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## **Freeze Risk and Adoption of Technology by Orange Producers**

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Orange producers in many regions of the U.S. are affected by the recurrence of frost. This study evaluated 147 California farmers' perceptions of frost risk relative to other business risks. Freeze risk perception was negatively related, for example, to farm size. Large farmers with diversified businesses had lower perceptions of freeze risk than small farmers. Change in crop location and the adoption of anti-frost technology were two important responses to freeze risk. California farmers shifted their location to frost-prone areas and adopted anti-frost technology. Florida farmers, however, diversified to less frost-prone areas and adopted new planting technologies instead of anti-frost technologies.

**Key Words:** anti-frost technologies, diversification, orange frost, ordered probit model, risk perception

Recurring frost is one of the major sources of risk faced by citrus farmers. Freezes, including the occurrences of 1991 and 1998, devastated California citrus crops. In the 1980s, central Florida citrus farmers faced an unprecedented number of freezes. The freezes in December 1983 and January 1985 eliminated one-third of Florida's commercial citrus trees (Miller and Downton). Citrus crop losses due to freezes have occurred frequently even though technologies have been available to help farmers cope with freeze risk. This dilemma poses three important research questions. First, having experienced many freezes over the years, how do citrus farmers perceive freeze risk in relation to the other business risks that they face? Second, what are the factors that influence farmers' perceptions of freeze risk? Finally, how do the farmers in the freeze-prone region cope with freeze risk?

### **Procedures**

The data used in this study were developed from a survey of Sunkist orange producers in California. The survey was conducted in 1993 as part of a risk study

undertaken by the Department of Agricultural and Resource Economics of the University of California at Berkeley. The survey was designed to identify the risks confronting California citrus growers. The seriousness of the threat that these risks posed for growers, farm structure, and the measures that growers took to reduce their vulnerability to these risks were also considered.

Surveyed growers were asked to select and then rank five sources of risk out of 15 different choices. Among others, the sources of risk included credit availability, water availability, freeze, and disease. A total of 181 Sunkist growers in California were interviewed. Of the 181 respondents, 147 provided information by identifying five different sources of risk from among the 15 risk choices. Information was obtained on variables such as farm size, farm operating credit, investment in frost risk-reducing technologies, and farm and nonfarm income.

### *Risk Perception*

The perceptions of risk associated with different risk sources were analyzed using data from the survey of California orange producers. Farmers were provided a list of 15 different business risks in orange production and were asked to choose and rank the five most important sources of risk. Respondents were asked to provide a relative measure of risk perception by giving a value of five to the most severe business risk and a value of one to the least severe. Those business risks not identified by farmers to be among their five risk choices were assigned a value of zero.

Table 1 provides the frequency distribution of the top six different sources of risk chosen by respondents for each of the five risk levels. These six risk sources included availability of water, freeze, price uncertainty, availability of pesticides, market access, and citrus acreage expansion in the United States. The information in table 1 identifies the number of respondents (as well as the percentage of total respondents) who chose a particular source of risk at a specific risk level.

As reported in table 1, 54 (36.7 %) of the farmers ranked water availability, and 34 (23.1%) of the respondents ranked freeze risk as their most severe risk choice (risk level 5). Based on these responses, it is likely that the farmers used water-based technology, such as sprinklers, to protect their orange crops from freeze damage. Price uncertainty had the highest number of responses under risk levels 4 and 2, while the availability of pesticide use received the highest response number under risk level 3. The two remaining sources of risk—market access and citrus acreage expansion in the United States—were chosen by a fewer number of respondents. Those who chose market access and citrus acreage expansion considered these risks to be relatively less severe.

Out of 147 respondents, 97 (65.9%) selected freeze risk as one of their top five business risk choices. Of this group, 34 (35.1%) indicated that freeze presented the highest level of risk, and only 13 (13.4%) considered freeze to represent the lowest level of risk (table 2).

**Table 1. Frequency Distribution of Six Main Sources of Risk, Ranked by Risk Level, as Perceived by 147 Sunkist Farmers Surveyed in 1993**

Sources of Risk	RISK LEVEL (5 = most severe, 1 = least severe)									
	5		4		3		2		1	
	No.	%	No.	%	No.	%	No.	%	No.	%
Water availability	54	36.7	17	11.6	11	7.5	10	6.8	13	8.8
Freeze	34	23.1	23	15.6	13	8.8	14	9.5	13	8.8
Price uncertainty	27	18.4	33	22.4	14	9.5	19	12.9	9	6.1
Pesticide availability	1	0.7	19	12.9	26	17.7	14	9.5	11	7.5
Market access	5	3.4	9	6.1	4	2.7	8	5.4	8	5.4
Citrus acreage expansion in U.S.	5	3.4	9	6.1	16	10.9	10	6.8	7	4.8

Source: Authors' calculations from survey data.

