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Effect of Weather Modification on Supply and Total Revenue of a Region

Orlan Buller, L. Dean Bark and Richard Vanderlip

Cloud seeding to increase precipitation is a supply increasing technology regulated by a State agency. The increase in production is limited to the farmers living in the region affected but the price effects are distributed to all farmers in the market. Total revenue to farmers in the region may increase because for them the percent in production may be greater than the percent decrease in price. Total in revenue to farmers in a region will increase with an increase in the supply of a commodity with an inelastic demand if their share of the total market is less than the coefficient of elasticity of demand.

The impact of a new technology which increases supply is usually approached from two ways: at the firm level or at the industry level. The effect of the technology on prices and total revenue are evaluated assuming a perfectly elastic demand for the commodity for the firm; or, as in the case of most agricultural commodities, assuming a highly inelastic demand for the industry. If the firm adopts the output-increasing technology, the manager foresees no perceptible influence on price so consequently he visualizes an increase in total revenue. However, a decrease in total revenue occurs at the industry level when demand is inelastic because the increase in supply of an inelastic demand re-

sults in a greater percent price reduction than the associated percent increase in quantity demanded.

Supply increasing technologies generally are available without regard to state boundaries. However, an exception to this is permission to seed clouds as a means of increasing crop production because this permission is granted by states. Thus, the evaluation of such state-controlled technology is based on the production increase within the state, but with the recognition that the increase will likely have some price depressing effect. Farmers in other states producing the same commodity or its substitute will be influenced by the policy through the price effect, but they receive no benefit because their crop production is unaffected. Thus, it may be feasible for state policy makers to rationally adopt a supply increasing technology even though the commodity affected by cloud seeding may have an inelastic demand. The result is that the adverse price effect is shared by all farmers in the total market, whereas only some portion, those in the state granting permission to seed clouds, receive the benefit from the increase in supply. Consequently, the total revenue may increase for the farmers in the state, whereas the remain-

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ing farmers experience a decrease in total revenue. If so, the adverse consequence of an inelastic demand has been shifted to those farmers not in the state.

The importance of the nature of a supply shift on benefits was discussed by Linder and Jarrett. The nature of cloud seeding is that the technology is equally applied to all farmers and acres in the area underlying clouding seeding and is not farm specific. We assumed that cloud seeding had the same absolute effect on every acre per crop in each region. Increasing the yield per acre lowers the average cost per unit production. Consequently, insofar as the average cost (supply) represents more production from more acres the old and the new supply curves diverge.

The objective of this study was to estimate the impact on the Kansas agricultural economy from increasing precipitation by cloud seeding. First, the paper analyzes the relationship between the share of the market made up by farmers in the state and the price elasticity of demand for the commodities produced in the state. This relationship determines the extent to which farmers in a state can expand supply of a commodity without decreasing their total revenue. Secondly, the linkage of the climatologic, agronomic, and the economic model used for the analysis is explained, and lastly, the effect of increased crop production on farm income and prices is explained. The analysis was restricted to the effect on major dryland crops: wheat (continuous and fallow), corn, grain sorghum, soybeans, alfalfa, silage, and pasture. It was assumed that rainfall augmentation would not be sufficient to change irrigation practices. The effect of increased grass and hay production on livestock numbers was estimated but not as a part of the linear programming model used for crops.

Studies in North Dakota, Montana, South Dakota, Oklahoma and Illinois have considered the impact of cloud seeding on their agricultural economy [Allaway; Inman; Johnson; Stroup and Townsend; and Swanson Huff and Changnon]. The findings are consistent in so far as all studies estimated rainfall

augmentation to have a positive effect on crop production and on farm income. Swanson, Huff and Changnon categorize cloud seeding as a biological-chemical type technology that increases the efficiency of crop production. Although cloud seeding affects the productivity of the land, the use of this technology is different than most biological-chemical technologies as fertilizers and pesticides. Cloud seeding is also used to suppress hail. Economic analysis of hail suppression has been reported by von Blokland, *et al*, and Swanson, *et al*. A study by Swanson estimated the potential impact of hail suppression on crop production in the United States and von Blokland estimated the impact of hail-suppression and rainfall alteration on crop yields in Illinois.

Relationship Between Market Share, Elasticity, and Total Revenue

The total revenue received by all farmers from the sale of a commodity in a specific market is shown in figure 1 as $TR = OP_1 \cdot OQ_1$. After the adoption of a supply increasing technology, shifting the supply curve from S to S' , total revenue changes to $TR' = OP_2 \cdot OQ_2$. Assuming an inelastic demand, then $TR > TR'$. The regional component of total quantity supplied is OR_1 and the increase in supply because of new technology is R_1R_2 which is the same as Q_1Q_2 .

