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Betting the Farm:

An Application of Modern Portfolio Theory to South Dakota Agriculture

by

Lucas Ladenburger

A Thesis Submitted in Partial Fulfillment
Of the Requirements for the
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The members of the Honors Thesis Committee appointed
to examine the thesis of Lucas Ladenburger
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ABSTRACT

Betting the Farm:
An Application of Modern Portfolio Theory to South Dakota Agriculture

Lucas Ladenburger

Director: Mike Allgrunn, Ph.D.

This project applies Modern Portfolio Theory to South Dakota agriculture to determine whether farmers can both increase their return and decrease their risk through their choice of crop. An econometric model is used to predict state-wide crop revenue for different “portfolios” which each involve planting a different proportion of the eleven crops grown in the state. These predictions are then evaluated for their respective risk and return, measured by average revenue and standard deviation of revenue. Those portfolios which have a higher average revenue and a lower standard deviation of revenue than South Dakota experienced historically are then analyzed to determine their feasibility. Based on this analysis, it appears South Dakota could have reduced its agricultural risk and increased its return by either planting corn and wheat in the acres used to plant barley, or by planting corn and wheat in the acres used to plant sorghum.

KEYWORDS: Agricultural Risk, Modern Portfolio Theory, Diversification

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CHAPTER ONE

Introduction

Agriculture plays an important part of the South Dakota economy, accounting for \$11.2 billion in 2019 (South, 2019). That industry is dominated by two players: corn and soybeans. According to the USDA National Agricultural Statistics Service, in 2019 4.35 million acres of corn were planted, accounting for \$2 billion. Likewise, 3.5 million acres of soybeans were planted adding \$1.2 billion. The next highest were wheat with 1.5 million acres (\$298 million), sunflower with 533,000 acres (\$148 million), and sorghum with 250,000 acres (\$47 million). The high degree of reliance on these two crops could present issues should the state be faced with a shock leading to a fall in the yield or price of these crops. The recent trade war represents one such shock, in which the negative impact on the soybean market was highly publicized (Ferguson & Fugleberg, 2018).

In the last century, there has been a substantial increase in agricultural production and yields. Ramírez (1997) showed an increase in corn and soybean yields over time, with a strong positive correlation between the two. There has been some disagreement as to where these increases originated. Fraser et al. (2005) attributed this increase to crop specialization. This specialization led to a competitive advantage allowing farms to take advantage of economies of scale. Chavas et al. (2001) found that technical progress was the major contributor to these increased yields with climate change playing a smaller part of the yield trends. In contrast, Thompson (1975) and Baker et al. (1993) argued that increases in yields up to the 1970's were due to particularly favorable climatic conditions. Regardless of the exact cause, the United States agricultural industry has managed to successfully increase production to accommodate a growing population.

With these increases in production has come an ever-larger focus on corn and then to a lesser extent, soybeans. While specialization in these two crops may have contributed to greater production, it has come at the expense of diversification and its associated benefits (Fraser et al., 2005). This has presented the agricultural industry with new risks. Pope and Prescott (1980) explained that there is a tradeoff between economies of scale and diversification and Ramírez (1997) found that, with higher yields has come higher variability. Chavas et al. (2001) showed this is in Wisconsin corn producers, who have seen their yields rise, but risk also increased as measured by the variance of yields, pointing to a tradeoff between yield and risk. Finally, climate trends though favorable to agricultural production in the first part of the twentieth century, led to much greater variability beginning in the 1970's and caused the agricultural depression of the 1980's (Baker et al., 1993; Thompson, 1975). The future risks associated with climate change may pose an even larger threat. Thompson (1975) found that the highest yields of corn and soybeans occurred in summers with lower than average temperatures, and when weather varied greatly from normal, yields were the lowest. As the earth faces increasing weather variability and higher average temperatures due to climate change, farmers could suffer greater variation in returns.

One way to handle this risk could come from an application of Modern Portfolio Theory (MPT). MPT states that in the construction of a portfolio of assets, one can maximize the expected returns for a given level of risk or minimize the risk for a given level of expected returns by diversifying the portfolio with assets that have a low covariance with the other assets in the portfolio (Markowitz, 1952). Several researchers have applied MPT to agriculture and crop choice (Figge, 2004; Fraser et al., 2005;

Johnson, 1967; Paut et al., 2019; Stovall, 1966). This involves choosing crops which are uncorrelated or negatively correlated with the other crops, to achieve the benefits of diversification (Figge, 2004; Kimura et al., 2010; Stovall, 1966). However, the current state of agriculture, with its reliance on corn and soybeans, does not fit this description. Rather, corn and soybeans are highly correlated and do not provide the benefits of diversification (Ramírez, 1997).

Markowitz (1952) illustrated MPT with a graph showing the expected value of a portfolio graphed against the variance of a portfolio, such as on Figure 1. Every possible portfolio falls within the area, A, while the efficient portfolios—those which maximize the return for a given level of risk or minimize the risk for a given level of return—are shown by the bold curve. If the portfolio chosen is not along the bold curve, then it is possible to increase returns while keeping risk constant, decrease risk while keeping returns constant, or both increase returns and decrease risk (Figge, 2004; Johnson, 1967; Markowitz, 1952). This project seeks to determine whether South Dakota can achieve that third case: increase its agricultural returns while decreasing its exposure to risk.

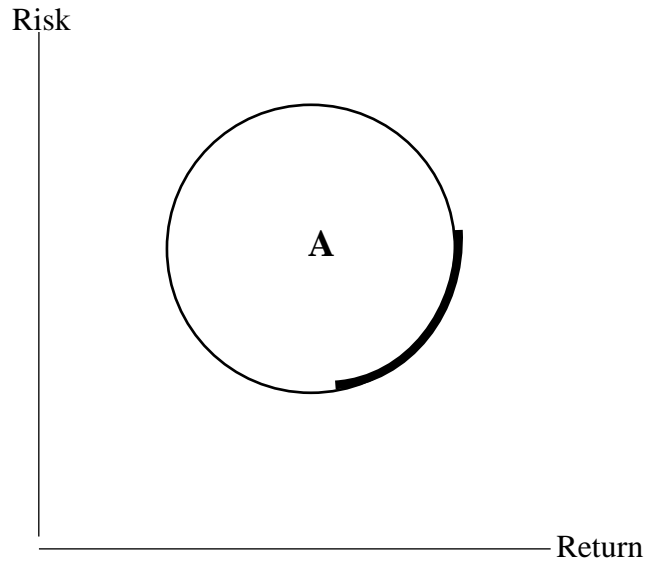


Figure 1. All possible portfolios with efficient portfolios in bold.

CHAPTER TWO

Conceptual Framework

In choosing what crops to plant, which this paper will call the “crop mix”, there should be a tradeoff between risk and reward (as there is for other assets) if the chosen crop mix is efficient. That is, taking greater risks may lead to significantly higher returns, but also increases the chances of receiving significantly lower returns. This is demonstrated by a hypothetical scenario in Figure 2. In this scenario, a farmer can choose from three crop mixes which have different payoffs depending on which of two events occurs. Without knowing whether he will face Event A or Event B, the farmer must commit to a single crop mix. In the most extreme case, a farmer may choose to plant only one crop, crop x, for example. He may receive \$100 or he may receive \$0. Conversely, if he chooses to plant equal amounts of each crop, he will receive only \$50, but faces no risk. The farmer’s choice will depend on his own risk aversion, as well as his expected return from each crop mix based on the likelihood of Event A or Event B occurring.

	Event A	Event B
100% Dedicated to Crop x	\$100	\$0
50% Dedicated to Crop x 50% Dedicated to Crop y	\$50	\$50
100% Dedicated to Crop y	\$0	\$100

Figure 2. Payoff table consisting of three alternative planting choices and two possible outcomes for each.

