The Freeze Risk to Florida Citrus. Part I: Investment Decisions

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ABSTRACT

In the 1980s Florida was struck by an unusual series of severe freezes that caused enormous damage to citrus groves. While citrus acreage in relatively freeze-free parts of the state has expanded rapidly since these freezes, serious questions remain about the commercial viability of growing citrus crops in some central Florida counties. This paper considers the role that freeze risk plays in the investment decisions of citrus growers. A simplified example is used to estimate tolerable levels of freeze risk for individuals evaluating the investment at different discount rates, and to show the impact of changes in the risk level. Changes in estimated freeze risk in the 1980s are computed over the historical temperature record, and related to the growers' replanting decisions. It is concluded that the computed changes in the probability of a killing freeze would be sufficient to alter the citrus planting decisions of some investors. Furthermore, the longest available climate record should be used to estimate the risk of such low-probability extreme events.

1. Introduction

Climate information is important for investment decisions in many fields (agriculture, energy, water, etc.) and uncertainties about climatic change put a new burden on planners. To be most useful to decision makers, projections of climatic change must include information related to specific climate risks, many of which involve extreme events. This paper is the first of two that examine apparent changes in the freeze risk for citrus growers in Florida. It focuses on information about climate variability that would be useful to growers in making investment decisions. The second paper (Downton and Miller 1993) examines climatic forces that affect this variability. The combined focus on decision making and climate processes leads, in the second paper, to a suggestion of the type of information climate modelers could offer that might help in the assessment of future freeze risk.

The decade of the 1980s brought a series of devastating freezes to central Florida's citrus industry. Tree killing freezes occurred in four out of five years between 1981 and 1985, with freezing temperatures affecting a large portion of Florida's citrus growing areas in January 1981, January 1982, December 1983, and January 1985. The latter two freezes were particularly severe. Together, they are estimated to have killed approximately one-third of the state's commercial citrus trees, virtually eliminating the groves in some counties (Miller and Glantz 1988). Another freeze in December 1989 appears to have killed a large number of the remaining and newly replanted trees in areas that already had been severely affected by the earlier freezes. In Lake County, for example, 69% of the bearing citrus trees and 61% of the immature trees that were alive in 1988 were lost before the 1990 tree inventory. Statewide, the 1989 freeze killed fewer trees than either the 1983 or 1985 freezes, in part because of a major shift in new citrus planting to more southerly areas (Florida Agricultural Statistics Service 1988, 1990).

The freezes of the 1980s represent an unusual sequence of extreme weather events. Less severe freezes have always been a common occurrence in central Florida, affecting some portion of the citrus crop approximately every other year (Florida Crop and Livestock Reporting Service, undated). During the 1980s, however, severe tree-killing freezes occurred far more frequently than growers might have expected on the basis of the previous climatic record. Such an apparent shift in Florida's climate is not unprecedented. A similar series of closely spaced freezes killed a major portion of Florida's citrus trees in the 1890s. But historical weather records are inadequate to determine rigorously whether temperatures in the 1890s and 1980s were comparable. Weather stations have been moved, monitoring equipment has been changed, and the orange groves have been moved southward in response to intermittent freezes.

The experience of Florida's citrus industry with the freezes of the 1980s suggests two research questions.

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First, how are citrus growers' investment decisions affected by the presence of freeze risks and by changes over time in the apparent frequency of freezes? Second, can causes be identified for the increased frequency of freezes in central Florida during the 1980s? This paper examines the first of these two questions; a companion paper examines the second.

2. Freeze risks and citrus investment decisions

Investment risks in agriculture result from an intricate mixture of climatic, biological, and market forces. The risk of freeze damage is only one of several sources of risk facing investors in Florida citrus groves. Individuals planting citrus groves in Florida are undertaking a calculated gamble. They are making a bet that the return on the investment will exceed the expected return on alternate uses of that land and capital by an amount sufficient to compensate them for the associated risks. Major uncertainties involve future fruit prices, operating costs, fruit yields adjusted for possible freeze damage, and losses of trees to freezes or disease.

Annual gross revenues for Florida citrus fluctuate considerably from year to year as a result of variations in prices and yields. Yields generally depend on the age of the tree, but fluctuate as a result of freeze damage and growing conditions. Prices are affected by fluctuations in citrus production, both in Florida and in competing areas such as Brazil, as well as by factors affecting world demand for citrus products such as income and population growth. Prices also vary with fruit quality, with freeze-damaged fruit commanding lower prices than undamaged fruit. Figure 1 depicts statewide average gross revenues per acre for early and midseason oranges, expressed in real (1989) dollars. The wide fluctuations that can be observed in this time series are the result of changes in both prices and yields.