From the relationship defined above and the assumption of price inelasticity of demand:

$$(1) \quad OP_1 \cdot OR_1 + OP_1 \cdot R_1Q_1 > OP_2 \cdot OR_1 \\ + OP_2 \cdot R_1Q_1 + OP_2 \cdot Q_1Q_2$$

The change in price, P_1P_2 as a result of a shift in supply is determined by the coefficient of elasticity K as follows:

$$-K = \frac{\% \Delta Q}{\% \Delta P} = \frac{\partial Q}{Q} \cdot \frac{P}{-\partial P}$$

$$(2) \quad P_1 P_2 = -\partial P = \frac{\partial Q}{Q} \cdot \frac{P}{-K}$$

The fact that the total revenue for the market is larger prior to the shift in the supply does not necessarily mean that the total revenue in region R is larger prior to the shift in supply. That is,

$$OP_1 \cdot OR_1 \geq OP_2 \cdot OR_1 + OP_2 \cdot R_1 R_2$$

To show the relationship between the coefficient of elasticity and the regional share of the market, we begin by assuming that the increase in supply does not affect the total revenue of the region, where R represents the output in region, and P is the price of output;

$$\frac{\partial TR}{\partial R} = 0 \text{ (for the region)}$$

which is,

$$\frac{\partial(P \cdot R)}{\partial(R)} = 0.$$

and

$$\frac{P \cdot \partial R}{\partial R} + \frac{R \cdot \partial P}{\partial R} = 0.$$

$$(3) \quad \text{and } P + \frac{R \cdot \partial P}{\partial R} = 0.$$

Price elasticity of demand is:

$$-\frac{\partial Q}{\partial P} \cdot \frac{P}{Q} = -K$$

$$-\frac{\partial Q}{\partial P} = -K \cdot \frac{Q}{P}$$

Since $\partial Q = \partial R$ for the region and by substitution in equation (3) and dividing terms by P/Q :

$$P + R \cdot \frac{1}{-K} \cdot \frac{P}{Q} = 0$$

$$1 + \frac{R}{Q} \cdot \frac{1}{-K} = 0$$

$$(4) \quad \frac{R}{Q} = K.$$

The ratio R/Q is the regional share of total production. If this share is equal to the numerical value of the coefficient of elasticity, then a change in the supply of commodity leaves the total revenue in the region unchanged. If the share is less than the coefficient of elasticity, then supply in the region can increase and total revenue within the region will increase. If the share is greater than the value of the coefficient of elasticity, then an increase in the supply for the region will lower the total revenue for the region.

Kansas' share of U.S. wheat production (1975-1977 average) was nearly 18 percent; in feed grains the share was 4.4 percent and 1.6 percent for soybeans. The price elasticities of demand used to determine the effect on total revenue resulting from a shift in supply were $-.2$ for wheat, $-.4$ for feed grains, and $-.4$ for soybeans. These estimates were from studies by Hutchinson and Royko. Because the Kansas fractional share of feed grain and soybean production was a value much less than the coefficient of elasticity of demand, a large increase in production of feed grains and soybeans in Kansas can occur with only a small decrease in price and with the result of increasing total revenue to Kansas farmers. For wheat, the situation is marginal as the elasticity of demand was $.2$ and the Kansas share was $.18$. Consequently, any increase in wheat production in Kansas will likely result in a small increase in total revenue to Kansas farmers.

Model

The effect on the Kansas agriculture of cloud seeding was studied by linking three models: (1) a model simulating the effect of cloud seeding on the amount of rainfall, (2) regression equations relating rainfall to yield, and (3) a linear programming model to estimate the effect of increased yield per acre on total production, prices, and income of the region.

The Model Simulating Effects of Cloud Seeding

The model simulating the increase in rainfall from cloud seeding was developed by Changnon and Huff. Their designated Model B was used to increase precipitation as specified in Table 1. The procedure was to use records of daily rainfall amounts for specific weather reporting stations and calculate an estimated increase had cloud seeding occurred at each of these stations. These estimated daily amounts were then added to obtain a total amount of precipitation for that month.

