Chapter 17

Safety first, gambling, and the subsistence farmer

Part V

The role of risk in agriculture
Chapter 12

Safety-first, gambling, and the subsistence farmer*

Howard Kunreuther and Gavin Wright

1. INTRODUCTION

Recent developments in economics have emphasized the importance of hierarchical goals in consumer and organizational decision making. On the theoretical level, pioneering articles by Georgescu-Roegen (1954), Chipman (1960) and Encarnacion (1964) have indicated that a lexicographic ordering may be a more appropriate way of structuring a class of decisions than by using a cardinal utility framework.

A number of examples have been cited by these authors and others to illustrate the validity of this approach. These illustrations have an appealing ring to them but they have not been supported by solid data. For example, Baumol (1967) postulates that firms tend to maximize sales subject to an acceptable profit constraint. Lintner (1956) and Meyer and Kuh (1957) explain investment decisions as a residual after the established dividend payments have been met. Reder (1947) and Shubik (1961) both allude to the firm’s concern with meeting other corporate aims aside from maximizing profits.2

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1 Fishburn (1972) presents an excellent survey of the literature on the theory of lexicographic orders and its use in models of preference and choice.

2 Shubik (1961) suggests that a firm may want to maximize profits subject to maintaining a specific growth program, dividend rate and employment policy which will satisfy stockholder and employees sufficiently that they do not act to change the firm’s environment.
Day, Aigner and Smith (1972) examine the effects of such constraints on the optimal pricing and output policies of both the monopolist and firms in a purely competitive industry.

The behavioral science and organization theory literature reinforce these conjectures that decisions are frequently guided by short-run goals and constraints rather than long-run objective functions. Simon (1955), in a seminal piece, argues that in actual choice situations, man has a difficult time making the computations required to maximize some objective function. Furthermore, it may be very difficult for him to gather the information necessary to make these decisions. Simon thus introduces the concept of an aspiration level which serves as a reference point for feelings of success or failure and may lead to satisficing behavior. Using these behavioral notions, Winter (1971) develops a model of a competitive industry in which firms satisfy in the short-run. He shows that this behavior can still lead to an industry long-run equilibrium position which is identical to that predicted by orthodox theory. Radner (1975) has recently developed a model of satisficing in an uncertain environment which incorporates short-run goals and the search for improvement. He then applies these models to the analysis of cost reduction and technical change.

In conjunction with these attempts to link behavioral theory to orthodox theory, there has also been a growing appreciation by social scientists of the limitations of man in processing probabilistic information and judging uncertainty. Slovic, Kunreuther and White (1974) summarize recent laboratory and field research illustrating the inability of the decision maker to think in probabilistic terms and to bring relevant information to bear on his judgments. These findings also reinforce the notion that for certain classes of decisions, individuals and firms may focus on short-run goals and follow a lexicographic or sequential process.

A principal purpose of this paper is to provide empirical evidence supporting the concept of lexicographic ordering and indicating why it may be preferable to the Von Neumann-Morgenstern cardinal utility function for a certain class of problems. To do this, we have focused on the plight of the low income farmer who has to allocate land to different crops but faces a short-run consumption constraint. The next section provides empirical evidence that low income farmers gamble in their crop growing decisions. We then develop a framework based on a lexicographic ordering for explaining such behavior. Data on small farms in Bangladesh illustrate how to estimate the critical parameters for this model, and historical evidence on the 19th century South indicates that the model is superior to the Von Neumann-Morgenstern utility function for interpreting behavior. The paper concludes with a discussion of policy implications of this approach.

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3 See in particular, Cyert and March (1963) for a more detailed discussion and other illustrations of this point.
2. FRAMEWORK OF ANALYSIS

Recent papers discussing the plight of the low income farmers hypothesize that their small land holdings cause them to risk averse in their crop planting decisions. The conventional wisdom has been that fluctuations in prices and yields lead small farmers to grow a larger proportion of their land with food crops which promise a lower expected return than the cash crop. In apparent contrast to these analyses, there is in fact empirical evidence that in many cases, farmers with the smallest holdings of land plant a larger percentage of their land with cash crops than those with somewhat larger farms, often a percentage comparable to that of the very largest enterprises. Table 12.1 presents illustrative data for three such cases: jute planting in Mymensingh (the largest jute growing district in Bangladesh), Nigerian cocoa farming, and cotton farming in the late nineteenth century in U.S. South. The appearance of the U-shaped pattern in such disparate situations suggests that an explanation of some generality is called for.