**Table 2. Percentage Distribution of the 97 Respondents Who Perceived Risk of Freeze Being in the Top Five Risk Categories**

Risk Level	Number of Respondents	Percentage (%)
5	34	35.1
4	23	23.7
3	13	13.4
2	14	14.4
1	13	13.4

Source: Authors' calculations from survey data.

#### *Predicted Probability of Perceived Risk of Freeze in Different Risk Categories*

An ordered probit model (Long; Godfrey; Yatchew and Griliches; Davidson and Mackinnon; Greene, 1993) was used to estimate the probability of farmers' perceived risk of freeze being in one of six risk levels (including zero risk). The objective was to determine the probability that orange farmers will select one level of perceived risk over the several levels defined above. The model is specified as follows:

$$(1) \quad y_i^* = x_i\beta + \varepsilon_i,$$

where values for  $y^*$  are 0, 1, 2, 3, 4, and 5, with a value of 0 indicating no freeze risk perceived, and a value of 5 indicating the highest level of perceived risk. The

$x_i$  term represents a set of exogenous variables affecting  $y^*$ ;  $\beta$  is a vector of unknown parameters to be estimated; and  $\varepsilon_i$  denotes the normally distributed random errors.

The parameters for the model were estimated using a maximum-likelihood procedure via LIMDEP (Greene, 1995). The independent variables included the absolute size of land (acres) used in orange production, the value of owned land used in orange production as a percentage of the total value of owned land, loans for fixed capital, measures adopted by farmers to protect from freeze, and nonfarm income as a percentage of total farm income. Loans for fixed capital and measures adopted by farmers to protect from freeze were represented by dummy variables. (For example, if a farmer took out a loan for fixed capital, a value of 1 was assigned; for no loan, a value of 0 was used.) Measures to protect from freeze included freeze-protection technologies (such as windmills and sprinklers), crop insurance, and freeze-resistant crop varieties.

Table 3 presents the descriptive statistics for the five independent variables, including their means and standard deviations. The total number of farmers who borrowed loans for fixed capital and those who adopted some measure of protection from freeze are reported in table 3 as the total number of "Yes" responses.

As seen in table 3, the value of the land in orange production constituted as much as 86% of the total value of the land farmed by the Sunkist growers in California. The absolute size of the orange orchards, however, varied quite significantly across the respondent farmers. The average orchard size was 78.35 acres of land, with a maximum of 1,498 acres and a minimum of 2.5 acres. Fifty-one farmers took out loans for fixed capital, or 34.69%. As many as 117 farmers (79.59%) had adopted some measure to protect against freeze, although fewer had adopted freeze-protection technology. Finally, approximately 50% of the total farm income of the sampled farmers came from nonfarm sources, such as services to other farms.

Estimated coefficients are reported in table 4. The overall significance level of the model was 99%. Furthermore, four independent variables were individually significant at 90% or higher, and each of these independent variables was negatively related to the probability of the perceived risk of freeze being in any one of six levels of risk, including zero risk. That is, risk perception increased as the levels of these variables decreased.

It is interesting to note that all of these variables measured the stake of growers in the business. The probability of farmers' perception of risk of freeze decreased as the value of land used in orange production as a percentage of the total value of farmers' land increased. Similarly, the probability of perception of risk of freeze decreased with an increase in the absolute size of the land used in orange production. Finally, as farmers took out loans for fixed capital, the probability of their perception of risk of freeze decreased. It is likely that these growers, with a higher stake in business, provided adequate protection against freeze by investing in freeze protection alternatives. As a result, their perception of freeze risk decreased. Also, growers receiving increasing proportions of their farm income from nonfarm sources had decreasing perceptions of freeze risk.

**Table 3. Descriptive Statistics of Independent Variables**

Variables	Mean	Standard Deviation	“Yes” Responses	
			No.	%
Value of owned land used in orange production as percentage of total value of owned land	85.45	31.80		
Absolute size of land used in orange production (acres)	78.35	180.60		
Loans for fixed capital			51	34.69
Measure adopted by farmer to protect against freeze			117	79.59
Nonfarm income as percentage of total farm income	48.37	34.84		

Source: Authors' calculations from survey data.