In an efficient market, those portfolios along the bold curve in Figure 1, crop prices, and by extension, revenue, should reflect the relative risk of pursuing a given

strategy. That is, there should be a tradeoff between low risk and high return. However, this paper poses a question: can a farmer choose his crop mix in such a way that he both reduces his risk and increases his revenue? This would require that the farmer's crop mix not be on the efficient curve.

Of course, for a farmer to move onto this curve by choosing the “best” crop mix—that crop mix which provides the best combination of high revenue and low risk—there must be variation in the prices and yields of the crops. If the prices and yields of all crops are perfectly correlated, then there is no way to reduce risk by changing the crop mix (Figge, 2004; Kimura et al., 2010; Markowitz, 1952; Stovall, 1966). In this case, the farmer would merely choose the crop mix which provides the highest expected revenue. Put another way, for diversification to successfully reduce risk, the given assets cannot be perfectly correlated. Price and yield are the two main types of risks faced by farmers, and thus, are of interest for diversification (Kimura et al., 2010). To gain a sense of the correlation of South Dakota crops, Tables 1 and 2 display the correlation coefficient (price and yield) for the twelve crops grown in South Dakota for which data are available.¹

¹ The correlation coefficients were calculated using statewide price and yield data retrieved from USDA NASS.

	Soybeans	Wheat	Sunflower	Sorghum	Oats	Millet	Safflower	Barley	Flaxseed	Peas
Corn	0.948	0.954	0.914	0.989	0.923	0.682	0.756	0.936	0.904	-1.000
Soybeans		0.940	0.914	0.928	0.946	0.562	-0.804	0.937	0.920	1.000
Wheat			0.924	0.946	0.945	0.577	0.864	0.964	0.935	1.000
Sunflower				0.922	0.895	0.493	-1.000	0.912	0.926	1.000
Sorghum					0.921	0.725	0.998	0.928	0.896	-1.000
Oats						0.626	1.000	0.954	0.912	-1.000
Millet							0.997	0.596	0.422	-1.000
Safflower								N/A	0.989	-1.000
Barley									0.920	N/A
Flaxseed										-1.000

Table 1. Price correlation coefficients. Colors signify the degree of correlation with yellow having a correlation coefficient below .799, orange being between .800 and .899, and red being above .900. Note that in some cases insufficient data were available to calculate the correlation coefficient, designated by “N/A”.

	Soybeans	Wheat	Sunflower	Sorghum	Oats	Millet	Safflower	Barley	Flaxseed	Peas
Corn	0.956	0.935	0.866	0.900	0.923	0.765	0.948	0.836	0.811	-0.026
Soybeans		0.861	0.824	0.912	0.888	0.768	0.794	0.771	0.730	-0.387
Wheat			0.762	0.858	0.957	0.321	0.266	0.901	0.845	0.370
Sunflower				0.797	0.777	0.810	0.901	0.423	0.476	-0.352
Sorghum					0.856	0.784	0.251	0.784	0.749	0.722
Oats						0.458	0.291	0.923	0.860	0.664
Millet							0.388	0.170	0.085	-0.132
Safflower								1.000	0.945	-0.256
Barley									0.890	-1.000
Flaxseed										0.339

Table 2. Yield correlation coefficients. Colors signify the degree of correlation with yellow having a correlation coefficient below .799, orange being between .800 and .899, and red being above .900.

As shown in Tables 1 and 2, both prices and yields of the various crops are highly correlated. This is not surprising since both prices and yields of each crop likely respond in a similar manner to the factors which affect the other crops. For example, if the state faces a drought, yields of most or all crops would likely decline. However, despite being highly correlated, there does seem to be enough variation to capture the benefits of diversification, particularly for crop yields. It should be noted that the correlation coefficients containing safflower as well as those containing peas are unusual because they have very little data to draw from—only four data points for each.

Having established evidence that a farmer could reduce risk through the construction of his crop mix, this paper will seek to identify if there is a crop mix which would both increase return and decrease risk over the seventy years studied, moving him onto the efficient curve in Figure 1. For this project, return is represented by average real revenue over all years while risk is represented by the standard deviation of revenue. The ideal way to conduct this analysis would involve examining individual farms, identifying their crop mix, and tracking their revenue over time in search of the “best” crop mix. However, farm level data is not publicly available. Instead, this project uses aggregate data for South Dakota, treating South Dakota as a single “farm” which defines its crop mix by choosing the proportion of each crop planted (acres of a crop divided by total acres planted) and generates a resulting revenue.² To identify how the crop mix affects revenue, an econometric model is used to predict the revenue that would result from planting various crop mixes.

² Aggregated data do tend to underestimate risk, so the actual risk faced on the farm-level is likely higher than the results show (Kimura et al., 2010; Schurle, 1996). However, because this project only examines state-wide data, comparing “apples-to-apples”, the results should hold when applied to a smaller scale, but with different values.

CHAPTER THREE

Econometric Model and Estimation Method

To predict real revenue based on the proportion of each crop planted, the following general model was used for a crop mix with n crops:

[1]

$$revenue_t = \beta_0 + \beta_1 crop_{1t} + \beta_2 crop_{2t} + \dots + \beta_{n-1} crop_{n-1t} + u_t$$

where $crop_{1t}$ is the proportion of crop 1 in time t (total acres of crop 1 planted divided by total acres of all crops planted), $crop_{2t}$ is the proportion of crop 2 planted in time t , and so on, and u_t is the error term. One crop proportion, $crop_{nt}$, is not included, and will be called the “excluded crop”. Thus, the model is used to predict how revenue will change as the acres used to plant crop n are substituted for one or more other crops, called the “substituted crop(s)”. For example, say crop n accounted for 25% of total acres planted, and one wished to determine how revenue would change if those acres were instead used to plant crop 1. One would add .25 to the exogenous variable $crop_{1t}$ and observe the change in predicted revenue. Or, if instead one hoped to see the effect of splitting the acres of crop n between crop 1 and 2, .125 would be added to both $crop_{1t}$ and $crop_{2t}$.

Other exogenous variables likely to influence revenue were considered and, in some cases, incorporated into the model including precipitation, temperature, the presence of a recession, and technological advancement leading to increased yields and production. Thus, the model is as follows:

[2]

$$\begin{aligned} \text{revenue}_t = & \beta_0 + \beta_1 \text{crop}_{1t} + \beta_2 \text{crop}_{2t} + \dots + \beta_{n-1} \text{crop}_{n-1t} + \beta_{x_1} x_{1t} + \beta_{x_2} x_{2t} + \dots \\ & + \beta_{x_m} x_{mt} + u_t \end{aligned}$$

where $x_{1t}, x_{2t}, \dots, x_{mt}$ are other exogenous variables. Ordinary least squares (OLS) was used for estimation.

CHAPTER FOUR

Revenue Estimation

The regressions were used to predict revenue from year to year for each of several different crop mixes, which will be called “portfolios.” This prediction was acquired via the following method. Say in a given portfolio the excluded crop, crop n, is replaced with crop 1 for year a. The equation to predict revenue would look like:

[3]

$$\widehat{revenue}_a = \hat{\beta}_0 + \hat{\beta}_1(crop_{1_a} + crop_{n_a}) + \hat{\beta}_2 crop_{2_a} + \dots + \hat{\beta}_{n-1} crop_{(n-1)_a} + \hat{\beta}_{x_1} x_{1_a} \\ + \hat{\beta}_{x_2} x_{2_a} + \dots + \hat{\beta}_{x_m} x_{m_a}$$

The variable $crop_{n_a}$ is the proportion of crop n planted in year a and x_{m_a} is the value for x_m in year a. This strategy, which provides a predicted revenue for year a, can then be extended to all years of interest. Once a revenue estimate is acquired for each year, average revenue and the standard deviation of revenue are calculated to evaluate the risk and return of the portfolio. Finally, these values are compared to the actual average revenue and standard deviation of revenue for South Dakota over the same time period.