It is easy to understand that high-income farmers are in a position to grow a larger proportion of their land with the crop having the highest expected return despite the concomitant higher variance, but why does the lowest income farmer want to gamble? One possible explanation is that the farmer has a Von Neumann-Morgenstern utility function which decreases sharply at some critical income level so that he prefers to gamble in order to avoid poverty. Such behavior is the obverse of that postulated by Friedman and Savage (1948) where the individual gambles in order to become wealthy. The principal difference is that the Friedman-Savage individual who loses the lottery can survive without taking drastic action while the farmer who does not have enough to feed his family is forced to borrow or starve.

As an alternative, we develop an extremely simple model based on a lexicographic preference order to explain gambling behavior on the part of the low income farmers. The importance of short-run goals in the decision making process is consistent with the general characterization of subsistence farmers as persons who are unable to bear substantial risk. Indeed, our model generates gambling behavior by maintaining the same psychological assumptions as earlier papers on peasant behavior. The approach has a further advantage in that it more closely corresponds to the terminology of "real" farmers and, hence, may be more amenable to survey techniques at the micro level.

4 See, for example, Falcón (1964), Mellor (1966), Boussard and Petit (1967), Behrman (1968) and Lipton (1968).

5 Masson (1974) has hypothesized that the utility function might have a kink at the critical income level. He then presents evidence for this hypothesis, using data by O'Mara (1971) on diffusion of technology in a Mexican farm project.

6 Roumasset (1973) has used a similar approach to model the choice-of-technology by low-income farmers.
<table>
<thead>
<tr>
<th>Acreage Class</th>
<th>Bangladesh (Mymensingh District)</th>
<th>Nigeria (96 Farms)</th>
<th>U.S. South (1880)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Per cent of Land</td>
<td>Per cent of Land</td>
<td>Per cent of Land</td>
</tr>
<tr>
<td></td>
<td>Cash crop (jute)</td>
<td>Food crop (rice)</td>
<td>Acreage Class</td>
</tr>
<tr>
<td>0.0–0.49</td>
<td>39.1</td>
<td>60.9</td>
<td>0–1.99</td>
</tr>
<tr>
<td>0.5–0.99</td>
<td>28.8</td>
<td>71.2</td>
<td>2–3.99</td>
</tr>
<tr>
<td>1.0–2.49</td>
<td>24.5</td>
<td>75.5</td>
<td>4–6.99</td>
</tr>
<tr>
<td>2.5–4.99</td>
<td>23.8</td>
<td>76.2</td>
<td>7–9.99</td>
</tr>
<tr>
<td>5.0–7.49</td>
<td>24.5</td>
<td>75.5</td>
<td>10–12.99</td>
</tr>
<tr>
<td>7.5–12.49</td>
<td>24.8</td>
<td>75.2</td>
<td>13–15.99</td>
</tr>
<tr>
<td>12.5 &amp; Over</td>
<td>26.3</td>
<td>73.8</td>
<td>16 &amp; Over</td>
</tr>
</tbody>
</table>

Safety-first and subsistence

At the outset, the point deserves emphasis that the cash crop is in fact the risky choice for a subsistence farmer in almost all cases. This relationship is not the result of a perverse quirk of nature, but is inherent in the process of exchange. A farmer who buys his food must consider the yield variance of the cash crop as well as the price variance for both crops; for the farmer who grows and consumes his own crop, only the yield variance is relevant. For example, in Bangladesh, the ratios of standard deviations of jute to rice are between two and three for different regions of the country (Table 12.2). In the nineteenth century South, the standard deviation of corn obtained in exchange for cotton at market prices was four to five times as great as that of corn grown at home.\footnote{Empirical estimates of this ratio are documented in Wright and Kunreuther (1975).} Hence, the simple model developed here has general applicability, whenever the major cash crop is not also a food crop.