**Table 4. Parameter Estimates for the Ordered Probit Model and Their Significance Levels**

Variables	Coefficients	Z-Value
Intercept	1.189**	3.92
Value of owned land used in orange production as percentage of total value of owned land	-0.005*	-1.62
Absolute size of land used in orange production (acres)	-0.001**	-2.22
Loans for fixed capital	-0.378*	-1.87
Measure adopted by farmer to protect against freeze	0.236	0.94
Nonfarm income as percentage of total farm income	-0.006**	-1.94

Notes: Single and double asterisks (\*) denote statistical significance at the 10% and 5% levels, respectively. The overall significance level of the model is 99%.

### Simulation Analysis

Table 5 reports predicted probabilities of several levels of freeze risk perceptions, including mean and range, given the set of independent variables. Consider the zero risk perception outcome. Within the sample, the minimum probability of zero freeze risk perception was 0.11, and the maximum probability was 0.95, resulting in a range of 0.84. Comparable results reported for the highest risk category show a minimum probability of 0.01, a maximum of 0.51, and a range of 0.50.

There was sufficient variation in these two categories to justify some type of simulation of risk scenarios, given the changes in key variables. The two key variables

**Table 5. Predicted Probabilities of Outcomes Within the Sample for the Ordered Probit Model**

Probabilities	Minimum	Mean	Maximum	Range
$\Pr(y = 0   x)$	0.11	0.33	0.95	0.84
$\Pr(y = 1   x)$	0.02	0.09	0.10	0.08
$\Pr(y = 2   x)$	0.01	0.10	0.10	0.09
$\Pr(y = 3   x)$	0.01	0.08	0.08	0.07
$\Pr(y = 4   x)$	0.01	0.23	0.19	0.18
$\Pr(y = 5   x)$	0.01	0.23	0.51	0.50

were absolute size of land (acres) used in orange production, and nonfarm income as a percentage of the total income of sampled farmers. Keeping other variables at their mean values, the effect of change in the size of orange acres on the predicted probabilities of freeze risk perception was first calculated and plotted (figure 1). We see from the graph in figure 1 that as the mean size of orange acres increased, the probability of zero freeze risk perception increased, but the probability of the highest level of risk perception decreased. This suggests that large farmers were less worried about freeze than the small holders.

Similarly, the effect of nonfarm income on predicted probabilities was calculated and plotted (figure 2). As the nonfarm income as a percentage of total income increased, the probability of zero freeze risk perception increased, and the probability of the highest level of risk perception decreased. Again, large farmers who were more diversified had lower perceptions of freeze risk compared to small farmers who depended solely on farm income.

### Adoption of Technology

More than 82% of the 147 Sunkist growers who responded to the survey have adopted freeze-protection alternatives including crop insurance, investment in anti-freeze technology (such as sprinklers, wind machines, heaters, etc.), and use of freeze-tolerant orange varieties. Among those who implemented crop-protection alternatives, 68% adopted anti-freeze technology.

### Distribution of Farm Size

The distribution of farmers who adopted anti-freeze technology, based on the size of the land used in orange production, is shown in table 6. More than 65% of the farmers who adopted the anti-freeze technology were from medium and large farms that constituted more than 95% of the area under anti-freeze technology.

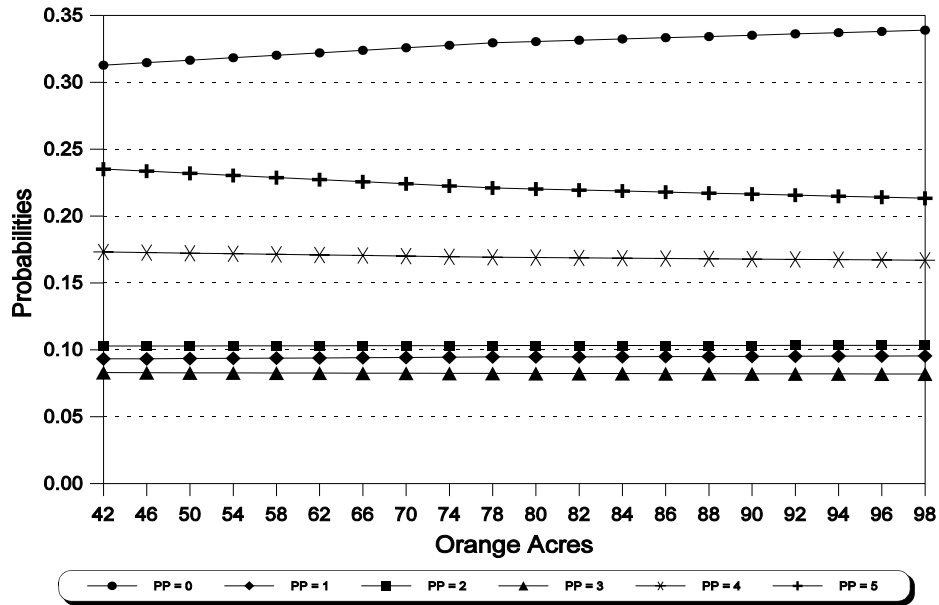


Figure 1. Predicted probabilities of freeze risk perception (risk levels 0–5) based on size of orange acres