This process was repeated for 1,925 portfolios (most of which involved substituting multiple crops for the excluded crop). Of interest for this project were those portfolios which had both a higher average revenue and a lower standard deviation of revenue than occurred in South Dakota. These portfolios both increased return and decreased risk and therefore would have been preferable in all cases. There were also portfolios which increased both return and risk or decreased both return and risk which

could be preferable to some farmers, depending on the risk aversion of the farmer. But for this project, these were disregarded.

CHAPTER FIVE

The Data

The data for this project are publicly accessible and were retrieved from the United States Department of Agriculture National Agricultural Statistics Service (NASS), the National Oceanic and Atmospheric Administration National Centers for Environmental Information (NCEI), the National Bureau of Economic Research (NBER), and the United States Bureau of Labor Statistics (BLS). Each data point represents a year and the data analyzed for this project cover 1949 to 2018.³ All data concern South Dakota as a whole. The data set does not include data on hay production as it is not planted like the other field crops studied. The data set also does not include production of animal goods and the associated revenue. A description of the variables is shown in Table 3. Table 4 contains summary statistics for the data.⁴

³ 1977-1981 are excluded as revenue data for sunflowers are unavailable. Sunflowers account for 4.5% of revenue in 1982 and were therefore considered too important to assume as zero for 1977-1981.

⁴ The time series data on revenue and several of the crops do seem to have a unit root, potentially impacting the results of this research. However, action to correct the issue is beyond the scope of this thesis.

Variable	Description
revenue ⁵	real revenue (\$ billions) from crops, adjusted using the PPI for farm products (2019 prices)
corn	corn proportion of total acres planted
soybeans	soybeans proportion of total acres planted
wheat	wheat proportion of total acres planted
sunflower ⁶	sunflower proportion of total acres planted
sorghum	sorghum proportion of total acres planted
oats	oats proportion of total acres planted
millet ⁷	millet proportion of total acres planted
safflower ⁸	safflower proportion of total acres planted
barley ⁹	barley proportion of total acres planted
flaxseed	flaxseed proportion of total acres planted
pea ¹⁰	pea proportion of total acres planted
aprilrain...novrain	total precipitation April...November (in.)
apriltemp...novtemp	average temperature April...November (°F)
recess	=1 if recession, 0 otherwise
45-49...15-19	5-year time indicators, =1 if observation falls in period, 0 otherwise

Table 3. Variable descriptions.

⁵ In calculating revenue, data on some crops were unavailable and in such cases, revenue was assumed to be zero. This assumption was made because the crops account for very little revenue in the surrounding years. For safflower, revenue data is missing for 2015 (accounts for .07% in 2016). For barley, revenue data for 2016 and 2017 are missing (accounts for .04%, and .05% of revenue in 2015 and 2018 respectively). For peas, revenue data are missing for 2016 and 2018 (accounts for .1% of revenue in 2017).

⁶ Sunflower data are first available in 1977. Prior to that, it is assumed that zero is planted as it accounts for very little in the first years data are available. Sunflowers account for 1.2% of total acres planted in 1977.

⁷ Millet data are first available in 1999. Prior to that, it is assumed that zero is planted as it accounts for very little in the first years data are available. Millet account for 1.4% of total acres planted in 1999.

⁸ Safflower data are first available in 2016. Prior to that, it is assumed that zero is planted as it accounts for very little in the years data are available. Safflower account for .2% of total acres planted in 2016.

⁹ Barley data are missing and assumed zero in 2016 and 2017. Barley accounts for .3% of total acres planted in both 2015 and 2018.

¹⁰ Pea data are first available in 2016. Prior to that, it is assumed that zero is planted as it accounts for very little in the years data are available. Peas account for .2% of total acres planted in 2016.

Variable	Mean	Standard Deviation	Minimum	Maximum
revenue	2.37	1.59	.55	5.98
corn	.33	.04	.24	.43
soybeans	.15	.14	.002	.40
wheat	.25	.06	.13	.35
sunflower	.03	.03	0	.10
sorghum	.03	.01	.01	.06
oats	.15	.11	.01	.32
millet	.003	.004	0	.02
safflower	.0001	.0003	0	.002
barley	.04	.03	.002	.12
flaxseed	.03	.03	.0003	.08
pea	.0001	.001	0	.003
aprilrain	2.07	0.95	0.36	5.14
mayrain	3.08	1.33	.99	6.78
junerain	3.42	1.23	1.38	6.16
julyrain	2.52	1.02	.75	6.00
augrain	2.14	0.77	.70	4.04
septrain	1.74	0.92	.20	4.29
octrain	1.43	1.10	.03	5.35
novrain	0.65	0.44	.05	1.86
apriltemp	44.48	3.58	36.70	51.60
maytemp	56.20	2.72	51.20	62.10
junetemp	66.18	3.00	59.30	75.30
julytemp	72.74	2.97	64.20	78.70
augtemp	70.88	2.55	64.90	77.10
septtemp	60.31	3.02	49.60	66.90
octtemp	47.85	3.20	39.50	57.20
novtemp	32.27	4.83	17.50	42.40
recess	.29	.46	0	1
Number of observations = 65				

Table 4. Summary statistics. Note that each crop variable represents the proportion of total acres planted with that crop.

CHAPTER SIX

Results

The general model, equation [1], was first used to provide a basic prediction for revenue based on proportion of crops planted with one crop excluded. This was repeated for all eleven crops. Next, additional explanatory variables were added to provide a better revenue prediction. Precipitation totals were considered in both annual and monthly terms. However, it was decided that monthly data was more appropriate, specifically data for April through November, as these are the months when most planting, growing, and harvesting is completed in South Dakota. As a proxy for technological advancement, year was included as an independent variable. This use of year as a proxy assumes that once a new technology is introduced, it is continuously used or improved on for all future time periods. The year variable was further broken into five-year increments (dummy variables) to account for those periods which saw significantly greater or significantly less technological advancement.

Monthly average temperature was also considered as an independent variable, both on its own and as an interaction term with precipitation. However, it was ultimately excluded as it was not significant and had little effect on the crop coefficients, which are most important for this project. The presence of a recession was also evaluated as a dummy variable in the regression. It was also excluded though, as it was not significant. This was the case whether it indicated the year of the recession, or was lagged one year behind to account for changes in planting behavior.

The results for the final eleven regressions, which were used for the remainder of the project to predict revenue, are summarized in Table 5.¹¹

¹¹ The data were tested for heteroskedasticity and autocorrelation. It was found that they do display heteroskedasticity, but there is no evidence of autocorrelation.

