optimal nitrogen <sup>b</sup>		
		0.25	0.50	0.75
4.00	30.88	31.82	32.77	33.71
		(3.04) <sup>c</sup>	(6.10)	(9.16)
4.50	30.92	31.87	32.82	33.77
		(3.06)	(6.14)	(9.22)
5.00	30.95	31.90	32.86	33.82
		(3.08)	(6.17)	(9.27)
5.50	30.97	31.93	32.89	33.85
		(3.09)	(6.20)	(9.31)
6.00	30.98	31.94	32.91	33.88
		(3.10)	(6.23)	(9.35)
6.50	31.00	31.96	32.93	33.90
		(3.11)	(6.25)	(9.38)
7.00	31.00	31.97	32.95	33.92
		(3.12)	(6.26)	(9.41)

<sup>a</sup> The first set of columns holds the amount of nitrogen applied to the original level (i.e., optimal for the original production function and price vector)—we assume in these columns that the farmer does not respond to the change in technology.

<sup>b</sup> In the second set of columns we assume that the farmer responds to the change in drought tolerance by increasing the level of nitrogen.

<sup>c</sup> Numbers in parentheses denote percent changes from the original yield.

nitrogen applied. Table 2 presents the effect of these decisions on wheat production.

The effect of this increased drought tolerance can be broken down into two changes (Figure 3). First, drought tolerance implies an upward shift in the average production function. This shift implies an increase in the wheat yield from Point A to Point B. Second, the change in production function may imply an increase in the opti-

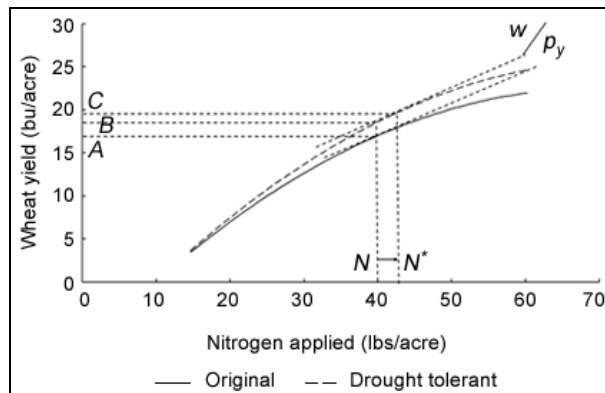
**Table 3. Profit levels from increased drought tolerance (\$/acre).**

Wheat price	Nitrogen constant <sup>a</sup>				Optimal nitrogen <sup>b</sup>		
	0.00	0.25	0.50	0.75	0.25	0.50	0.75
4.00	105.59	109.35 (3.55) <sup>c</sup>	113.13 (7.13)	116.91 (10.71)	109.37 (3.58)	113.23 (7.23)	117.14 (10.93)
4.50	121.04	125.30 (3.52)	129.59 (7.06)	133.87 (10.60)	125.33 (3.54)	129.70 (7.15)	134.13 (10.81)
5.00	136.51	141.27 (3.49)	146.06 (7.00)	150.86 (10.51)	141.30 (3.51)	146.19 (7.09)	151.15 (10.72)
5.50	151.99	157.25 (3.46)	162.55 (6.95)	167.85 (10.44)	157.29 (3.49)	162.69 (7.04)	168.17 (10.65)
6.00	167.48	173.24 (3.44)	179.05 (6.91)	184.86 (10.38)	173.28 (3.47)	179.21 (7.00)	185.20 (10.58)
6.50	182.97	189.24 (3.43)	195.56 (6.88)	201.87 (10.33)	189.28 (3.45)	195.72 (6.97)	202.24 (10.53)
7.00	198.47	205.25 (3.41)	212.07 (6.85)	218.89 (10.29)	205.29 (3.43)	212.25 (6.94)	219.29 (10.49)

<sup>a</sup> The first set of columns holds the amount of nitrogen applied to the original level (i.e., optimal for the original production function and price vector)—we assume in these columns that the farmer does not respond to the change in technology.