A risk-averse investor's goal is to achieve a desired balance between risk and expected return. An investor who did not care about risk would be called risk neutral. Such an individual would always invest in whatever asset promised the highest mean (expected) return regardless of the variability of actual returns around that mean. The risk-averse investor, on the other hand, is concerned about both the expected return and the risk associated with that return. Higher risk investments will be chosen only if the expected return is also higher by an amount sufficient to compensate the individual for bearing the additional risk. The attempts of a risk-averse individual to maximize expected utility (defined as a qualitative measure of satisfaction) may lead to investment in a diversified portfolio, since such a strategy often reduces the variance of returns.

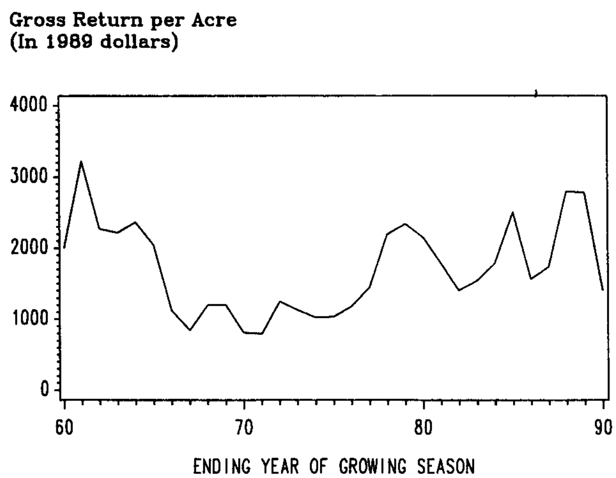

FIG. 1. Florida early and midseason oranges—statewide average gross returns per acre.

Investments in citrus groves are subject to both fluctuating annual returns and the risk of the loss of trees to freezes. Individuals considering such an investment will weigh their expectations regarding monetary returns against their assessments of and aversion to uncertainty associated with those returns. Because individuals differ in their perceptions, expectations, and willingness to undertake risky investments, they may come to somewhat different conclusions about the desirability of planting citrus in various Florida locations. Nevertheless, more complete information about the nature of the freeze risk can be expected to help growers make more informed decisions regarding citrus investments.

Among the risks faced by Florida's citrus producers, the risk of freeze has had a major impact on grove investment decisions and on the organization and structure of the industry. One way that citrus growers have adapted to the freeze risk has been through diversification. Examples of diversification strategies include the ownership of groves in multiple locations, the selection of an appropriate mix of citrus varieties (with different vulnerabilities to freeze damage), and the derivation of income from other sources (Miller 1991; Brey 1985). Even before the recent series of devastating freezes, individual citrus acreages tended to be relatively small throughout the state, most frequently less than 50 acres, and generally somewhat smaller in the northern growing areas than farther to the south (Florida Grower and Rancher 1986; Central Florida Freeze Recovery Task Force 1984). In addition, citrus growers in freeze-prone areas frequently derived a large share of their income from other agricultural and nonagricultural activities (Florida Grower and Rancher 1986). Some groves have also been owned by absentee investors who contract with local custom management companies for all harvesting, pruning, and other grove maintenance services.

Freezes severe enough to kill trees present the most serious risk. These have much more severe financial consequences than freezes damaging only the fruit. Damaged fruit can be partially salvaged for processing, although its value will be reduced, whereas a tree must survive for many years to pay back the initial investment plus a reasonable rate of return on invested capital.

3. The relationship between freeze risk and expected return

The decision to invest in a citrus grove involves a balancing of perceived risks and expected returns over a long (i.e., more than a decade) investment horizon. For example, an orange tree generally does not bear a significant quantity of fruit until five years after it is planted. The yield from the tree gradually increases as the tree matures. Once mature, an orange tree can remain productive for several decades. How long must a grove survive to make it a profitable investment? At what probability of a killing freeze would investors no longer be willing to gamble on planting citrus groves?

The answers to these questions are not as simple as one might suppose because they hinge on assumptions about future costs, future fruit prices, and the opportunity cost of capital. In addition, investors with different degrees of risk aversion will come to different conclusions regarding the tolerable risk of a killing freeze. To illustrate the type of analysis involved, it is instructive to look at cost and return projections prepared for prospective orange grove planters by the Florida Cooperative Extension Service (Ford et al. 1989). These are shown in Tables 1a and 1b. For a new Hamlin orange grove (a relatively freeze-hardy early variety) planted in north-central Florida, it is estimated that if future costs and returns are discounted at a 5% real (inflation-adjusted) annual rate of interest, the present value of the net revenue stream would become positive when the grove reached 12 years of age. At a 10% real annual rate of interest, the present value becomes positive at 15 years of age (see Table 1a). When the possibility of reselling the mature grove at its increased capital value is considered, Ford et al.'s calculations suggest that a grove surviving at least 15 years would have a net present value of $11 462 per acre at a 5% discount rate, or $3649 at 10% in 1989 dollars (see Table 1b).