Dependent Variable: revenue

Ind. Var.	corn excluded	soybeans excluded	wheat excluded	sunflower excluded	sorghum excluded	oats excluded	millet excluded	safflower excluded	barley excluded	flaxseed excluded	pea excluded
corn		7.88 (8.05)	4.53 (4.94)	12.71 (12.60)	18.12 (14.36)	10.21* (5.96)	11.38 (40.36)	-984.73 (879.50)	6.16 (6.03)	.22 (11.19)	554.12 (552.88)
soybeans	-7.88 (8.05)		-3.35 (6.67)	4.83 (16.74)	10.24 (16.50)	2.34 (7.97)	3.51 (44.61)	-992.60 (883.21)	-1.71 (8.79)	-7.66 (12.34)	546.24 (550.65)
wheat	-4.53 (4.94)	3.35 (6.67)		8.18 (11.95)	13.59 (12.46)	5.69 (4.97)	6.85 (40.85)	-989.26 (880.00)	1.63 (6.42)	-4.31 (9.29)	549.59 (552.04)
sunflower	-12.71 (12.60)	-4.83 (16.74)	-8.18 (11.95)		5.41 (12.22)	-2.49 (12.11)	-1.32 (38.74)	-997.43 (875.44)	-6.55 (13.94)	-12.49 (14.58)	541.41 (554.72)
sorghum	-18.12 (14.36)	-10.24 (16.50)	-13.59 (12.46)	-5.41 (12.22)		-7.91 (12.89)	-6.74 (40.21)	-1002.85 (877.19)	-11.96 (14.71)	-17.90 (13.81)	536.00 (553.65)
oats	-10.21* (5.96)	-2.34 (7.97)	-5.69 (4.97)	2.49 (12.11)	7.91 (12.89)		1.17 (41.34)	-994.94 (879.67)	-4.05 (7.70)	-9.99 (12.74)	543.90 (552.82)
millet	-11.38 (40.36)	-3.51 (44.61)	-6.85 (40.85)	1.32 (38.74)	6.74 (40.21)	-1.17 (41.34)		-996.11 (866.00)	-5.22 (40.68)	-11.16 (40.49)	542.73 (561.41)
safflower	984.51 (879.55)	992.38 (883.25)	989.04 (880.04)	997.22 (875.49)	1002.63 (877.24)	994.72 (879.71)	995.89 (866.04)		990.67 (881.15)	984.73 (880.37)	1538.49 (1405.60)
barley	-6.16 (6.03)	1.71 (8.79)	-1.63 (6.42)	6.55 (13.94)	11.96 (14.71)	4.05 (7.70)	5.22 (40.68)	-990.89 (881.10)		-5.94 (9.45)	547.95 (551.21)
flaxseed	-.22 (11.19)	7.66 (12.34)	4.31 (9.29)	12.49 (14.58)	17.90 (13.81)	9.99 (12.74)	11.16 (40.49)	-984.95 (880.32)	5.94 (9.45)		553.89 (551.01)
pea	-554.20 (552.85)	-546.32 (550.62)	-549.67 (552.00)	-541.49 (554.69)	-536.08 (553.61)	-543.99 (552.79)	-542.82 (561.38)	-1539.06 (1405.44)	-548.04 (551.17)	-553.98 (550.98)	
aprilrain	.04 (.09)	.04 (.09)	.04 (.09)	.04 (.09)	.04 (.09)	.04 (.09)	.04 (.09)	.04 (.09)	.04 (.09)	.04 (.09)	.04 (.09)
mayrain	.01 (.06)	.01 (.06)	.01 (.06)	.01 (.06)	.01 (.06)	.01 (.06)	.01 (.06)	.01 (.06)	.01 (.06)	.01 (.06)	.01 (.06)
junerain	-.01 (.08)	-.01 (.08)	-.01 (.08)	-.01 (.08)	-.01 (.08)	-.01 (.08)	-.01 (.08)	-.01 (.08)	-.01 (.08)	-.01 (.08)	-.01 (.08)
julyrain	.11 (.08)	.11 (.08)	.11 (.08)	.11 (.08)	.11 (.08)	.11 (.08)	.11 (.08)	.11 (.08)	.11 (.08)	.11 (.08)	.11 (.08)
augrain	-.003 (.10)	-.003 (.10)	-.003 (.10)	-.003 (.10)	-.003 (.10)	-.003 (.10)	-.003 (.10)	-.003 (.10)	-.003 (.10)	-.003 (.10)	-.003 (.10)
septrain	-.07 (.09)	-.07 (.09)	-.07 (.09)	-.07 (.09)	-.07 (.09)	-.07 (.09)	-.07 (.09)	-.07 (.09)	-.07 (.09)	-.07 (.09)	-.07 (.09)

octrain	.12 (.11)	.12 (.11)	.12 (.11)	.12 (.11)	.12 (.11)	.12 (.11)	.12 (.11)	.12 (.11)	.12 (.11)	.12 (.11)	.12 (.11)
novrain	-.10 (.15)	-.10 (.15)	-.10 (.15)	-.10 (.15)	-.10 (.15)	-.10 (.15)	-.10 (.15)	-.10 (.15)	-.10 (.15)	-.10 (.15)	-.10 (.15)
50-54	.76 (.47)	.76 (.47)	.76 (.47)	.76 (.47)	.76 (.47)	.76 (.47)	.76 (.47)	.76 (.47)	.76 (.47)	.76 (.47)	.76 (.47)
55-59	.50 (.53)	.50 (.53)	.50 (.53)	.50 (.53)	.50 (.53)	.50 (.53)	.50 (.53)	.50 (.53)	.50 (.53)	.50 (.53)	.50 (.53)
60-64	.52 (.52)	.52 (.52)	.52 (.52)	.52 (.52)	.52 (.52)	.52 (.52)	.52 (.52)	.52 (.52)	.52 (.52)	.52 (.52)	.52 (.52)
65-69	.96 (.60)	.96 (.60)	.96 (.60)	.96 (.60)	.96 (.60)	.96 (.60)	.96 (.60)	.96 (.60)	.96 (.60)	.96 (.60)	.96 (.60)
70-74	.99* (.49)	.99* (.49)	.99* (.49)	.99* (.49)	.99* (.49)	.99* (.49)	.99* (.49)	.99* (.49)	.99* (.49)	.99* (.49)	.99* (.49)
75-79	.92 (.57)	.92 (.57)	.92 (.57)	.92 (.57)	.92 (.57)	.92 (.57)	.92 (.57)	.92 (.57)	.92 (.57)	.92 (.57)	.92 (.57)
80-84	2.16** (.81)	2.16** (.81)	2.16** (.81)	2.16** (.81)	2.16** (.81)	2.16** (.81)	2.16** (.81)	2.16** (.81)	2.16** (.81)	2.16** (.81)	2.16** (.81)
85-89	1.90** (.91)	1.90** (.91)	1.90** (.91)	1.90** (.91)	1.90** (.91)	1.90** (.91)	1.90** (.91)	1.90** (.91)	1.90** (.91)	1.90** (.91)	1.90** (.91)
90-94	1.78 (1.06)	1.78 (1.06)	1.78 (1.06)	1.78 (1.06)	1.78 (1.06)	1.78 (1.06)	1.78 (1.06)	1.78 (1.06)	1.78 (1.06)	1.78 (1.06)	1.78 (1.06)
95-99	2.42 (1.63)	2.42 (1.63)	2.42 (1.63)	2.42 (1.63)	2.42 (1.63)	2.42 (1.63)	2.42 (1.63)	2.42 (1.63)	2.42 (1.63)	2.42 (1.63)	2.42 (1.63)
00-04	2.60 (1.93)	2.60 (1.93)	2.60 (1.93)	2.60 (1.93)	2.60 (1.93)	2.60 (1.93)	2.60 (1.93)	2.60 (1.93)	2.60 (1.93)	2.60 (1.93)	2.60 (1.93)
05-09	3.70* (1.83)	3.70* (1.83)	3.70* (1.83)	3.70* (1.83)	3.70* (1.83)	3.70* (1.83)	3.70* (1.83)	3.70* (1.83)	3.70* (1.83)	3.70* (1.83)	3.70* (1.83)
10-14	4.61** (2.05)	4.61** (2.05)	4.61** (2.05)	4.61** (2.05)	4.61** (2.05)	4.61** (2.05)	4.61** (2.05)	4.61** (2.05)	4.61** (2.05)	4.61** (2.05)	4.61** (2.05)
15-19	4.53** (2.12)	4.53** (2.12)	4.53** (2.12)	4.53** (2.12)	4.53** (2.12)	4.53** (2.12)	4.53** (2.12)	4.53** (2.12)	4.53** (2.12)	4.53** (2.12)	4.53** (2.12)
constant	4.97 (3.21)	-2.91 (6.74)	.44 (2.23)	-7.74 (12.01)	-13.15 (12.89)	-5.24 (4.06)	-6.41 (40.75)	989.70 (879.98)	-1.19 (5.27)	4.75 (9.85)	-549.15 (552.26)

Table 5. OLS results. Standard errors are shown in parentheses. The number of stars represents the significance level with one star * significant at the 10% level, two stars ** significant at the 5% level, and three stars *** significant at the 1% level. For each regression, there were 65 observations and an R^2 of .954. The data displayed heteroskedasticity. Thus, the standard errors shown are heteroskedasticity-robust standard errors. Also, the year term for 1945-1949 was excluded to avoid perfect collinearity.