Consider a farmer with present wealth ($W_0$) which can be allocated to activities $x$ and $y$ (e.g., rice or corn) next period. The value of $W_0$ consists of a certain amount of land as well as labor and capital, and his decision governs the amount of land devoted to the subsistence crop such as rice or corn ($x$) and the cash crop such as jute or cotton ($y$).

The individual is assumed to allocate his initial wealth ($W_0$) in such a way as to maximize some objective function (e.g., expected return) but he has certain goals which may constrain his behavior. For example, a farmer may want to maximize the expected return from his land but has certain minimum requirements which may be critical to his future survival as well as desired cash reserves which he would like to have on hand at the end of the season. The individual is assumed to be able to rank these goals in order of importance to him, with 1 being the most important goal and $R$ the least. In this two-goal example, the subsistence requirement would normally be ranked number 1.

The possible outcomes of each goal, $i$, are given by a random variable $Z_i$ with predetermined target value $Z_i^*$.\footnote{For example $Z_i^*$ may be the random variable “net return per unit of land” and $Z_i$ may be the “minimum required return per unit of land” as determined by minimum food requirements over the course of the year.} For each goal, $i$, the decision maker is assumed to be willing to tolerate a maximum risk level, $\alpha_i^*$ that $Z_i < Z_i^*$. As shown in the next section, the value of $\alpha_i^*$ can be determined by cost considerations, such as the differential between lending and borrowing costs for the small farmer, or by some personal preference function.

Given these assumptions, an appropriate model to describe an individual’s behavior in allocating his land to two different crops would be

\[
\begin{align*}
\text{Maximize} & \quad E \{W_1\} \\
\text{subject to} & \quad \text{Probability} \left[ Z_i < Z_i^* \right] \leq \alpha_i^* \quad i = 1, \ldots, R.
\end{align*}
\]
A decision rule based on a lexicographic order suggests that the farmer modifies his constraint set by using a system of priorities dictated by the relative importance of each of the goals, low-numbered goals being more important than high-numbered ones. If he cannot satisfy all goals, he first accepts a lower probability of achieving goal $R$ than any of the others. His modified objective is thus:

Maximize Probability \( [Z_{r} > Z_{r}^*] \)

subject to Probability \( [Z_{i} > Z_{i}^*] \) \( \leq \alpha_i \), \( i = 1, \ldots, R - 1 \). \(^9\)

If there is still no feasible alternative, then goal $R - 1$ is relaxed and the first $R - 2$ constraints are maintained, and so on down to the last possible case where the objective function is minimize Probability \( (Z_i < Z_i^*) \). In terms of the Arrow-Debreu state-preference formulation, this approach implies that for each goal, $i$, there is a critical state of the world $Z_i^*$, towards which the decision maker is aiming. Given uncertainty, he is assumed to tolerate some maximum risk level, $\alpha_i^*$, that future wealth will fall below this state of the world. If the set of goals are estimated subsistence requirements during each of the next $R$ periods, then a lexicographic preference order is a reasonable decision rule for the farmer to follow.

The lexicographic approach implies that a behavioral kink exists at a critical income level; the kink may be due to either psychological or economic factors, rather than a generalized rate-of-preference for goods. Psychological factors, such as losing face by having to borrow, encourage individuals to focus on a short-run consumption goal. Similar incentives exist if there are imperfections in the capital market so that the cost of borrowing for low income farmers is extremely high. Empirical evidence on the point has been documented by Long (1968). Masson (1972) has shown that such imperfections with or without transaction costs lead risk-neutral individuals to behave as if they were risk-averse. He has not examined the case, considered in this chapter, where an individual must borrow if his income falls below a critical level.

Day and Robinson (1973) have shown that such a model possesses the continuity properties required for the existence of general economic equilibria among individuals, each of whom has many goals, and that this behavior can

\(^9\)If the objective function does not have a unique maximum and yields more than one feasible solution, then ties are resolved by choosing the portfolio which maximizes the Probability \( (Z_j > Z_j^*) \). If ties still exist, then goal 2 is investigated, etc.
be rationalized by a utility function of the usual kind. They also point out that in practice, it may be impossible to construct such a utility function so that the explicit consideration of the lexicographic preference order may be the only practical alternative.