These calculations are intended to represent average expected returns, and they do not directly address year-to-year variability. The average expected yields incorporated into the calculations assume a 6% average annual loss of fruit to freeze damage. Two percent average annual loss of trees (to be replaced by replanting) is also assumed, which is close to the actual average rate of attrition for north Florida Hamlin orange trees prior to the recent series of killing freezes (Florida Crop and Livestock Reporting Service, biennial series 1978–86). It is smaller than Ford et al.'s estimate of annual tree attrition in south Florida groves, where the losses would be primarily attributable to causes other than freeze. It therefore does not appear that the risk of a severe tree-killing freeze is captured in Ford et al.'s analysis. Their expected return figures can, however, be adjusted to examine the effects of a change in the risk of a tree-killing freeze.

To simplify the problem for the purpose of illustration, assume that the prospective investor will hold on to the grove for as long as it survives up to a 15-year planning horizon. If the grove survives for the entire 15-year period, the investor will sell out and retire. Note that since the selling price of a mature grove reflects the market's assessment of the expected discounted future stream of net returns, this simplifying assumption should not substantially alter the analysis.

Also assume that there is an X% annual risk of a freeze causing tree damage so severe as to effectively

TABLE 1a. Net revenues per acre, new north Florida Hamlin orange grove (not adjusted for risk of severe freeze).

Year	Undiscounted net revenues	Present value in year 0 (discounting at 5%) Annual	Present value in year 0 (discounting at 5%) Cumulative	Present value in year 0 (discounting at 10%) Annual	Present value in year 0 (discounting at 10%) Cumulative
1	−5366	−5110		−4878	
2	−1646	−1493	−6603	−1360	−6238
3	−663	−573	−7176	−498	−6736
4	−430	−354	−7530	−294	−7030
5	−99	−76	−7606	−61	−7091
6	297	222	−7384	168	−6923
7	901	640	−6744	462	−6461
8	1483	1004	−5740	692	−5769
9	2237	1442	−4298	949	−4820
10	2598	1595	−2703	1002	−3818
11	2913	1703	−1000	1021	−2797
12	3072	1711	+711	979	−1818
13	3085	1636	2347	894	−924
14	3112	1572	3919	819	−105
15	3181	1530	5449	762	+657

TABLE 1b. Net present value, including value of mature grove.

	Undiscounted	Discounted at 5%	Discounted at 10%
Value of mature grove	12 500	6013	2992
Cumulative net revenue		5449	657
Total: net present value of investment to year 15		11 462	3649
Price of raw land: $3632/acre			
Source: Ford et al. (1989)			

destroy the entire grove, in which case the individual is left with a land asset having the raw land value. Under these assumptions the expected net present value of the orange grove investment can be calculated as follows for different levels of X (the risk of a complete kill).

The probability that the grove will still be alive at the end of year t is

$$Y_t = (1 - X)^t.$$

The probability that the grove will be alive at the beginning of year t but die during that year is

$$Z_t = X(Y_{t-1}).$$

If future returns are discounted at a fixed annual interest rate (set in these examples at $i = 0.05$ or $i = 0.10$), then the expected net present value of the investment is

$$\sum_{t=1}^{15} \frac{Y_t R_t + Z_t S}{(1+i)^t} + \frac{Y_{15} M}{(1+i)^{15}},$$

where R_t is the projected net return in year t [from Ford et al. (1989), R_1 is assumed to include the cost of land acquisition and preparation, and R_2 includes tree-planting costs], S is the selling price or salvage value of raw land, and M the price of a mature grove. A positive value suggests that the investment should be undertaken, while a negative value implies that it should not.

Taking Ford et al.'s price and cost figures as reasonable estimates of average expected returns, in Table 2 we present the results of this analysis at two different discount rates (i), 5% and 10%. Since a large share of the costs of an orange grove comes at the beginning of the investment period while the revenues are delayed, the expected net present value of the investment, and hence its desirability, is highly sensitive to the interest rate at which future costs and returns are discounted. All cost and return figures used in the analysis are assumed to be in constant dollars (Ford et al. 1989), so the appropriate discount rate reflects the real (inflation adjusted) rate of return available on alternative investments plus a premium for the relative risk of the grove investment. The appropriate risk premium depends upon both the uncertainty of returns from the investment and the individual's aversion to risk. The uncertainty of returns arises from uncertain prices and yields, as well as from the possibility of freeze kills. Since individuals differ in their aversion to risk, their willingness to forego current consumption for higher future income, and their knowledge and perceptions of other investment alternatives, different individuals are likely to apply different discount rates to the evaluation of citrus investments. Available real rates of return cover a broad spectrum with returns below 5% being fairly typical for relatively risk-free investments such as Federal Treasury Bills, while real rates of return in the neighborhood of 10% may be less common but have been achieved over the long term by some relatively risky mutual funds (e.g., Standard and Poor's 1992). The discount rate chosen to evaluate a citrus investment will reflect the expected rate of return on alternative investments of similar perceived risk.