The results show that substituting for corn will generally have a positive effect on revenue. This is not surprising as it is the largest crop in terms of acres planted and production. Soybeans are less certain. The results show that substituting for soybeans will have a negative effect on revenue when the excluded crop is corn, wheat, safflower, barley, or flaxseed. This is surprising as soybeans are the second most planted crop. Additionally, the year terms show that revenue mostly trends upward over time, unsurprising when one considers that agriculture has seen technological advancement. It should be noted that the predicted betas on safflower and peas have an unexpectedly large magnitude. However, they also have very large standard errors, owing to a lack of years in which these crops were planted.

The estimated equations were used to predict revenue each year from 1949-2018 for 1,925 portfolios, 175 per regression. The model was used to test every possible portfolio when the excluded crop was replaced with one, two, and three substituted crops. Each portfolio then provided an associated average revenue and standard deviation of revenue to measure risk and return. The results are shown in Figure 3, where average revenue is graphed against standard deviation of revenue.

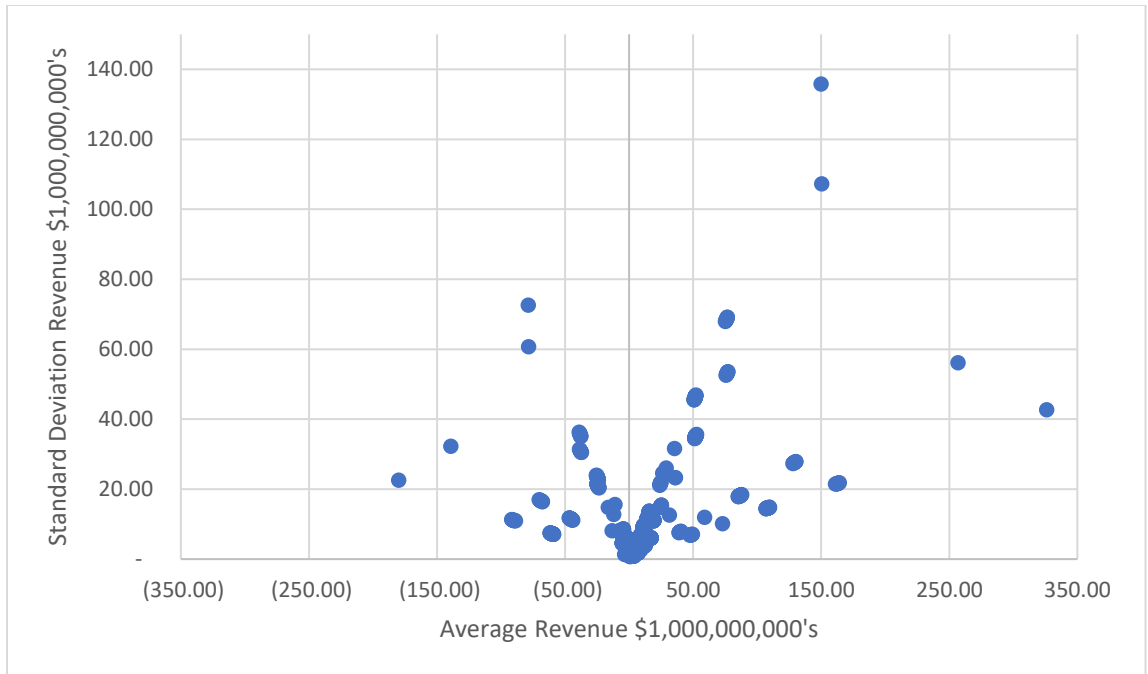


Figure 3. Predicted average revenue and standard deviation of revenue for every portfolio.

From 1949-2018, South Dakota had an actual average real revenue of \$2.37 billion and the standard deviation of real revenue was \$1.59 billion. Thus, this project sought those portfolios with a higher predicted average revenue and a lower predicted standard deviation of revenue over the same time period.¹² Figure 4 shows a close-up of the area surrounding the actual average and standard deviation of revenue. The portfolios around actual average and standard deviation of revenue create a star shape, with each ray of the star representing a single excluded crop being substituted for combinations of other crops. The point reflecting reality has coordinates (2.37, 1.59) and is at the center of the star. So, if one were to track a ray from left to right, they would begin with portfolios having a lower average revenue than reality, before passing through and to the right of

¹² Although 1977-1981 are excluded from the calculation of actual average revenue and standard deviation of revenue, in each portfolio a revenue prediction was made for 1977-1981 and factored into that portfolio's average and standard deviation of revenue.

reality, leading to those portfolios for which the crop combination results in a higher average revenue than reality.

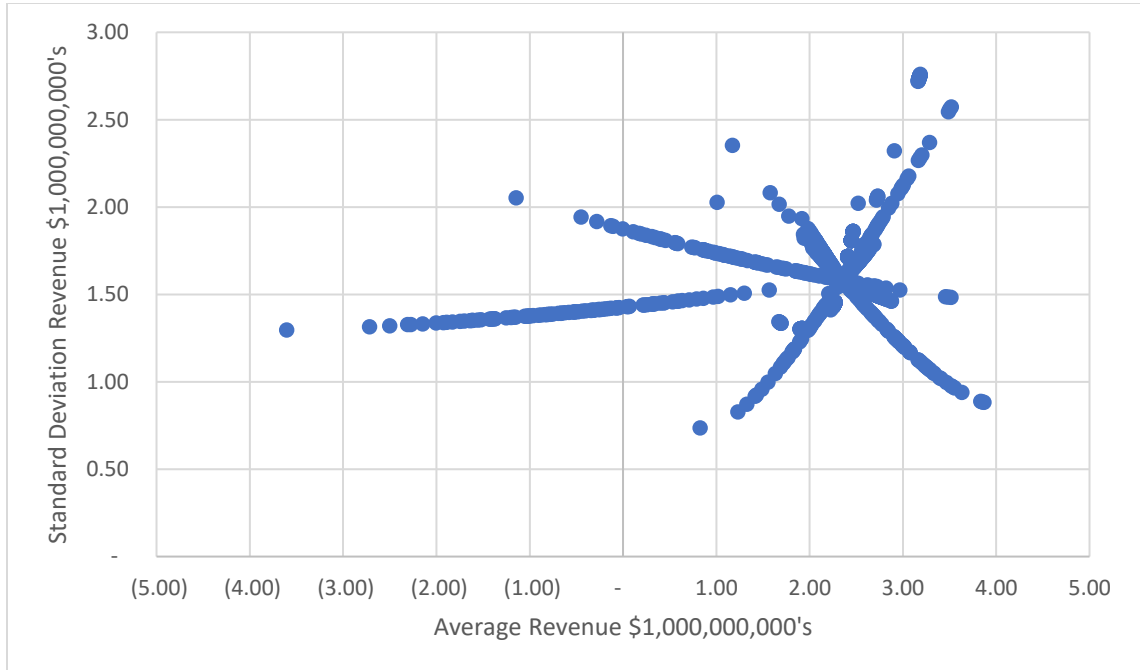


Figure 4. Portfolios around reality.