Cloud seeding has greatest results if applied to convective clouds (clouds that have relatively strong updrafts). The frequency and timing of the occurrence of these clouds varies considerably throughout the year and from east to west in the Great Plains. Convective clouds rarely occur after September and before March in Kansas; they occur more frequently over eastern than western Kansas and during spring and early summer. Thus, the benefits from cloud seeding depends on the timing of the cloud patterns in relation to crop growing patterns. The increase in rainfall was estimated for each month from March to September when convective clouds are most frequent in Kansas. Rainfall data from several reporting stations in each crop reporting district were averaged to estimate the rainfall for that district.

The Regression Model

Thirty-nine regression equations relating crop yields to climatic data were developed

[Bark, Buller, and Vanderlip] for the major dryland crops in each of the nine Kansas Crop Reporting Districts. The R^2 for these equations were from .61 to .92 with most in the .70's and .80's. Time series crop yield, rainfall, and temperature data were used to estimate parameters for an equation of the form:

$$(5) Y_{ij} = a_{ij} + \sum_k b_{ijk} R_{jk} + d_{ij} T_{ij} + \sum_k c_{ijk} H_{jk}$$

where:

i = major small grains, alfalfa, forage, and silage

j = 1,, 9 crop reporting districts

k = months April through September

Y = crop yield per harvested acre

R = average monthly rainfall

H = average monthly temperature

T = trend variable with 1950 = 0 and increasing one unit for each year until 1975

Equation (5) was quadratic as the rainfall and temperature variables were entered as both linear and squared.

To estimate the effect of cloud seeding on crop yields, equation (5) and augmented rainfall data were used as follows:

$$(6) AY_{ij} = a_{ij} + \sum_k b_{ijk} AR_{jk} + \sum_k c_{ijk} H_{jk} + d_{ij} T_{ij}$$

where AY is the estimated crop yield per harvested acre for each major crop with augmented rainfall amounts; a , b , c , d , H , and T are the same as in equation (5), and AR_{jk} is the amount of augmented rainfall estimated

TABLE 1: Percentage Change In Daily Rainfall Amounts by Model and Amount of Rainfall.

Daily Rainfall (inches)	Variable Percentage Change for Given Model				
	E	A	B	C	X
.10 or less	150	100	75	50	-50
.11 - .50	75	50	30	20	-30
.51 - 1.00	30	20	10	0	-10
over 1.00	10	0	-10	-20	0

from the model simulating the effect of cloud seeding in region j and in month k . Thus, AY is the estimated effect of cloud seeding on crop yields. Estimates of Y and AY were made for each year of the data set and differences were calculated for each year. These differences were averaged to estimate the effect of cloud seeding. The results from three western crop reporting districts were combined into an estimate for the western region, the three central crop reporting districts combined into the central region, and the three eastern crop reporting districts combined into the eastern region. The estimated effects of clouding by month and crop are reported in Table 2.

Linear Programming Model

Estimates of the changes in the income caused by cloud seeding for each region of the state were made using a linear programming model. The model consisted of eight Kansas regions with regional differences based on soil and climate differences.

The objective function was to maximize returns to land and operator labor. It was in the form:

$$(7) \text{ MAX } Z = \sum_{i,j} P_{ij} X_{ij} - \sum_{i,j} C_{ij} Z_{ij} - \sum_i L_i W_i$$

in which i was the crop and livestock enterprise in region j , P was the selling price per unit of commodity i in region j , X was the quantity of commodity sold, C was the variable cost of producing enterprise i in region j and Z was the number of acres or head produced, and L is the adjustment in per unit value associated with an increase in crop production above the specified amount of commodity W . The model structure is illustrated in Table 3. Crop production is limited to a specified quantity SP , which is the region's share at the original price-quantity equilibrium (OR_1 in Figure 1). The quantity OR_1 is sold at price P_1 represented by the selling activities in the model. The income adjustment coefficient represents the following calculation using Table 3:

$$L = \Delta TR = \partial(TR) = \partial(P \cdot Q)$$

$$= Q \cdot \partial P + P \cdot \partial Q$$

$$(8) \text{ which is, } (P_1 - P_2) \cdot (OR_1)$$

$$+ P_1 \cdot (R_2 - R_1) = (P_1 - P_2) \cdot (OR_2).$$

The income adjustment activity relaxes the state production limit by increasing production allowable by K bushels providing the income adjustment associated with K . The selling activities sell all quantities at the original price OP_1 , therefore the income adjustment coefficient subtracts $(P_1 - P_2) (OR_2)$. The coefficient K in Table 3 represents $R_1 R_2$ in Figure 1. The structure of this part of the model was similar to that used by Duloy and Norton, and Taylor.