TABLE 2. Expected net present value ($ per acre) of 15-year investment. North-central Florida Hamlin grove.

	Annual risk of total kill (%)			
	3	5	8	12
5% discount rate	6494	4077	1419	−1245
10% discount rate	1122	−99	−1464	−2577

As indicated in Table 2, the grove investment appears attractive at either discount rate if the risk of a complete kill (X) is as low as 3% per year. It becomes marginally unattractive at a 10% discount rate in the vicinity of a 5% risk, and the investment would be rejected by an individual evaluating the investment using a 10% discount rate at an 8% kill risk. At 5%, the investment is still attractive at an 8% kill risk, but would be rejected if the risk rose to 12%.

It should be noted that as the risk of a killing freeze increases, there will also be an increase in the probability of freezes sufficiently severe to damage fruit without actually killing trees. Therefore, as the risk of a severe freeze increases, the financial attractiveness of the investment would further diminish if the average annual loss in the value of the fruit harvest rises above Ford et al.'s 6% figure. The lack of location-specific price and yield data make it impossible to accurately estimate the relationship between temperatures and the loss of fruit value resulting from freeze damage. However, the likelihood that freeze-related losses in crop value may also increase implies that the decision to invest in a citrus grove is likely to be even more sensitive to an increasing risk of severe freeze than is suggested by Table 2. In addition, it should be noted that the investment decision is not just a simple "yes" or "no" decision. Rather, as the perceived freeze risk increases toward the level at which the expected net present value of a new grove is negative, risk-averse individuals may attempt to reduce the proportion of their total assets devoted to citrus (Miller 1991).

While this is an artificial and highly simplified example, it suggests that a change of only a few percentage points in the risk of freeze damage may have a large impact on the expected profitability of investments in Florida citrus groves. Therefore, it is of interest to examine the Florida temperature record and to compare estimates of the probability of a severe freeze that would be obtained using records of different lengths.

4. Freeze risk in Florida

The closely spaced freezes in the 1980s prompted speculation in Florida about possible underlying climate change (Gerber 1985). Chen and Gerber (1985) reported an apparent downward trend in seasonal minimum temperatures between 1898 and 1985 at several Florida locations and suggested that recent low temperatures may represent the low point of underlying climatic cycles. To assess the apparent changes in freeze probabilities, it is necessary to look at long-term fluctuations in the climate record.

a. Florida winter temperature record

Eight weather stations in the citrus growing region of central Florida were selected that had reasonably complete data and relatively few changes in location. Those stations are shown on the Florida map in Fig. 2, and counties that had at least 10 000 bearing acres of citrus in 1980 are shaded on the map to show the region of interest. Daily minimum temperatures at these stations for 1931–85 were obtained from the National Climatic Data Center. Time series of monthly mean minima averaged over the eight stations were computed for December, January, and February. The three monthly series were then averaged to produce a time series of winter mean minima for central Florida, 1932–85.

The longest possible time series is needed to get a perspective on apparent changes in climate and the frequency of extreme events. Minimum temperatures were unavailable for years prior to 1931, so to enlarge the time-frame of the study, Florida monthly mean temperatures for 1895–1983, averaged over the state, were obtained from the National Climatic Data Center.