<sup>b</sup> In the 2<sup>nd</sup> set of columns we assume the farmer responds to the change in drought tolerance by increasing the level of nitrogen.

<sup>c</sup> Numbers in parentheses denote percent changes from the original yield.



**Figure 3. Effect of increased drought tolerance on yield.**

mal level of fertilizer applied (from  $N$  to  $N^*$ ). Table 2 highlights these two impacts of increased drought tolerance. Columns 3 through 5 depict the increase in average yield holding the nitrogen level constant. Hence, elimination of the lower tail of the distribution causes the average yield to increase. Next, Columns 6 through 8 depict the yield given the increased level of nitrogen presented in Table 1. In general, the larger impact results from the reductions in yield losses. Returning to the results depicted in Table 1, the relative increase in nitrogen applied is fairly small (i.e., averaging around 1.5% for  $\tau = 0.25$ , 3.0% for  $\tau = 0.50$ , and 4.5% for  $\tau = 0.75$ ). Hence, the increase in the yield from a more drought-resistant variety is around 3.1% for  $\tau = 0.25$ , increasing to 3.3% when we consider the increase in fertilizer in

response to changes in the state-contingent production functions.

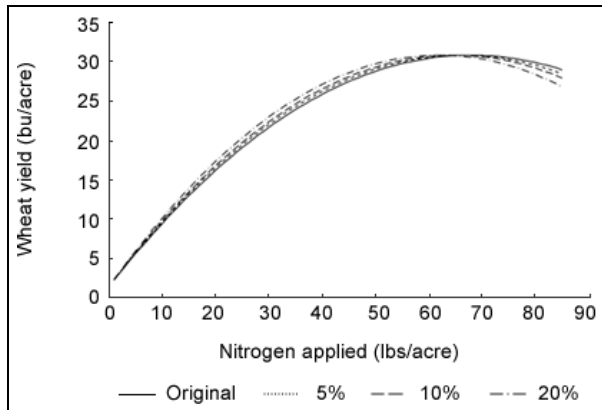
Table 3 presents the implications for the use of drought-tolerant varieties on profit. Columns 3 through 5 (in Table 2) present the effect of drought tolerance on profit with the level of nitrogen held constant, while Columns 6 through 8 depict the effect of the increased fertilizer usage on profits. Consistent with the results from Table 2, the largest portion of the gain from drought tolerance results from the shift outward in the expected production function. Specifically, for  $\tau = 0.25$ , profit increases by around 3.5% holding the level of nitrogen constant. This increase is only slightly higher when the level of nitrogen is increased.

### Increased Nitrogen Use Efficiency

To value the potential economic gains from a genetic event that increases the efficiency of nitrogen use, we take a variation in the production function with respect to nitrogen use. Suppose we replace the nitrogen argument in the production function with a function of nitrogen equation of

$$f(x) = f(\psi(x)), \tag{3}$$

where  $\psi(x)$  is a function representing the efficiency of nitrogen use. In our original model,  $\psi(x) = x$  for all  $x$ . If we assume that a genetic modification increases the crop's efficiency of nitrogen use, we conjecture that  $\psi(x) > x$  for at least some set of input use.<sup>1</sup> Figure 4 presents



**Figure 4. Increased efficiency of nitrogen use for wheat production.**

the effect of a 5%, 10%, and 20% variation in the efficiency of nitrogen use.

The numerical estimates of the effect of improved nitrogen efficiency are presented in Table 4. The amount of nitrogen applied declines as the efficiency of nitrogen use increases. As presented in the table, a 0.05 variation in nitrogen efficiency reduces nitrogen use across the board by around 2.3%. This savings doubles as the variation increases to 0.10%, but increases less rapidly at 0.20%, where nitrogen use declines by slightly over 8%. Interestingly, while improving nitrogen efficiency leads to somewhat significant declines in nitrogen use, this increased efficiency has relatively little effect on either the production of wheat or the profitability of wheat production. The increase in wheat production is almost zero, while the profitability of wheat production increases in most cases by less than 1.0% (Table 4).