The model was structured with stepped demand functions for each major crop. The model had several income adjustment activities for each major crop with the values of L and K representing incremental steps along the demand curve. Y was the estimated yield as in equation (5) and K was an increase in production ($R_1 R_2$, Figure 1) associated with cloud seeding. SP was the limit on production as illustrated by OR_1 in Figure 1. State production limits were imposed on all major commodities.

A series of equations link crop production activities Z with selling activities X :

$$(9) \quad \sum_{i,j} X_{ij} - \sum_{i,j} Y_{ij} \cdot Z_{ij} \leq 0$$

where Y is the yield per acre of each crop i in region j which is the same value but opposite sign as in equation (5).

The model included equations for labor and field time requirements and limits on the availability of these resources. Labor requirements were representative of an average sized farm in each region.

The economic analysis was based on comparing results from two linear programming situations — a base and a modified situation. The base situation was with all prices com-

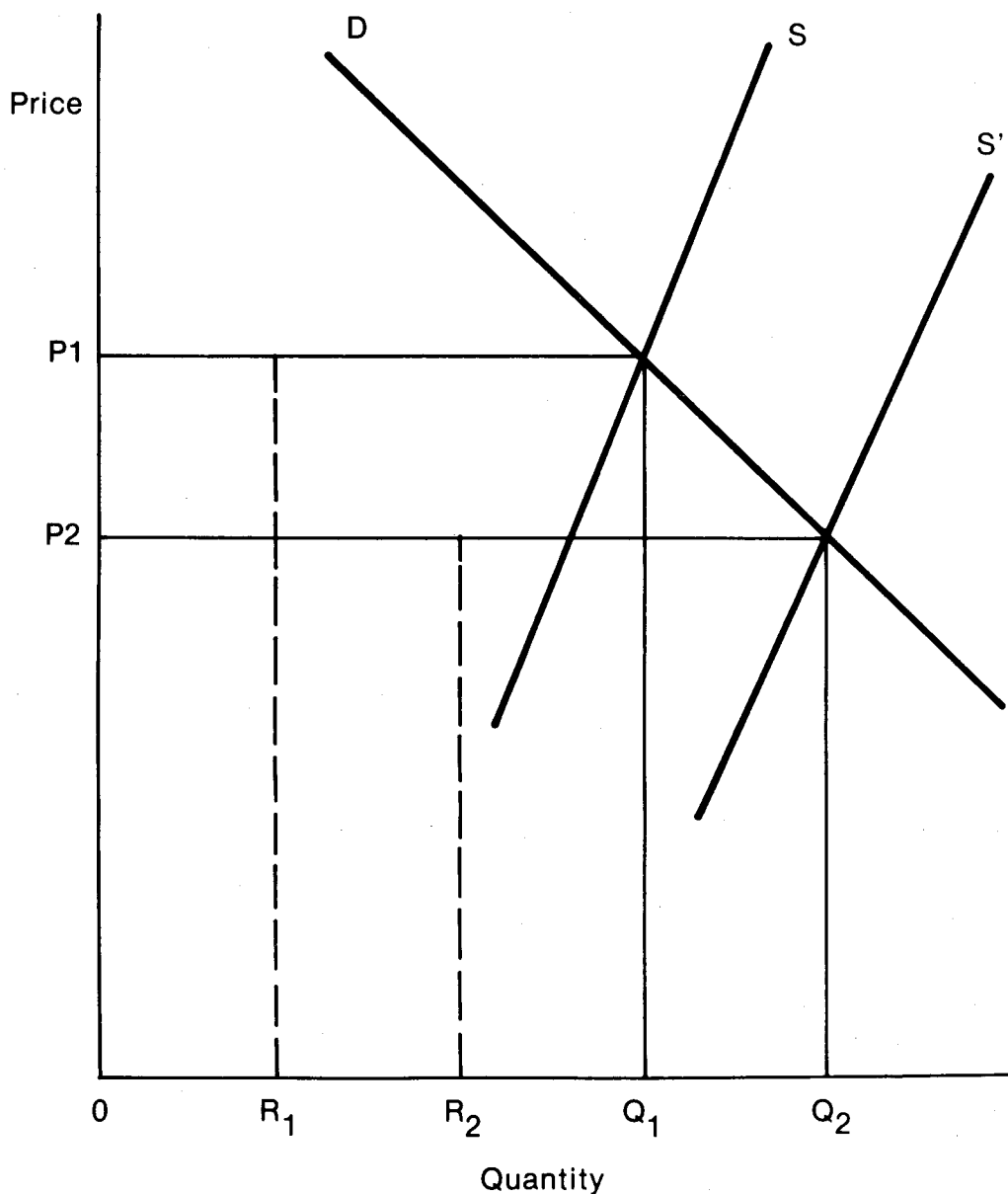
TABLE 2. Estimated Yield Per Acre Changes From Cloud Seeding by Month and Crop for Western, Central and Eastern Kansas.