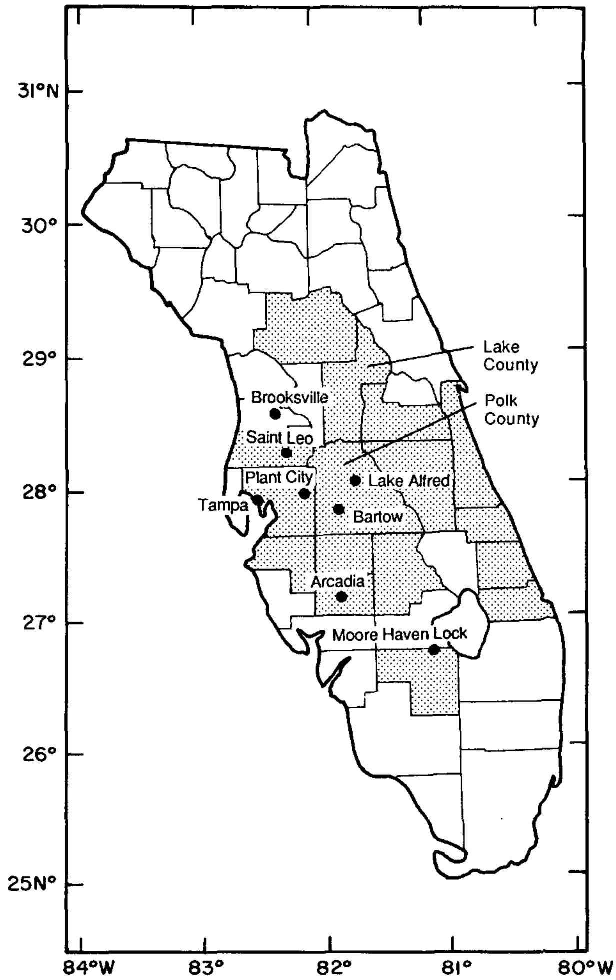

FIG. 2. Weather stations in central Florida. Shaded counties had at least 10 000 bearing acres of citrus in 1980.

The monthly means for December, January, and February were averaged to create a time series of mean temperatures for Florida, 1896–1983. (Throughout this paper, winters are identified by the year of their January–February.)

The winter season temperature series are shown in Fig. 3, with dashed lines showing the nine-year running means to highlight any underlying trends. In the longer record, 1896–1983, there is no apparent long-term trend; thus, speculation about unprecedented climate change in Florida is not supported. However, shorter trends are apparent in the series, including a cooling since approximately 1950. It is unlikely that growers in the 1980s would have had detailed knowledge of temperatures prior to 1940, since climate normals reported by the U.S. Weather Service were based on 30-year periods, 1941–70 or 1951–80. Thus, the shorter temperature series (Fig. 3b) indicates the information that was made available to growers, while the longer series (Fig. 3a) gives a more complete view of normal climate variation in the region.

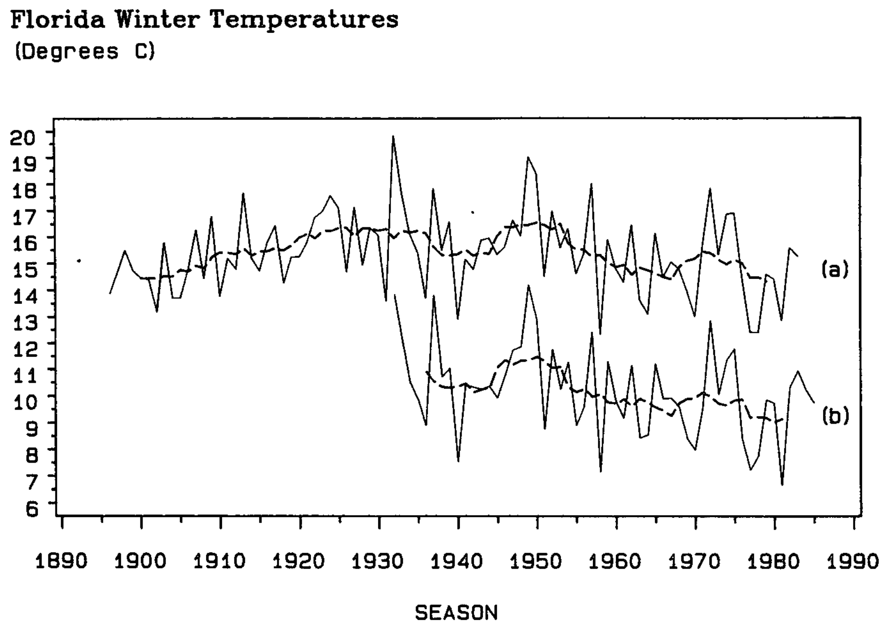

FIG. 3. Florida winter temperatures (°C). (a) Mean winter temperatures, entire state. (b) Mean minimum winter temperatures, eight central Florida stations. Dashed lines are 9-year running means.

b. Working definitions: Severe freeze season and local killing freeze

The freeze risk is highly location specific. Since the terrain in much of central Florida is rolling and studded with numerous lakes, there is often a great amount of spatial variation in temperatures during freeze events. Land in the vicinity of a large lake will often remain much warmer than locations a few miles away. In addition, during radiative freezes temperatures in low-lying "cold-pockets" will be much colder than on nearby slopes and ridge tops, whereas during windy advective freezes north-facing slopes and ridge tops will be particularly at risk. Since the temperature recorded at a local weather station represents only a single point in this varying landscape, groves in the vicinity of the station may suffer severe damage even when the temperature recorded at the station does not appear sufficiently cold to kill citrus trees.