Of the portfolios tested, 194 had a higher average revenue and lower standard deviation of revenue than reality—those in the bottom right section of the star which correspond to the bottom right of the graph inspired by Markowitz (1952) in Figure 1. These 194 points are shown in Figure 5 where the upper left corner of the graph represents the real point with coordinates (2.37, 1.59). 92 of these portfolios use sorghum as the excluded crop (represented by the purple points in Figure 5), 69 exclude oats (the orange points), 21 exclude barley (the red points), and 12 exclude wheat (the green points).

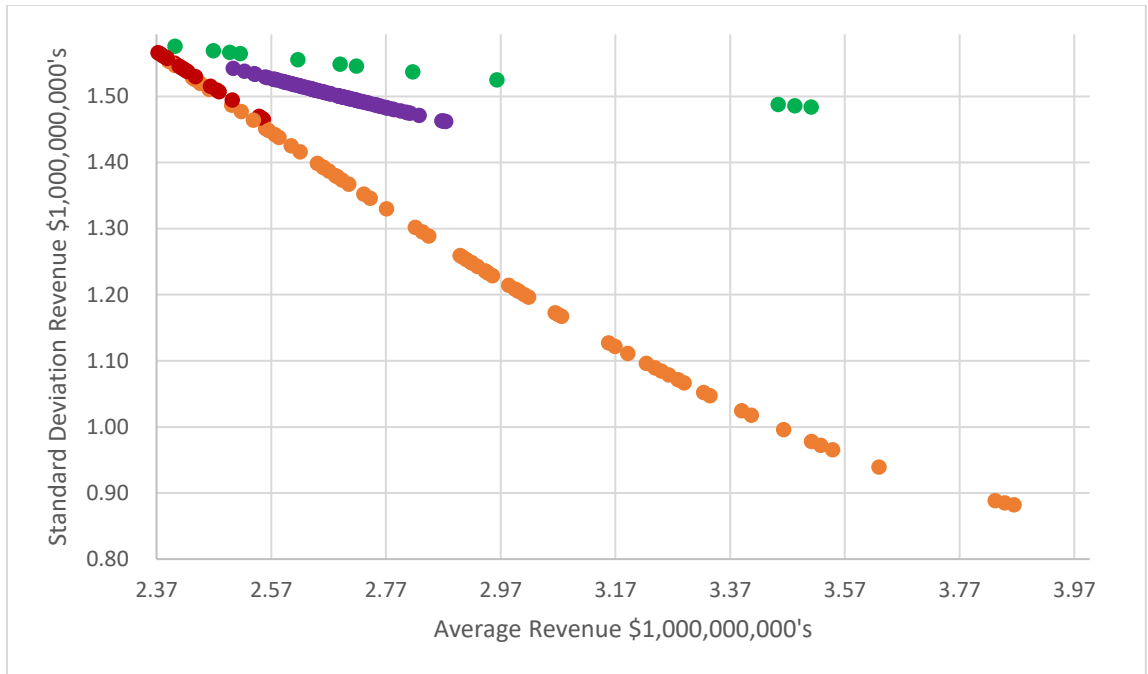


Figure 5. Efficient portfolios. Each portfolio is color coded to signify the excluded crop: purple for sorghum, orange for oats, red for barley, and green for wheat.

To determine which of these 194 portfolios would be realistic for the state to pursue, three different steps were used to analyze the portfolios. First, confidence intervals were considered to determine a range of predicted average revenue. Second, location was accounted for to determine where in South Dakota the crops are grown. Third, considerations were made for the supply increase and the resulting change in price that would come from a portfolio.

The results were first analyzed by considering the standard errors and confidence intervals of the predicted betas. This was important as some of the coefficients were unrealistically large or small due to having few observations. To conduct this analysis, the 95% confidence interval was applied to the beta of the substituted crop(s) to identify a range for the average revenue prediction. Equation [4] shows how this method was

applied where crop n is the excluded crop, crop 1 is the substituted crop, and CI_l is the upper or lower 95% confidence interval for $\widehat{\beta}_1$.

[4]

$$revenue = \widehat{\beta}_0 + \widehat{\beta}_1 crop_1 + \widehat{\beta}_2 crop_2 + \dots + \widehat{\beta}_{n-1} crop_{n-1} + CI_l * crop_n$$

When this analysis was conducted, none of the 194 portfolios had a lower range which was higher than the actual average revenue: \$2.37 billion. However, some were close to this value. The portfolios with a lower range of at least two are summarized in Table 6 and were considered for additional analysis.

Portfolio	Excluded Crop	Replaced Crops	Average Revenue Prediction	Lower Range	Upper Range
{1}	Barley	Corn	2.56	2.14	2.98
{2}	Oats	Corn	3.87	2.06	5.67
{3}	Sorghum	Flaxseed	2.87	2.05	3.69
{4}	Barley	Corn, Wheat	2.48	2.05	2.92
{5}	Sorghum	Corn, Flaxseed	2.87	2.04	3.71
{6}	Sorghum	Wheat, Flaxseed	2.81	2.03	3.59
{7}	Sorghum	Corn, Wheat, Flaxseed	2.83	2.03	3.64
{8}	Sorghum	Corn	2.88	2.02	3.73
{9}	Barley	Corn, Flaxseed	2.56	2.02	3.09
{10}	Sorghum	Corn, Wheat	2.81	2.02	3.61

Table 6. Summary of selected portfolios.

To further identify those portfolios which could be a realistic option for the state to pursue, consideration was made for where in South Dakota the crops are grown. The

USDA divides South Dakota into 9 regions for statistical purposes. These are shown in Figure 6, retrieved from the USDA NASS website.

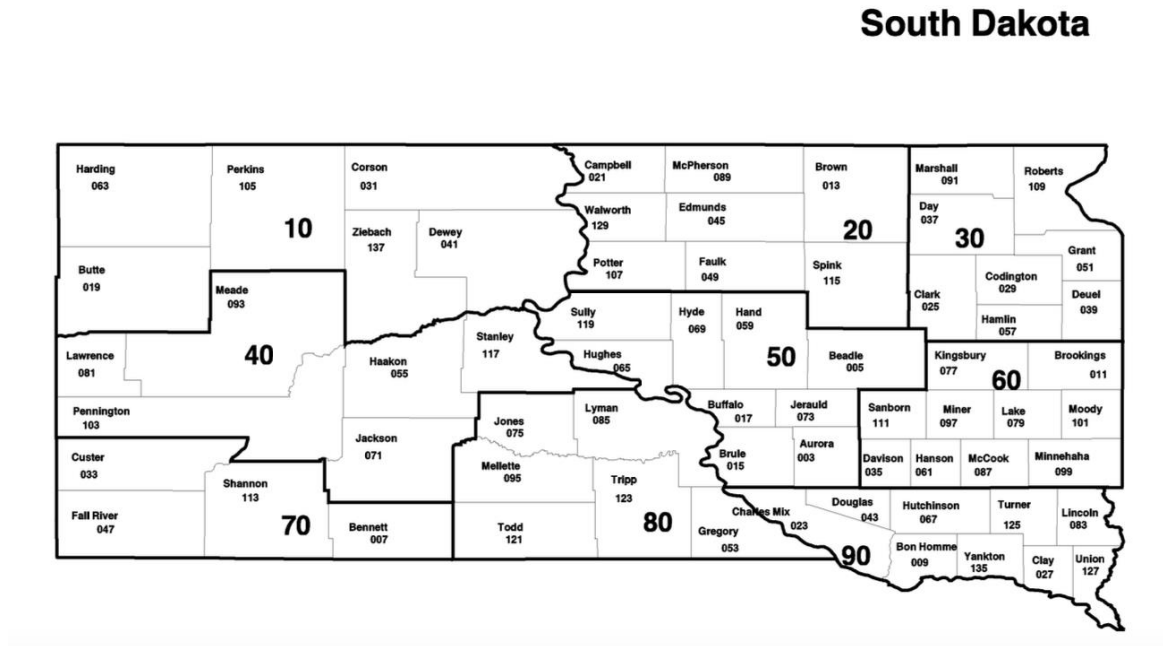


Figure 6. South Dakota regions defined by the bold lines. Region 10 is the northwest, region 20 is the north central, region 30 is the northeast, region 40 is the west central, region 50 is the central, region 60 is the east central, region 70 is the southeast, region 80 is the south central, and region 90 is the southeast.