### Stacking the Traits

A comparison of the gains from drought tolerance in Table 3 with the gains from increased nitrogen efficiency in Table 4 leads to the conclusion that the drought-tolerant event is more profitable. However,

1. This study constructs a variation of the original production function. Specifically starting with Equation 3

$\delta f(\psi(x)) = \frac{\partial f(\psi)}{\partial \psi} [\psi(x) - x]$ , where  $f(\cdot)$  is redefined as a functional (a function of functions). We then consider a linear variation of the input

$$\frac{\delta f(\psi(x))}{f(\psi(x))} = \left[ \frac{\delta f(\psi(x))}{\partial x} \frac{1}{f(\psi(x))} \right]_{x \rightarrow x^*} = \kappa \text{ s.t. } \psi(x) = a + bx,$$

solving for  $a$  and  $b$ , where  $\kappa = (0.05 \ 0.10 \ 0.20)$  and  $x^*$  and is the level of input that maximizes the profit for the original specification.

**Table 4. Effect of increased nitrogen efficiency.**

Wheat price	Optimal levels of production				Percent change		
	Original <sup>a</sup>	0.05 <sup>b</sup>	0.10	0.20	0.05	0.10	0.20
<b>Nitrogen input (lb/acre)</b>							
4.00	62.62	61.19	59.89	57.61	-2.29	-4.37	-8.00
4.50	63.22	61.76	60.43	58.11	-2.31	-4.41	-8.09
5.00	63.69	62.21	60.86	58.50	-2.33	-4.45	-8.15
5.50	64.08	62.58	61.21	58.82	-2.35	-4.48	-8.20
6.00	64.40	62.88	61.50	59.09	-2.36	-4.50	-8.24
6.50	64.68	63.14	61.75	59.32	-2.37	-4.52	-8.28
7.00	64.91	63.37	61.97	59.52	-2.38	-4.54	-8.31
<b>Wheat yield (bushel/acre)</b>							
4.00	30.72	30.72	30.73	30.75	0.03	0.05	0.10
4.50	30.75	30.76	30.77	30.78	0.02	0.04	0.08
5.00	30.78	30.79	30.79	30.80	0.02	0.03	0.06
5.50	30.80	30.81	30.81	30.82	0.02	0.03	0.05
6.00	30.82	30.82	30.82	30.83	0.01	0.02	0.04
6.50	30.83	30.83	30.84	30.84	0.01	0.02	0.04
7.00	30.84	30.84	30.84	30.85	0.01	0.02	0.03
<b>Profit (\$/acre)</b>							
4.00	105.83	106.26	106.64	107.31	0.40	0.77	1.40
4.50	121.20	121.63	122.02	122.70	0.35	0.68	1.24
5.00	136.58	137.02	137.41	138.09	0.32	0.60	1.10
5.50	151.98	152.41	152.81	153.50	0.29	0.55	1.00
6.00	167.38	167.82	168.22	168.91	0.26	0.50	0.91
6.50	182.79	183.23	183.63	184.33	0.24	0.46	0.84
7.00	198.21	198.65	199.05	199.75	0.22	0.42	0.77

<sup>a</sup> Original refers to the production function without a change in nitrogen efficiency (i.e., the original production for wheat).

<sup>b</sup> The subsequent columns refers to the variation (percent increase) in the production function.  $\kappa = 0.05$  refers to a 0.05 increase in the production function assuming a linear variation at the original level of nitrogen.

another trend in the development of GM crops involves stacking the events. Table 5 presents the profit from the combined effect of drought tolerance and improved nitrogen efficiency, holding the price of wheat constant. These results reinforce the conclusion that the payoff for drought tolerance exceeds that of increased nitrogen use efficiency. For a 10% reduction in the lower bound, the gain from drought tolerance alone is \$2.13/acre, while a 31% increase in nitrogen efficiency is required to generate the same improvement. The results in Table 5 can also be used to derive an “indifference map” for the stacked genes. Specifically, assume the targeted increase in profitability is 5% (i.e., \$7.63/acre, yielding a return of \$160.31/acre). First, note that it is impossible to meet this goal with a change in the lower bound of moisture

Table 5. Profit for stacked genetic events (\$/acre).