The likelihood that a citrus tree will be killed during a cold event depends on several factors in addition to temperature. These include duration of the freeze, wind speed, the condition of the trees, and whether or not sprinklers or other cold protective devices are in use in the grove. Brey (1985) states that serious tree damage commences when temperatures below 24°F (−4.4°C) are sustained for at least 3 hours; however, the relationship between temperature and tree damage is complex, and damage thresholds are inexact. The damage threshold cited by Brey (1985) may be sufficiently cold to kill trees if it occurs when the trees are actively growing and not in a cold-hardened state or when the trees have been severely weakened by a previous freeze. Otherwise, the trees may be able to withstand much colder temperatures provided that they are not sustained for too long a period. The Institute of Food and Agricultural Sciences (IFAS 1985) found that the killing-point temperatures of several varieties of orange in Polk County (Fig. 2) fluctuate between about 23° and 20°F (−5.0° and −6.7°C) during a winter season.

For purposes of this paper, the definition of a severe freeze season should correspond to seasons of widespread severe tree damage in the citrus-growing region of Florida. The winters identified by the Florida Crop and Livestock Service as having widespread severe tree damage are listed in Table 3. During the 1931–85 period of our data, the winters appearing in Table 3 are precisely those in which the minimum temperature fell to −5.0°C or below at four or more of our eight central Florida stations. We will adopt that criterion as a working definition of a "severe freeze season" based on daily minimum temperature data. It is reasonably compatible with the findings of Brey and IFAS.

Table 3 shows that during 1885–1985 severe freeze episodes occurred most frequently in January (13), followed by December (9) and February (6). Widespread severe freezes occurred in November and March only once each, in 1940–41, and are not included in the table.

Our simplified example of investment risk focuses on the risk of a complete kill. The IFAS determination of killing-point temperatures of 20°–23°F indicates

TABLE 3. Winters of widespread severe freeze in Florida, 1886–1985.*

Winter (DJF) season**	Months of severe freeze
1886	J
1895	DF
1898	J
1899	F
1900	JF
1902	DJ
1905	J
1907	D
1910	D
1917	F
1918	D
1927	J
1935	DF
1940	J
1958	DJF
1963	D
1971	J
1977	J
1981	J
1982	J
1984	D
1985	J

* Freeze months identified by the Florida Crop and Livestock Service (undated and biennial series 1980–88).
** Winter season identified by January year.

that temperatures of approximately 20°F (−6.7°C) might be required to kill a substantial portion of a grove. Thus, for use in the investment risk example we define a "local killing freeze" as one in which the temperature drops to −6.7°C or below at a single station.

c. Relationship of freezes to mean temperatures

Sometimes severe freezes occur as isolated events—short cold spells in an otherwise average winter. More often, the average monthly and seasonal temperatures are low as well, indicating sustained cold weather patterns. Both cases can be seen in Table 4, which shows standardized deviations from mean and mean minimum temperatures in seasons that had severe freezes. Isolated freezes occurred in the winters of 1898, 1907, 1917, 1927, 1935, 1971, and 1984, although the mean and mean minimum temperatures deviated little from the long-term means. Sustained cold spells occurred in 1902, 1905, 1910, 1918, 1940, 1958, 1963, 1977, and 1981, when winter and monthly means and mean minima were substantially below the long-term means (by at least one standard deviation).

d. Annual freeze probabilities

The list of freezes (Table 3) shows that severe freezes recurred at 1–9-year intervals during the century 1886–1985, except for a 17-year gap from 1941 to 1957. Tree-damaging freezes were somewhat more frequent in the first 50 years (13 in 1886–1935) than in the second (9 during 1936–85); however, this comparison does not take the relocation of citrus groves into account. In Table 4 it would appear that the coldest winters of the first half-century (1902, 1905, 1910) were less cold on average than those of the second (1958, 1977, 1981); however, it is uncertain whether these temperatures are completely comparable since they have not been adjusted for station changes.

Estimated probabilities of a severe freeze season and of local killing freezes are shown in Table 5, based on freeze frequencies during 1932–80 and 1932–85. Taking the perspective of a grower facing a planting decision in the summer of 1980, before the recent series of devastating freezes, the regionwide estimated probability of a severe freeze season would have been 0.122, or about 1 widespread freeze in every 8 years. As of 1985, the probability of a widespread severe freeze, estimated over the period since 1932, had risen to 0.185, or more than 1 severe freeze in every 6 years, a substantial change in calculated risk.