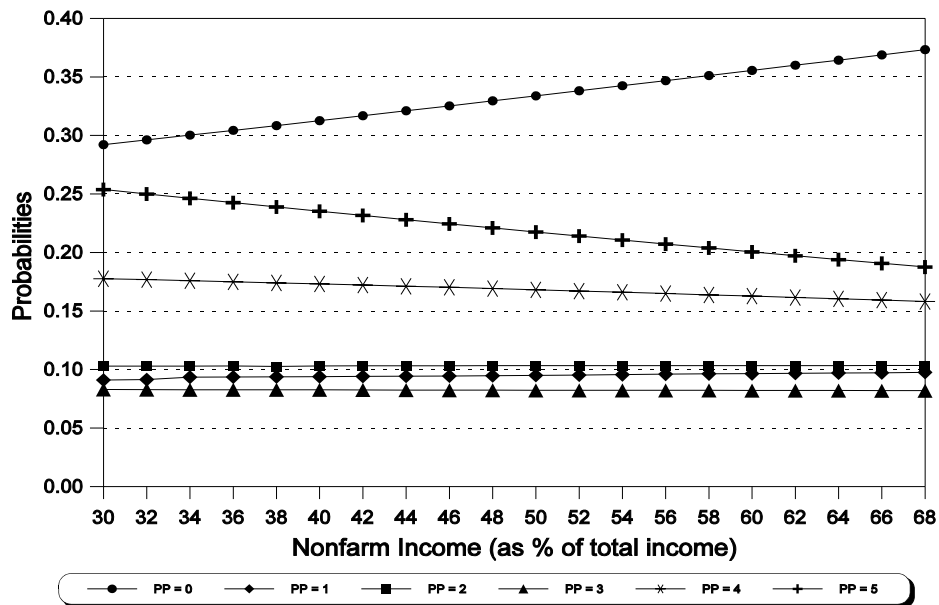


Figure 2. Predicted probabilities of freeze risk perception (risk levels 0–5) based on nonfarm income as a percentage of total income

**Table 6. Distribution of 83 Farmers Who Adopted Anti-Freeze Technology, Based on Size of Land Used in Orange Production**

Size of Land Used in Orange Production	Farmers		Percentage of Land Under Anti-Freeze Technology <sup>a</sup>
	No.	%	
Less than 25 acres	29	34.9	4.4
25 to 100 acres	38	45.8	24.3
More than 100 acres	16	19.3	71.2

Source: Authors' calculations from survey data.

<sup>a</sup> Sprinklers, wind machines, heaters, etc.

**Table 7. Distribution of Level of Freeze Risk Perception Among Farmer Groups With and Without Anti-Freeze Technology**

Risk Level	With Anti-Freeze Technology		Without Anti-Freeze Technology	
	No.	%	No.	%
5	17	20.5	17	26.6
4	14	16.9	10	15.6
3	9	10.8	4	6.3
2	7	8.4	7	10.9
1	9	10.8	4	6.3
0	27	32.5	22	34.4
Total:	83	100%	64	100%

Source: Authors' calculations from survey data.

**Table 8. Spatial Changes in the Orange Acreage Planted in California and Florida: 1982, 1986, and 1994**

Years	CALIFORNIA				FLORIDA			
	South		Central		Ridge		Flat	
	Acres	% Change	Acres	% Change	Acres	% Change	Acres	% Change
1982	53,311	NA	128,585	NA	167,019	NA	236,221	NA
1986	52,685	-1.2	134,140	+4.3	30,730	-81.6	243,442	+3.1
1994	40,309	-24.4	162,675	+26.5	39,199	-76.5	404,468	+71.2

Sources: Sunkist Corporation (California), unpublished 1997 data; Zanzig, Moss, and Schmitz.

Notes: Base year = 1982; NA = not applicable.

In table 7, the 147 respondent farmers are divided into those who adopted anti-freeze technology (83) and those who did not (64), by level of freeze risk perception. The percentage distribution of the two groups of farmers with varying degrees of freeze risk perception showed that those who perceived freeze risk to be zero were nearly equal in both groups (32.5% and 34.4% for technology adopters and non-adopters, respectively). However, among farmers who perceived some level of freeze risk, the percentage of those who perceived freeze risk at the highest level (level 5) was higher in the group that did not adopt any kind of anti-freeze technology (26.6%) than in the group that adopted the technology (20.5%).

