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RISK REDUCTION AND VARIATION IN AGRICULTURAL ECONOMIES: A COMPUTER SIMULATION OF HOPI AGRICULTURE

Michelle Hegmon

INTRODUCTION

Risk is becoming an increasingly important factor in anthropological explanation. Cultural practices are often explained in terms of the advantages they provide, and one important advantage is the ability to cope with or to reduce risk. Foraging strategies (Winterhalder 1986a,b), settlement systems (Wiessner 1982a), the development of tribal social networks (Braun & Plog 1982), peasant morality (Godoy 1985, Scott 1976), decision making, agricultural and pastoral practices (Browman 1987, Cancian 1980), and modern American attitudes to-

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The different levels of social organization entail different degrees of interdependence. At the household, lineage, and clan levels there are strong obligations to exchange or share food, labor, and ritual services. Above the level of the clan, sharing is not obligatory, social relationships are characterized as nominal (Connelly 1979), and divisions are defined architecturally (Adams 1983). Hopi food sharing—prevalent within clans but restricted above the clan level—generally fits patterns described above for sedentary, nonpeasant societies. Sharing and other aspects of social organization provide means of buffering the variability inherent in Hopi production.

Subsistence

Hopi subsistence is broadly based, including not only corn but also beans, squash, gourds, wild plants and animals, and sheep-raising. Subsistence variety provides an important backup, but corn is *the* Hopi staple; 72 percent of farmland is devoted to it (Hack 1942:19). Corn is preeminent not only in subsistence but also in social and ritual contexts: "Plaques piled high with cornmeal are one of the commonest forms of payment in exchanges between households" (Kennard 1979:561). Furthermore, there is no substitute for corn in social and ritual contexts; therefore, if the harvest is poor, social failure may be felt even in the absence of nutritional deficiencies. The primacy of social and ritual failure is an important adaptation, since failure will be perceived socially (and perhaps rectified) before starvation sets in. Because of the importance of corn in all aspects of Hopi culture, the model used in this research includes only corn.

Conditions on the Hopi Mesas are generally sufficient for growing corn, but rainfall and growing season length are unpredictable and often limit productivity (Hack 1942). The average growing season lasts 130 days and is just sufficient for corn.[4] Rainfall is marginal and often limited in areal extend (Leopold 1942), but the Hopi obtain additional water through runoff and seepage.

The Hopi plant corn as early as March and as late as June, and they harvest the early crop in July and the main crop in September (Bradfield 1971:6; Titiev 1938). A number of factors affect the growth and productivity of corn, and many factors are highly variable from field to field and year to year and, thus, are essential to an understanding of variation and risk. Moisture is especially critical when the corn is beginning to sprout (approximately April through June, the driest season in Hopi country) and during pollination (in July and August, when rainfall is more common but still not predictable) (Bradfield 1971:5–6; Purseglove 1972). Corn is susceptible to spring frosts, which destroy seedlings, and to fall frosts, which stunt growth and reduce yield. Heavy storms, sometimes carrying hail, and swarms of grasshoppers damage fields. The Hopi adapt to this difficult environment in two general ways: (1) with agricultural techniques developed to take advantage of microtopographic variation, and (2) with a system that mitigates the effects of failure.

Hopi corn is adapted to arid conditions and can sprout even if no rain falls in the spring (Collins 1914). In addition, the Hopi maintain many varieties of corn—possibly kept distinct because of the ritual requirement to have pure colors of corn in ceremonial bundles (Ford 1980, Nequatewa 1946, Whiting 1937)—each suited to a slightly different microenvironment (Brown et al. 1952, Collins 1914).

Hopi agricultural techniques are also specially adapted to the environment. Various planting strategies take advantage of runoff or seepage from a broad area, so that water from limited or violent storms can reach the fields in a controlled manner. Five general kinds of Hopi corn fields are used in the simulation and are described below.

1. *Akchin* fields are set at the mouth of an arroyo and are watered by runoff. Proper placement of the fields is critical and may change every year (Hack 1942:29). Some failures of *akchin* fields are expected; too little water will not allow the corn to grow, while too much water will wash away the field or cover it with silt (Forde 1931:362). *Akchin* fields are the most common in the Hopi villages (Hack 1942:28).
2. Terrace fields are located on the low terraces just below the flood levels of large arroyos (Hack 1942:30). The water supply is regular, and, before the downcutting of the wash, these fields were considered the best corn land in Oraibi (Bradfield 1971:17). Terrace fields are not always reliable, however, since the water sometimes comes down the arroyos in violent and destructive surges (Hack 1942:30).
3. Arroyo bottom fields are planted in small arroyos and are precarious. The water supply—from the small arroyos—is undependable; it may be too little or come in too much force (Hack 1942:30).
4. Dammed, or *trinchera*, fields are also built in small arroyos, but with more care and a greater chance for success. These plots are planted on terraces created by a series of small dams built across arroyos. The water supply is not regular, but it can be controlled, and the arroyos provide good protection from spring frosts (Hack 1942:30).
5. Dune seepage fields do not receive runoff from arroyos. Instead, the fields are planted to take advantage of seepage through the massive sandstone reservoir of Black Mesa to the north. They do not receive large amounts of moisture, but neither are they susceptible to flooding (Hack 1942:32–34).