Locally, the estimated probability of a killing freeze at Arcadia, Lake Alfred, and Plant City increased from 0.04 to 0.07, and at Saint Leo increased from 0.02 to 0.07 (bottom of Table 5). In Table 2 of the investment risk example, such a change in the risk of total kill would be sufficient to reverse the investment decision of an investor who used a 10% discount rate. A decision that was "correct" based on the information available in 1980 would have had a poor outcome as a result of unforeseen climatic conditions. This implies that individuals in 1985, having more information than their counterparts in 1980, could be expected to arrive at different investment decisions. This is an artificial example, of course, but it illustrates that changes, comparable to those seen in the 1980s, in the estimated probability of a killing freeze could make the difference between success and failure for a citrus grower.

This analysis suggests that the longest possible meteorological record should be used in assessing the risk of extreme events such as freezes. For many years, climatic normals reported by the U.S. Weather Service have been based on a 30-year time span, which is updated each decade. Climatic data provided to growers have been developed using the same 30-year periods. For example, 1941–70 data were used by Bradley (1983) to compute freeze probabilities for use in Florida agriculture—a period in which there were only two (or 7%) severe freeze seasons. Including records of the previous half-century provides a dramatically different view of the freeze risk. Because comparable minimum temperature data are not available for the early years, precise comparisons are impossible; however, a rough approximation illustrates the importance of considering the longer time span. From 1886 to 1980 there were 18 (or 19%) severe freeze seasons, and extending the period to 1985, there were 22% severe freeze seasons. The 1941–70 base period gives a serious under-

TABLE 4. Standardized deviations from long-term means in severe freeze seasons; D: Dec, J: Jan, F: Feb.

	Mean temperatures (T_F)				Mean minimum temperatures (T_{min})			
	Winter statistics (Florida 1895–1983)	Monthly statistics Dec	Monthly statistics Jan	Monthly statistics Feb	Winter statistics (eight stations 1931–85)	Monthly statistics Dec	Monthly statistics Jan	Monthly statistics Feb
Mean (°C)	15.4	15.4	14.9	15.7	10.2	10.6	9.6	10.3
Std dev (°C)	1.5	1.9	2.2	2.1	1.7	2.2	2.6	2.3

Winter (DJF) freeze season*	Standardized deviations from long-term mean: Winter	Coldest month	Winter	Coldest month
1895	—	F −2.2	—	—
1898	0.0	J 0.4	—	—
1899	−0.4	F −0.4	—	—
1900	−0.6	J −0.7	—	—
1902	−1.5	J −0.9	—	—
1905	−1.1	J −1.4	—	—
1907	0.6	D −0.1	—	—
1910	−1.1	D −1.3	—	—
1917	0.7	F −0.2	—	—
1918	−0.7	D −1.6	—	—
1927	1.2	J −0.1	—	—
1935	−0.0	D −0.1	−0.2	D −0.3
1940	−1.6	J −2.3	−1.6	J −1.8
1958	−2.1	F −2.2	−1.9	F −2.0
1963	−1.2	D −1.1	−1.1	D −1.2
1971	0.1	J −0.1	−0.4	J −0.3
1977	−2.0	J −2.2	−1.8	J −1.9
1981	−1.6	J −2.3	−2.1	J −2.7
1982	0.2	J −0.3	0.1	J −0.5
1984	—	—	−0.0	D 0.2
1985	—	—	−0.3	J −1.3

* Identified by January year.

estimation of the freeze risk. [Changnon and Changnon (1990) give another example of the danger of using a short data record to estimate the risk of a low-probability climatic event.]

A long record is needed to cover, as fully as possible, the range of climatic variability that produces low-probability extreme events. In Florida, updated estimates of freeze probabilities should encompass both the warm period of the 1940s and 1950s and the cool period of the 1980s.

5. The growers' response

The pattern of replanting activity by Florida's citrus growers suggests that the experience of the 1980s has resulted in the perception of an increased probability of freeze damage in the north-central growing areas. At the same time, growers in less freeze-prone areas appear to be very optimistic about the future profitability of citrus groves.

As of the 1988 Commercial Citrus Inventory (Florida Agricultural Statistics Service, biennial series 1988–90), damaged groves in the northern growing areas were being partially replanted, but the mix of varieties had shifted strongly toward early varieties such as Hamlins, which are harvested before the coldest months of winter. In the northern growing areas such as Lake County, many of these newly replanted groves were destroyed by the December 1989 freeze (Florida Agricultural Statistics Service, biennial series 1988–90). It is not yet clear what further impact this most recent freeze will have on growers' willingness to plant citrus in north-central Florida.