Below is a summary of this analysis for the ten portfolios in Table 6. The analysis is based on the proportion and acres of each crop that is planted in the various regions of the state. It is assumed that if a certain region of the state already plants a large amount of both the excluded crop and the substituted crop, then it would be possible to plant more of the substituted crop in that region. Region-level data from the USDA NASS are often missing certain years, so when analyzing the portfolios, the most recent year for which region-level data was available for all crops involved in a portfolio was used. For example, in portfolio {1}, 2006 was the most recent year for which region level data were available for both barley and corn.

Portfolio {1}: In 2006, 84% of the barley planted in the state was planted in the three northern regions: 44% in the northwest (24,000 acres), 28% in the north central (15,500 acres), and 12% in the north east (6,500 acres). In the same year, these three regions accounted for 35% of the corn planted: 1% in the northwest (60,000 acres), 19% in the north central (846,000 acres), and 14% in the northeast (651,000 acres). Because of the high amounts of both corn and barley grown in the north central and northeast, it should be possible to exclude barley in these regions and substitute corn. However, substituting for corn in the northwest could present a problem as it would represent a 40% increase in the amount of corn planted in the region.

Portfolio {2}: In 2014, oats were planted fairly widely across the state with no one region accounting for more than 20% of acres planted. 18% was planted in the south central (44,900 acres), 17% in the northwest (42,700 acres), 14% in the central (35,000 acres), 13% in the northeast (31,500 acres), and 12% in the north central (28,800 acres). For corn, these same regions accounted for 5% in the south central (268,000 acres), 2% in the northwest (134,000 acres), 15% in the central (859,000 acres), 16% in the northeast (910,000 acres), and 20% in the north central (1,146,000 acres). Corn represents a much greater proportion of total acres planted than does oats, and so, even in the regions where a relatively small proportion of corn was planted, such as the south central, it could still probably absorb the additional acres from excluding oats. The only region which causes some pause is the northwest in which substituting for corn would lead to a 32% increase

in the acres of corn in the region. However, this substitution should be possible as there is already a large amount of corn grown in the region.

Portfolio {3}: In 1988, 84% of the sorghum planted was planted in a swath across the central and southern part of the state: 37% in the south central (170,000 acres), 17% in the central (80,000 acres), 17% in the west central (80,000 acres), and 13% in the southeast (58,000 acres). The same regions accounted for only 9% of the flaxseed planted the same year: 3% in the south central (1,200 acres), 2% in the central (900 acres), 3% in the west central (1,300 acres), and <1% in the southeast (100 acres). Rather, most of the flaxseed was planted in the northern part of the state. Therefore, it is probably not possible to substitute for flaxseed in these regions.

Portfolio {4}: As in portfolio {1}, 84% of the barley and 35% of the corn was planted in the three northern regions in 2006. Likewise, 43% of the wheat planted was in these regions: 12% in the northwest (381,400 acres), 21% in the north central (698,500 acres), and 10% in the northeast (332,000 acres). This portfolio should be possible and largely resolves the concern in portfolio {1}. Now, only half of the barley acres are substituted for corn, so these acres could be allocated such that most of the excluded barley in the northwest are substituted for wheat, with the corn distributed in the remaining two regions.

Portfolio {5}: Like portfolio {3}, 1988 saw 84% of the sorghum planted and 9% of the flaxseed planted in a swath across Central and Southern South Dakota. These regions

accounted for 46% of the corn planted: 4% in the south central (111,800 acres), 13% in the central (394,800 acres), <1% in the west central (15,000 acres), and 29% in the southeast (916,800 acres). This portfolio is also probably not possible for the same reasons as portfolio {3}.

Portfolio {6}: Again, 1988 saw 84% of the sorghum planted and 9% of the flaxseed planted in the four central and southern regions. These also accounted for 39% of the wheat planted: 8% in the south central (305,000 acres), 17% in the central (625,000 acres), 12% in the west central (425,000 acres), 2% in the southeast (72,000 acres). It may be possible to substitute half of the acres for wheat, but would still likely be impossible to substitute the other half for flaxseed.

Portfolio {7}: Same analysis as portfolios {5} and {6}. This would also likely be impossible.

Portfolio {8}: In 2007, 81% of the sorghum planted was in the central regions of the state: 43% in the south central (90,000 acres), 20% in the west central (41,000 acres), and 19% in the central (39,000 acres). These regions accounted for 18% of the corn planted: 4% in the south central (187,000 acres), 1% in the west central (26,000 acres), and 14% in the central (669,000 acres). It should be possible to substitute the acres for corn in the south central and the central regions. It may be possible to make the substitution in the west central region as there is a significant amount of corn grown, however, that it would be a 158% increase in the amount of corn planted is concerning.

Portfolio {9}: In 1988, 83% of the barley planted was in the northeastern and central corner of the state: 36% in the north central (250,000 acres), 23% in the northeast (163,000 acres), 14% in the central (96,000 acres), and 11% in the east central (74,600 acres). These regions accounted for 65% of the corn planted: 11% in the north central (355,200 acres), 14% in the northeast (435,200 acres), 13% in the central (394,800 acres), and 27% in the east central (857,700 acres). Additionally, the regions encompass 86% of the flaxseed planted: 26% in the north central (10,200 acres), 53% in the northeast (21,300 acres), 2% in the central (900 acres), and 5% in the east central (1,900 acres). It should not be a problem to substitute half the land used to plant barley for corn because of the large amounts of each grown in the same regions of the state. Additionally, if the other half of the land was substituted for flaxseed, the supply of flaxseed would increase dramatically. That said, most of the flaxseed grown is planted in these regions, so the substitution may be possible.

Portfolio {10}: As in portfolio {8}, 2007 saw 81% of sorghum and 18% of corn planted in the central region of the state. 47% of wheat planted was in these regions: 10% in the south central (348,000 acres), 14% in the west central (479,000 acres), and 23% in the central (813,000 acres). Excluding sorghum and dividing the land between corn and wheat lessens the concerns of portfolio {8}. Thus, this portfolio is probably possible.

Based on this analysis, portfolios {2}, {4}, {9}, and {10} should be feasible while portfolios {1} and {8} may also be possible, but have some concerns. The final way in

which these portfolios were examined involved considering how large the increase in supply of the substituted crops would be relative to the national supply. The revenue simulation used in this project assumes crop prices are held constant as supply changes—a large assumption to make. However, if the change in supply relative to national supply is sufficiently small, then it may be that the price change would have little to no effect on the outcome of the predictions¹³. This analysis is summarized below for the four portfolios which were determined to be feasible in the previous analysis and the two which may also be possible.

Portfolio {1}: From 1949 to 2018, the average number of acres planted with barley was 415,235 in South Dakota, and 48,000 acres in 2018. Over the same period, an average of 78,648,843 acres of corn were planted nationwide and 88,871,000 in 2018. Therefore, excluding barley and substituting for corn would amount to a .5% increase in the national supply of corn on average, with a .05% increase in 2018.