Despite the special agricultural techniques, not all fields yield each year. Hopi flexibility insures that at least some fields will yield and that the yield will be widely available. The scheduling and placement of fields provides one source of flexibility. Hopi households plant at different times and spread their planting from March to the summer solstice (Bradfield 1971:7; Titiev 1938). Thus, if there are no late spring frosts, the early fields will do particularly well; if there are late frosts, the early fields will be damaged and need to be replanted, but the damage will be limited and other fields will yield. The distribution of different kinds of fields is similarly advantageous. In low-moisture years, terrace fields have a good chance of yielding; in years with high rainfall, the terrace fields often flood while dune seepage fields do well. Furthermore, depending on the exact placement of the rainfall, some arroyos run and others remain dry in any particular year.

A second aspect of Hopi flexibility involves the social organization. Household fields are scattered, that is, each clan has land in several areas and each household has several different fields (Hack 1942:18; Kennard 1979:554). The scattering of fields is maintained in part because of the strongly lineal organization and matrilineal inheritance of land (F. Plog 1978) and by the ritual need to maintain pure strains of corn (Ford 1980). This distribution of fields increases the chance that each household will have access to some good yields. Corn is also shared among households, but—because it is distributed in many different, often small-scale social contexts—the extent of sharing cannot be determined from ethnographic accounts. The purpose of my research is to investigate the effects of sharing practices and other strategies of risk reduction.

THE SIMULATION OF HIGH-RISK AGRICULTURE

I use computer simulation to model highly variable agricultural production and to examine how various social strategies—involving consumption and distribution—affect the risk of not having enough food. The simulation is based on Hopi data, as summarized above. It was written in Turbo Pascal 3.0 (Borland 1985) for a Zenith 150 personal computer. The first part of the simulation models production and is described in this section.

The basic unit in the Hopi economy and in the simulation is the extended-family household. Households differ and change over time, but the differences are equalized to some extent because several generations live together in an extended family. Furthermore, social expectations do not promote inequalities in production or consumption. Therefore, in the simulation, households are assumed to be effectively equal in their needs and production capabilities. Each household consists of seven members: an elderly married couple, a married couple of child-bearing age, and three children under the age of ten.

Simulated households plant 3.15 ha of corn,[5] divided among three fields.[6] Each household has two *akchin* fields (totalling 80–90 percent of the household's area) and a third field that is either terrace, dammed, arroyo bottom, or dune seepage. Since land around arroyos is limited, the terrace, dammed, and arroyo bottom fields comprise only 10 percent of a household's field area, while dune seepage fields comprise 20 percent. The simulation begins by randomly assigning each household a set of three fields (Table 1).

Table 1. Simulation of Sets of Fields[a] and Expected Yields of Corn Under Average Conditions

	Field Types and Areas (ha)			
Set	*Field 1*	*Field 2*	*Field 3*	*Total Corn Yield (kg)*[b]
1.	akchin (1.42)	akchin (1.42)	terrace (0.32)	1633
2.	akchin (1.42)	akchin (1.42)	dammed (0.32)	1633
3.	akchin (1.42)	akchin (1.42)	arroyo bottom (0.32)	1633
4.	akchin (1.26)	akchin (1.26)	dune seepage (0.63)	1527

[a]Each simulated household is randomly assigned one set.
[b]Based on yields of 500 kg/ha for akchin fields, 667 kg/ha for terrace, dammed, and arroyo bottom fields, and 425 kg/ha for dune seepage fields.

Expected yields of the fields are first estimated for average rainfall and growing season conditions. The simulated average yield for *akchin* fields is 500 kg/ha, based on repeated appearance of this figure in the literature (Spielmann 1982, Trigg 1984, Wetterstrom 1976). Dune seepage fields receive less water, so Wetterstrom's (1976) estimate of 425 kg/ha for dry fields on mesa top is used here. Terrace, dammed and arroyo bottom fields generally are better watered, so Ford's (1968) estimate of 667 kg/ha for irrigated Indian corn is used. Expected average yields for the simulated fields are shown in Table 1.

The majority of the first part of the simulation is used to generate variation in the average yields. Two general sets of factors are considered: (1) weather conditions that affect corn's growth and, thus, the *baseline yield*; and (2) other factors that damage crops and subtract from the baseline.