	West			Central			East			
	Fallow Wheat	Continuous Wheat	Grain Sorghum	Fallow Wheat	Continuous Wheat	Grain Sorghum	Continuous Wheat	Grain Sorghum	Corn	Soybean
Aug.*	.16			-.03						
Sept.*	.11			-.01						
Mar.*	.13			-.05						
Apr.*	.17			-.04						
May*	.20			-.04						
June*	.19			-.03						
July*	.16			-.01						
Aug.	.87	.58		.18	.22		.03			
Sept.	.60	.40		.15	.19		-.02			
Mar.	.62	.44	.41	.18	.20	-.08	-.05	-.08	-.25	.02
Apr.	.79	.40	.50	-.19	-.02	-.12	.04	-.14	-.21	.02
May	.68	.42	.55	.35	.27	-.18	.02	-.16	-.25	
June	.18	.11	.08	.23	.05	-.55	-.02	.05	.09	.01
July			.40			.26		.67	.64	.17
Aug.			.42			.44		.04	-.02	.16
Sept.			.72			.38		-.02		.03

*Fallow year

TABLE 3. General Structure of Equations Showing Linkages Between Regional Production and Income Adjustments.

Type Row	Equation Name	RHS	Crop Production	Selling Activities	Income Adjustment
max	Objective		$-C_{ij}$	P_{ij}	$-L_i$
\leq	Crop Production	0	$-Y_{ij}$	1	
\leq	State Production	Sp_i	Y_{ij}		$-K_i$
\leq	Demand Limit	1			1

**Figure 1: Demand and Supply Schedules and a Shift in the Supply Schedule.**

parable to corn and the corn price at 1977 levels; crop yields were estimated using equation (5). The base situation was modified by changing crop yields as estimated using equation (6) to study the effect of cloud seeding.

Cloud seeding in Kansas would likely increase the production of wheat, corn, grain sorghum and soybeans. The increase in wheat production would likely decrease the price of wheat received by all wheat growers. Consequently farmers not in Kansas might adjust downward their acreage of wheat resulting in an increase in the Kansas share of wheat production in the United States. The increase in corn, grain sorghum and soybeans production in Kansas would have less of an impact on their market prices because Kansas' share of U.S. production of these crops is much less than for wheat.

Results

Cloud seeding will be more effective in some years and some months of each year, than in others. Rainfall benefits crops but it can also delay planting, interfere with harvesting, or run off because the soil is saturated. Thus, the benefit of additional rain depends on when it is received, the crop, stage of crop development, and soil moisture conditions. For the western region, it is estimated that in most years cloud seeding in every month has a positive effect on crop yields for every crop studied. The monthly effects vary greatly for each crop and among crops. For central and eastern regions, cloud seeding during spring may reduce production.

Table 4 presents the resulting changes in acres, production and income by major crop and region from cloud seeding. It was assumed that cloud seeding occurs only during those months showing a net positive effect for all crops affected. Information from Table 2 was used to calculate the net effect. For the western region, cloud seeding was assumed during all months from March through September; for the central region, months during which cloud seeding was assumed were

March, May, July, August, and September. In the east, cloud seeding during only July and August were assumed.

The linear programming model considers changes in the comparative advantage among crops within a region, and among regions within the state, as well as the potential for increasing production for the state. The state was subdivided into regions based on farming practices determined by rainfall differences. These differences in rainfall also influence the effectiveness of cloud seeding. Thus, results are presented for three major regions of the state as well as for the total state.

Cloud seeding is estimated to increase farm income in Kansas \$66 million even though the commodities produced have an inelastic demand, Table 4. Most of the increase in income is from corn and soybean production with a small increase from wheat and grain sorghum.

Income from wheat greatly increases in the western district which is almost offset by reductions in the central and east. Cloud seeding changes the comparative advantage of producing wheat in the west by increasing the productivity of western cropland much more than in the central and east. Rainfall is much more limiting in the west and so cloud seeding increases crop yields in the west relative to the central and east. Corn in the west is irrigated and it was assumed that the yield per acre would not be significantly affected by cloud seeding. Thus, the increase in income from corn in the western district is not directly caused by cloud seeding but by a shift in comparative advantage among crops. Cloud seeding increases yields of dryland grain sorghum, but its impact on income was much less than for dryland wheat.