Change in nitrogen efficiency	Weight of average rainfall										
	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.00	152.68	154.81	156.94	159.09	161.25	163.42	165.60	167.80	170.00	172.22	174.45
0.06	153.20	155.33	157.47	159.62	161.78	163.96	166.14	168.34	170.55	172.77	175.00
0.12	153.66	155.79	157.93	160.09	162.25	164.43	166.62	168.82	171.03	173.25	175.49
0.18	154.07	156.21	158.35	160.51	162.68	164.86	167.05	169.25	171.46	173.69	175.93
0.24	154.45	156.58	158.73	160.89	163.06	165.24	167.43	169.64	171.85	174.08	176.32
0.30	154.78	156.92	159.07	161.23	163.40	165.59	167.78	169.99	172.21	174.44	176.68
0.36	155.09	157.23	159.38	161.54	163.72	165.91	168.10	170.31	172.53	174.76	177.00
0.42	155.37	157.51	159.67	161.83	164.01	166.19	168.39	170.60	172.83	175.06	177.30
0.48	155.63	157.77	159.93	162.09	164.27	166.46	168.66	170.87	173.10	175.33	177.58
0.54	155.86	158.01	160.17	162.33	164.51	166.70	168.91	171.12	173.34	175.58	177.83
0.60	156.08	158.23	160.39	162.56	164.74	166.93	169.13	171.35	173.57	175.81	178.06
0.66	156.29	158.43	160.59	162.76	164.95	167.14	169.34	171.56	173.79	176.03	178.28
0.72	156.47	158.62	160.78	162.96	165.14	167.33	169.54	171.76	173.98	176.22	178.48

of 10%. It is possible to meet this goal with a change in the lower bound of 20% with more than a 60% variation in nitrogen efficiency. Further, if we consider a 30% increase in the lower bound, the required increase in nitrogen efficiency required to meet the target falls to 18%. Finally, if we increase the lower bound to 40%, the return target can be met without improvements in nitrogen efficiency. However, what is the benefit? To decide on a strategy we must have some idea of the cost. For example, if the research program (in terms of direct and opportunity cost) of nitrogen efficiency costs less than the research into drought tolerance, it would be economically efficient to emphasize nitrogen efficiency.

## Conclusions

Few would disagree that the introduction of GM crops has significantly changed the landscape of agriculture in the United States. The rapid and almost complete adoption of GM varieties of corn, cotton, and soybeans indicates that adoption increases producer profitability. There remain many avenues for the creation of new varieties to increase farm profitability. This study examines two possible pathways through which genetic modifications may affect producers. Specifically, we analyze the potential effect of a genetic modification making hard red winter wheat more drought tolerant in Oklahoma and the potential effect of a genetic event that would increase the efficiency of nitrogen use. Farmer A in Oklahoma may choose a different variety because of the probability of drought than Farmer B due to differences in rainfall patterns. Hence, Farmer B may place

more value on increased nitrogen efficiency than Farmer A if such a variety is available, but Farmer A may place more value drought tolerance.

The empirical results indicate that drought-tolerant innovation would have the greatest impact on the supply of hard red winter wheat and farmer profitability. Of course, these are the potential benefits to technology—given the *ex ante* nature of the study, we do not consider the cost of generating the innovation. For the purposes of our analysis, it would be difficult to speculate about differences in the cost of each innovation (i.e., drought tolerance versus nitrogen augmentation). However, we note that such differences would affect the design of a research program.

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