Variation due to weather conditions depends on rainfall and its timing, growing season length, and the probability that these factors will affect a specific field (e.g., will this arroyo run?). Rainfall is interpreted as a measure of the amount of water available to the fields from runoff and seepage, as well as from direct showers. Annual rainfall and growing season length are entered, and the simulation determines the variable effects of the weather conditions on the fields using probabilities and computer generated random numbers. Since rainfall in July and August is the most critical to the growth of corn, only rainfall in these months is taken into account. The growing season is the number of days from the last frost

Figure 1. Mean Yields (kg of corn), 1932–1951

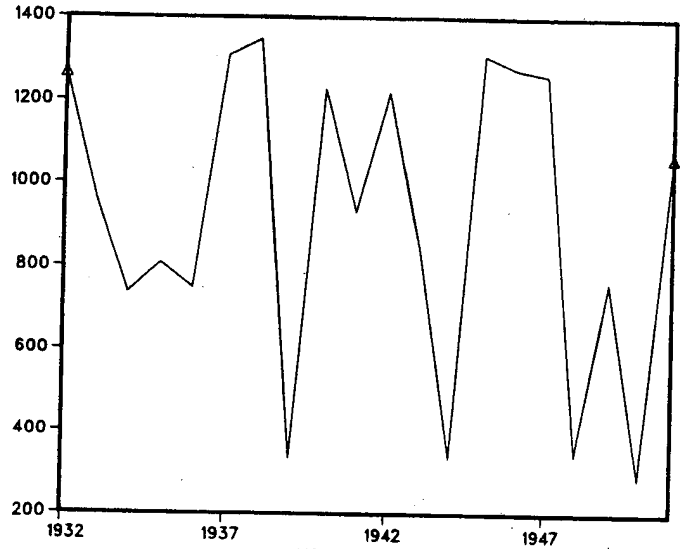

Figure 2. Mean Yields (kg of corn), 1952–1972

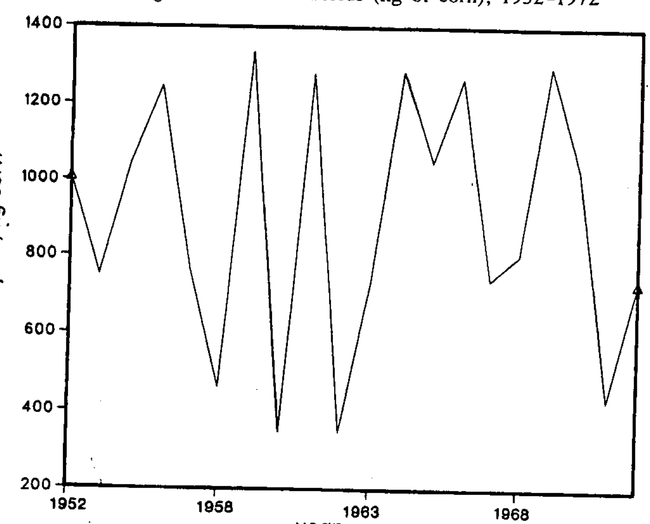

Table 12. Insufficient Annual Household Yields at Different Thresholds

	Years below Threshold[a]			
	1932–1951		1952–1972	
Threshold[b]	In a Row	Total	In a Row	Total
1017 kg	4	11	2	11
μ − sd	1	4	1	3
μ − sd/2	1	4	1	4
μ − sd/4	3	7	2	9
μ	3	9	2	10
μ + sd/4	4	11	2	11
μ + sd/2	4	12	3	14
μ + sd	20	20	20	20

[a]Maximum years in a row and total number of years that the average annual yields of households' fields (Table 11) are below the given threshold.

[b]Thresholds are based on average annual yields for the period (Table 8). For 1932–1951 the mean is 919 kg of corn, with a standard deviation of 461; for 1952–1972 the mean is 899 kg, with a standard deviation of 442.

defined as only one year below the threshold, then the number of bad years in a row is not a critical factor. Households may be able to survive one year of low yield if they—or their sharing partners—have substantial stores, but if they experience a second bad year they will fail, regardless of the number of bad years that follow. On the other hand, if household failure is defined as three years in a row below the threshold, the number of bad years in a row is more critical. A household that fails with three years in a row below the threshold would have a greater chance of survival in the second period, when overall variation or variance is greater but good years often follow bad.

SUMMARY AND CONCLUSIONS

This essay has explored risk, and cultural means of reducing risk, through research with a simulation of a highly variable agricultural economy, derived from data on the Hopi. Three basic strategies for organizing consumption and distribution were compared and their potential for reducing risk under a variety of circumstances was assessed. The strategies—independence, pooling, and restricted sharing—all included scattered fields and storage as buffering mechanisms; they differed in that one strategy included no interhousehold sharing and the other two strategies included different degrees of sharing.