Income on the central region is reduced because of the shift in production of wheat to the west. A small increase is indicated from dryland grain sorghum production but this increase does not offset the effect on wheat.

For the east a large loss in income from wheat is almost offset by the increase in income from corn, grain sorghum, and soybeans. To take advantage of the benefits from

TABLE 4. The Base and Changes in Acreage, Production and Income by Crop for Western Central and Eastern Kansas.

	Western Kansas		Central Kansas		Eastern Kansas		State Total	
	Base	Change	Base	Change	Base	Change	Base	Change
----- 1,000 Acres -----								
Acreage								
Wheat	3,775	+ 230	6,081	- 537	1,430	- 540	11,286	- 847
Corn	897	+ 29	279	0	375	+ 118	1,551	+ 147
Grain Sorghum	972	+ 20	1,412	0	870	- 25	3,254	- 5
Soybeans	-----	-----	-----	0	837	+ 246	837	+ 246
----- 1,000 Bushel -----								
Production								
Wheat	112,103	+ 31,192	187,086	- 11,690	50,063	- 18,754	349,251	+ 748
Corn	101,307	+ 3,232	29,025	0	26,541	+ 9,989	156,874	+ 13,126
Grain Sorghum	49,844	+ 3,888	68,485	+ 840	55,191	- 945	173,520	+ 3,783
Soybeans	0	0	0	0	22,000	+ 6,830	22,000	+ 6,830
----- 1,000 dollars -----								
Income								
Wheat	308,283	+ 85,778	514,487	- 32,148	137,673	- 51,574	960,440	+ 2,056
Corn	202,614	+ 6,464	58,050	0	53,082	+ 19,978	313,748	+ 26,442
Grain Sorghum	84,735	+ 6,610	116,425	+ 1,428	93,825	+ 1,606	294,984	+ 9,644
Soybeans	0	0	0	0	88,000	+ 27,300	88,000	+ 27,700
		+ 98,852		- 30,720		- 2,298		65,842

cloud seeding in the east, farmers would have to change their organization to include more corn, soybeans, and grain sorghum.

Increasing corn and soybean production has less adverse effect on their prices because Kansas' share of production of these crops is relatively much less than for wheat. Therefore, a one percent increase in corn and soybean production in Kansas has little effect on prices received and consequently a relatively large increase in total revenue.

Estimation of the cost of cloud seeding is based on a recent agreement between the Kansas Water Resources Board and counties in Western Kansas. Each county contributes \$.015 per acre rangeland and \$.036 per acre cropland. Applying these rates to the acres of rangeland and cropland in the western, central and eastern region, the cost per region is \$493,280 for the west, \$505,880 for the central, \$320,410 for the east and \$1,319,570 for the state. These cost estimates do not cover all of the research and development costs. Funds for cloud seeding are also received from Ground Water Management Districts and other subsidies. Doubling the above costs is probably a close estimate of the total cost of cloud seeding. The estimated returns greatly exceed the estimated cost of cloud seeding in the western region. In the central and eastern regions, the estimated returns to clouding are negative without the cost of cloud seeding. Thus only in the western region would cloud seeding likely have a positive effect on farmers' income.

Summary

Some public policies affecting production are made in the context that excludes many farmers affected by the decision. The decision to seed clouds to increase rainfall thereby increasing the output of crops grown in the region is an example. The decision to seed cloud is based on the cost and benefits of those affected in the region and ignores the effect on price to farmers not in the region. The price effects of increasing production is shared by all farmers producing the commodities, however, the decision to seed

clouds excludes some of those affected by the decision from the decision making process.

Increasing production of commodities with an inelastic demand reduces the total revenue to all farmers in the market. However, if the increase in production is restricted to a small region of the market, total revenue to these farmers in the region may increase because for them the percent increase in their production may be greater than the percent decrease in price. This group has shifted the adverse effect of a lower price on total revenue to all other farmers not included in their group. The extent to which this shift can occur depends upon their share of the total production in the market, and in the increase in production by a group of farmers.

For Kansas, it was estimated that cloud seeding increases the total revenue to its farmers in spite of the influence of an inelastic demand for the commodities produced. The economic benefits from increased wheat production is relatively small because Kansas farmers produce a larger share of the total market than for the other major commodities.

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