Portfolio {2}: The average number of acres planted with oats in South Dakota over the time studied was 1,733,014 with 290,000 acres planted in 2018. Thus, the substitution would result in a 2% increase in the supply of corn on average with a .3% increase in 2018.

Portfolio {4}: The average number of acres planted with wheat nationwide over the time studied was 64,303,243 with 47,815,000 acres planted in 2018. Thus, planting half corn

¹³ National supply was used instead of global supply, as it was found to be a better predictor of price.

and half wheat on the land used for barley would result in a .3% increase in the supply of both corn and wheat on average and a .03% increase in the 2018 supply of corn and a .05% increase in the 2018 supply of wheat.

Portfolio {8}: The average number of acres planted with sorghum in South Dakota was 341,357 with 260,000 acres planted in 2018. Excluding sorghum and substituting for corn would lead to an average increase of .4% in the national acres of corn planted with a .3% increase in 2018.

Portfolio {9}: The average number of acres planted with flaxseed nationwide was 1,587,771 with 208,000 acres planted in 2018. Planting corn and flaxseed on the land used for barley would lead to .3% increase in the supply of corn on average and a .03% increase in 2018. Also, there would be 13% average increase in flaxseed planted with a 12% increase in 2018.

Portfolio {10}: Excluding sorghum and substituting for corn and wheat would lead to .2% increase in corn and a .3% increase in wheat on average. Also, there would be a .1% increase in corn and a .3% increase in wheat in 2018.

Based on this analysis, portfolios {1}, {4}, {8}, and {10} should lead to a small enough change in national supply and crop price, that the results will be mostly unchanged. Portfolio {2} may have caused a larger change in the price of corn from 1949-2018 with a 2% average increase in the acres planted, so the results cannot be

trusted. Portfolio {9} also represents such a large increase in the national supply of flaxseed that the price would undoubtedly fall dramatically, leading to different results than the model predicts.

Using the three methods, portfolios {4} and {10} appear as the best options for South Dakota to pursue. Portfolios {1} and {8} may also be valid strategies, but the concerns presented by these two are essentially solved by the other portfolios, {4} and {10}. These portfolios are shown on Figure 7 by the red points. Portfolio {4}, where barley is excluded and substituted for corn and wheat has coordinates (2.48, 1.51). Portfolio {10}, where sorghum is excluded and substituted for corn and wheat has coordinates (2.81, 1.48).¹⁴

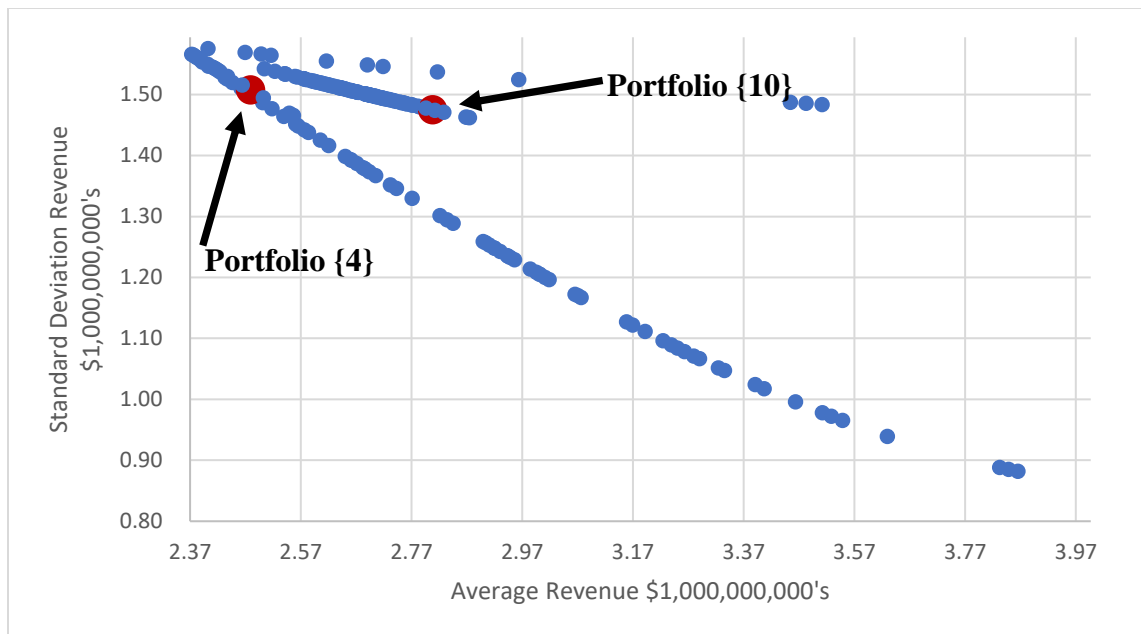


Figure 7. Two portfolios to reduce risk and increase returns. These portfolios are represented by the red points. They consist of substituting the acres planted with barley for equal parts corn and wheat in portfolio {4} and substituting the acres planted with sorghum for equal parts corn and wheat in portfolio {10}.

¹⁴ From mid-April to mid-May 2018, China imposed a tariff of 178% on U.S. sorghum (Nelson & Nigh). However, the price used for 2018 as retrieved from USDA NASS did not deviate significantly from prior years (\$5.86 in 2018 versus \$5.64, \$5.05, \$5.80, \$5.95, \$6.57 in the previous five years). Thus, the results should not be affected by the tariff.

CHAPTER SEVEN

Conclusions

This project applies Modern Portfolio Theory to agriculture in South Dakota. It asks whether South Dakota can change its crop mix to decrease risk and increase return by moving closer to the curve of efficient portfolios shown in Figure 1. This is accomplished by using multiple regression analysis to predict the impact on agricultural revenue of excluding one of the eleven crops planted in the state, and substituting one or more other crops in its place. These equations are then used to predict revenue for 1949-2018. From the predictions, the average and standard deviation of predicted revenue are compared with South Dakota's actual average and standard deviation of revenue. Those portfolios which have a higher average revenue and a lower standard deviation of revenue than South Dakota had are then evaluated in three ways. First, the confidence intervals are analyzed to identify a range of revenue predictions. Second, location is considered to determine whether the substitution would be possible. Third, the national change in supply that would result from the substitution is analyzed, and the associated change in price is considered.

Based on this analysis, two portfolios were found which increased average revenue and decreased the standard deviation of revenue for the state and which would be a realistic option for the state to pursue: dividing the acres used to plant barley between corn and wheat, and dividing the acres used to plant sorghum between corn and wheat. In the first, average revenue is predicted to rise to \$2.48 billion and the standard deviation of revenue to fall to \$1.51 billion (from \$2.37 billion and \$1.59 billion respectively). On average from 1949-2018, 415,235 acres were planted with barley (of an average of

12,132,195 total acres). These would be divided between corn and wheat, with half going to each. In the second portfolio, average revenue is predicted to rise to \$2.81 billion and the standard deviation of revenue to fall to \$1.475 billion. An average of 341,357 acres were planted with sorghum from 1949-2018 which would be divided equally between corn and wheat. While the excluded crops in these two portfolios, barley and sorghum, represent a relatively small proportion of total acres planted, they do have a large enough impact on revenue to reduce risk and increase return for 1949-2018.

Both portfolios would entail an increase in the acres of corn planted, which would seem to counter the benefits of diversification discussed in the first section of this paper. However, to achieve an efficient crop mix, it is less important that there are many types of crops planted than that the crops which are planted are not perfectly correlated (Figge, 2004; Markowitz, 1952, Stovall, 1966). One weakness of this model is that it requires the same substitution to be made every year. Further research could involve the creation of a model which allows for a different portfolio from year to year based on future expectations of other exogenous variables.

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