Restricted sharing was consistently the most effective strategy for reducing risk, and any degree of sharing was more effective than independence. Only under the most dire circumstances—when the risk threshold was high, when one year under the threshold meant failure, and when no more than seven percent of the households survived—was independence the most advantageous strategy. The buffers worked to reduce variance, but reduced variance did not always translate into reduced risk. The effects of the buffers also depended on their ability to function year after year; storage, for example, was unreliable, because it could be depleted in one bad year. Comparison of the simulation results in two time periods demonstrated that risk depends on the pattern of variation at least as much as on the average variation or variance.

Variation was an important but seemingly inconsistent factor throughout the analyses. Some researchers have suggested that low average variation (variance) should result in low risk, but the pooling strategy, which produced the lowest variance, did not result in the lowest risk. Foraging theory predicts that high variance will be beneficial when the mean is below the risk threshold; this theory possibly explains only the extreme case in which household independence is the only chance for survival under very dire circumstances. Neither theoretical perspective explains the consistent advantage of restricted sharing, the strategy that produced an intermediate degree of overall variation.

One conclusion to draw from these results is that, in order to reduce risk, it is not always necessary to reduce variation but merely to cope with the variation and survive the bad years. Thus, the advantage of restricted sharing over complete sharing can be explained. Restricted sharing includes a system of buffers that protects most, if not all, households against bad years and failure; complete sharing reduces variance but it is not as effective in preventing failure. The ability to cope with variation is termed resilience, defined by Holling (1973:14) as a measure of "the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationship between populations or state variables" (see also Vayda & McCay 1975). Variation is common in resilient ecosystems.

Resilience is contrasted with stability, "the ability of a system to return to an equilibrium state after a temporary disturbance" (Holling 1973:14). Adams (1978) compares the long-term survival of resilient small-scale tribal or semi-nomadic societies and the rise and fall of "stable" states, including Ur (see also F. Plog 1983, Stuart & Gauthier 1981). In these terms, the flexible Hopi clans can be characterized as resilient rather than stable. The simulated restricted sharing strategy (similar to strategies used by tribes and Hopi clans) is resilient in that it can absorb change (including the loss of some households), cope with variation, and allow most households to survive. The simulated strategy of pooling is better characterized as stable. States and groups that pool share at least one important property: the parts are closely interrelated, so that failure in one part may bring down the system or cause the group to fail (see Flannery 1972, on hypercoherence).

The second conclusion of this research is that, in assessing risk, both the pattern and the degree of variation are important variables. Studies of risk often mention the importance of understanding not just average conditions, but the maximum, minimum, and variation in the conditions. Similarly, variation cannot be evaluated fully with measures of variance or average variation. Comparison of the simulation results in the two time periods showed that, depending on the level of the risk threshold and temporal dimensions of failure, the number of bad years in a row can be a more critical variable than an absolute measure of variance. Furthermore, sharing, particularly restricted sharing, was successful at reducing risk because it persisted as a buffer even in multiple bad years. Thus, reductions in variation are not always necessary in order to reduce risk. The most effective risk-reduction strategies provide means for coping with variation, including multiple bad years.

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NOTES

1. Some foraging theory studies also employ another definition of risk, equating it with variance. According to this definition, organisms that pursue strategies involving high variance are risk-prone and those that pursue low variance strategies are risk-averse (Real & Caraco 1986). Following Winterhalder (1986b:207), I assume that organisms (with the possible exception of human adolescents) are risk-averse and that strategies may be either variance-prone or variance-averse.

2. Stephens & Charnov (1982) also argue that this model, known as the extreme variance rule, does not work neatly in nature because the mean and variance both vary, and a general relationship between mean and variance cannot be specified.

3. Following traditional usage in the American Southwest, the term corn is used to refer to maize, or "Indian corn."

4. The growing season on the Hopi Mesas is adequate for corn every year, according to Adams (1979:293), who argues that evidence for short growing seasons is based on weather data from canyons subject to cold air drainage. However, Adams' analysis is based on only one full year of weather data. Therefore, I continue to use Hack's (1942) figures. Means of accounting for cold air drainage in the simulation data are discussed further below.

5. The figure of 3.15 ha/household is based on an estimate of 0.45 ha/person. The literature on pueblo agriculture provides a range of estimates, from 0.29 ha corn/person at San Juan Pueblo (though corn and wheat acreage totaled 0.46 [Ford 1968]) to 0.6 ha/person for lean years in the Mimbres area (Minnis 1985). E. Beaglehole (1937:36) estimated 0.4 ha/person on Hopi Second Mesa, and in prefission Oraibi, a population of 880 had 372 ha under cultivation (Bradfield 1971:19,30) for a mean of 0.42.