The vast majority of new planting is occurring farther south in areas considered relatively safe from freezes. Growers' optimism about future market conditions has led to very rapid planting of citrus in several south Florida counties. In fact, the total number of citrus trees in the state reached a record in 1990, but fully one-third of that total had been planted in 1987 through 1989 and were thus nonbearing at the time of the 1990 Citrus Inventory (Florida Agricultural Statistics Service, biennial series 1988–90). A large share of these newly planted trees are located in southerly areas such as Hendry County, south of Lake Okeechobee, where 4.9 million new citrus trees were planted in the 1987–89 period, more than twice the number planted in Polk County over the same period. Until recently, Polk County had the largest number of citrus trees in the state, but it was more heavily affected by the freezes than Hendry County and several other southern and southeastern Florida counties. In Hendry County,

TABLE 5. Frequency of severe freeze seasons* and local killing freezes** during winters of 1932–80 and 1932–85.

(a) Severe freeze

Station	1932–80 Total seasons	1932–80 No. of seasons ≤ −5°C	1932–80 Estimated probability	1932–85 Total seasons	1932–85 No. of seasons ≤ −5°C	1932–85 Estimated probability
Arcadia	48	9	.188	53	12	.226
Bartow	49	5	.102	54	9	.167
Brooksville	49	10	.204	54	14	.259
Lake Alfred	49	7	.143	54	11	.204
Moore Haven	49	2	.041	54	3	.056
Plant City	49	9	.184	54	13	.241
Saint Leo	49	8	.163	54	12	.222
Tampa	48	2	.042	53	5	.094
Regionwide severe freeze*	49	6	.122	54	10	.185

(b) Local killing freezes**

Station	1932–80 Total seasons	1932–80 No. of seasons ≤ −6.7°C	1932–80 Estimated probability	1932–85 Total seasons	1932–85 No. of seasons ≤ −6.7°C	1932–85 Estimated probability
Arcadia	48	2	.042	53	4	.075
Bartow	49	1	.020	54	2	.037
Brooksville	49	3	.061	54	6	.111
Lake Alfred	49	2	.041	54	4	.074
Moore Haven	49	0	0	54	0	0
Plant City	49	2	.041	54	4	.074
Saint Leo	49	1	.020	54	4	.074
Tampa	48	1	.021	53	2	.038

* Winter minimum ≤ −5°C at four or more of the eight stations.
** Winter minimum ≤ −6.7°C at an individual station.

nearly one-half of the citrus trees in commercial groves as of January 1990 had been planted in the previous three years. While Hendry County remained in third place behind St. Lucie and Polk Counties in terms of bearing citrus trees in 1990, it had moved into first place in terms of total trees (Florida Agricultural Statistics Service, biennial series 1990).

The rate of planting activity in other counties appears to be inversely related to the proportion of total citrus trees lost to the freezes of the 1980s (Miller 1991; Florida Agricultural Statistics Service biennial series 1988, 1990). In Lake County, for example, planting has been much less rapid than farther to the south.

Favorable fruit prices and growing world consumption of citrus products have contributed to growers' optimism and willingness to invest in groves in relatively freeze-free locations. Despite that apparent optimism, the strong relative shift in new plantings away from formerly important citrus-growing counties in north-central Florida suggests an increased wariness of the risk of freeze damage in those areas.

6. Conclusions

Freeze frequencies in the citrus-growing region of central Florida increased in the 1980s to a level that caused speculation about climate change and, temporarily at least, raised doubts about the commercial viability of citrus production in some areas. To address the speculation about climate change and to estimate the risk of low probability freeze events, the longest possible climate record is needed. Consistent station-level data for daily minimum temperatures are not available prior to 1931. However, freeze records and statewide mean temperature data indicate that the recent series of freezes is not unprecedented, with a similar series of cold winters occurring during 1895–1905. Prior to the recent freezes, the early data was largely ignored in published estimates of freeze risks. Use of the conventional 30-year climate record made the risk of freeze damage appear much lower than is indicated by a longer record.

Estimates of freeze risk based on 1932–85 daily minimum temperatures may appear unacceptably high for commercial citrus production over a substantial area of central Florida. The theoretical estimates of freeze risk and potential economic return presented above are consistent with the decisions of growers in the later 1980s to move groves from central Florida to southern Florida where initial costs are higher but the freeze risk is substantially less.

Given the virtual elimination of the groves in the northern part of the traditional citrus belt, the question now facing the owners of the destroyed groves is, What is the risk of another tree-killing freeze over the next 15 or 20 years? We have indicated that an estimate of the risk should be based on the longest possible climatic record. In the second paper, we look at climatic causes of cold periods in Florida and the prospects for understanding potential changes in the freeze risk.

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