Large- and medium-sized farmers adopted anti-freeze technology and had a relatively lower perception of freeze risk than the smaller farmers who did not adopt the technology (tables 6 and 7). This conclusion is consistent with the results obtained from the simulations above, which were based on the parameters estimated from the ordered probit model.

Effectiveness of technology in controlling freeze damage depends on the extent of the freeze. Despite frost warnings and anti-freeze technologies, most farmers in California were not able to protect many of their crops in 1990/91 (Bailey). Farmers in California, however, still use anti-freeze devices like sprinklers, heaters, wind machines, etc., and believe such technologies are effective for less than severe frosts (Smith).

### *Diversification*

An alternative to the adoption of anti-freeze technology is the diversification of the orange production area. The spatial changes in acreage planted in both California and Florida in 1982, 1986, and 1994 are shown in table 8. For the selected years 1982–94, there was an increase of 26.5% in acreage planted in frost-prone central California, while acreage planted during the same period declined by 24.4% in southern California.

The shift toward central California was prompted by factors including the rapidly increasing real estate values in southern California. As our results show, growers did invest in anti-freeze technology as they moved to the cheaper central California land. They did not relocate their groves to warmer climates but, rather, moved their groves to colder climates and confronted frost risk.

The reverse trend was found in Florida (Miller and Downton). As shown in table 8, between 1982 and 1994, the flatter region of Florida, which is at the southern end of the state, observed an increase of 71.2% in the acreage planted, while acreage planted in the northern ridge region (central Florida) declined by 76.5%. The shift in Florida, unlike that in California, was largely due to the lesser probability of frosts in south Florida compared to central Florida. Thus, Florida exhibited an example of a diversification strategy against frost that included the ownership of groves in multiple locations and a location change to areas where the expectation of frost is at a minimum. In addition, the new technology of mounding, which helps with water

drainage, allowed orange producers in Florida to move farther south. Zanzig, Moss, and Schmitz found that Florida farmers used new technologies to develop land in the southern part of the state that was suitable for orange groves.

### **Summary and Conclusions**

Orange producers in California, Florida, and other regions of the United States are affected by the repeated occurrence of frost. Our results show that 23% of the 147 survey respondent farmers perceived freeze risk to be in the highest level of risk, and 66% perceived freeze risk to be in one of five levels of risk.

An ordered probit model was used to estimate the probability of the perception of freeze risk at various levels (ranked from 0 to 5), given a set of five independent variables. These independent variables included: (a) the value of land used in orange production as a percentage of the total value of owned land, (b) the absolute size of land (acres) used in orange production, (c) loans for fixed capital, (d) measures adopted by farmers to protect against freeze, and (e) nonfarm income as a percentage of total income. Four of these variables were found to be statistically significant and negatively related to freeze risk perception. (Only the variable representing measures adopted by farmers to protect against freeze was not statistically significant.) A simulation analysis based on estimated parameters showed that large farmers with more diversified farm businesses were less likely to perceive freeze risk as a high level of risk compared to small farmers. Adoption of anti-freeze technology and diversification were two different strategies followed by farmers in response to freeze risk.

A separate aggregate data set showed that California farmers shifted their orange groves to the frost-prone central part of the state and adopted anti-frost technologies. Florida farmers moved to the flatter lands in south Florida where there was less likelihood of frosts. In contrast to their California counterparts, Florida growers selected technologies designed to make lands suitable for orange groves instead of investing in anti-frost technologies.

Although anti-freeze technologies were adopted to cope with frosts, farmers were unable to totally eliminate the damage to crops when freezes were severe. Hence, it is important to further investigate the level of emphasis that should be given to developing farm-level anti-frost technologies. Perhaps a more concerted effort should be made in predicting frosts.

Other important frost risk considerations are the implications of recurring frosts on the statewide citrus industry. Florida growers face a relatively elastic excess demand for their production because they mainly produce processed oranges, thus encountering stiff trade competition from countries like Brazil. Because of the given quantity and price relationship, a decrease in orange production due to frost is not offset by an increase in price. As a result, Florida is negatively impacted by frosts. The situation is different for California. California produces mainly fresh oranges, which have a relatively inelastic demand due, in part, to the lack of competition from

other countries. Consequently, a reduction in the quantity of California oranges because of frost is at least partially offset by an increase in price. However, a detailed study is required to investigate the economics of these changes.

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