3. APPLICATIONS TO CROP ALLOCATION DECISIONS IN BANGLADESH

In this section, we provide empirical estimates of minimum consumption requirements (Z*), show how to determine maximum acceptable risk levels (a*) and then utilize a simple one goal model to classify jute-rice farms in Bangladesh into gambling and safety first regions.

In Bangladesh, farmers must decide how much of their land should be allocated to jute and the aus variety of rice. These crops are predominantly grown on relatively small owner-occupied farms, the average size rarely exceeding ten acres with three to six acres being the most common plot. Aus rice is sown between the middle of February and the middle of April while jute is planted between early March and early May. Both crops are harvested between July 1 and early October. In general, land, labor and equipment are readily interchangeable between the two. There is some land suitable only for rice and jute alone, but for most land, a decision must be made between a subsistence crop (rice) and cash crop (jute).

To illustrate the rationality of gambling behavior on the part of the subsistence farmers, it is only necessary to introduce a single short-run goal—a desired level of rice to feed one's family next year.

For analysis purposes, it is most convenient to express the crop returns and the minimum consumption requirement in terms of rice per acre since this is the critical constraint. Letting \( X \) and \( Y \) represent the net returns from rice and jute, respectively, define

\[
X = r
\]

\[
Y = (jP_j - C)P_r
\]

\( 10 \) According to the 1960 Pakistan Census of Agriculture, approximately 60 per cent of all Bangladesh farms were owner-operated and another 37 per cent were owner-cum-tenant. The owner-operated farms contained 82 per cent of total land area. For a more detailed discussion of the structure of agriculture in Bangladesh, see Khan (1972), pp. 38-56. For a more detailed description of the economic characteristics of these farmers who grow jute and rice and the importance of the subsistence constraint, see Rabbani (1965), *Economy of Jute* (1966) and Hussain (1969).
where

\[ j = \text{yield of jute per acre (in maunds)} \]
\[ r = \text{yield of aus rice per acre (in maunds)} \]
\[ P_j = \text{price of jute per maund at the grower's level (in rupees)} \]
\[ P_r = \text{current retail price of rice per maund (in rupees)} \]
\[ C = \text{cost differential per acre of growing jute rather than rice (in rupees)} \]

Using (1) and (2) and assuming constant returns to scale, the allocation model is

\[
\text{Maximize } E\{mX + (1-m)Y\} \quad (3)
\]

subject to Probability \( mX + (1-m)Y < Z^* \) \( \leq \alpha^* \) \quad (4)

\[ 0 \leq m \leq 1 \]

where \( Z^* \) represents the minimum consumption level in rice per acre.

Those farmers having large parcels of land or other outside income have a sufficiently low value of \( Z^* \) so that they can satisfy the minimum consumption constraint given by (4) by maximizing (3). Let \( A_{\text{max}} \) represent the acreage size above which the farmer is not constrained by (4). Farmers with land holdings below \( A_{\text{max}} \) have a value of \( Z^* \) sufficiently high that they are forced to sacrifice some expected return in order to reduce the variance and will determine their crop allocation pattern by the minimum return constraint. These farmers are designated as safety-first farmers to indicate that their decision is based first on satisfying a predetermined safety level (\( \alpha^* \)).

The poorest farmers may find that no crop allocation pattern yields a feasible solution as specified by (4). If \( Z^* \) remains fixed, as assumed here, then such a farmer is forced to raise his acceptable risk level above \( \alpha^* \) and thus grows more of the high return-high variance crop. These farmers are appropriately designated as gamblers. Let \( A_{\text{min}} \) represent the acreage size below which the farmer is forced to gamble. For any given value of \( \alpha^* \) a sufficient increase in \( Z^* \) (e.g., a decrease in available land) causes the minimum return constraint to be operative. Similar behavior is observed if \( Z^* \) remains constant and \( \alpha^* \) decreases. Relatively high required returns (\( Z^* \)) combined with relatively low acceptable risk levels (\( \alpha^* \)) leads to gambling behavior.

To determine what region the farmer is in if his acreage is below \( A_{\text{max}} \) simply allocate land so as to satisfy the following objective function:

\[
\text{Minimize } \left\{ \text{Probability } [mX + (1-m)Y < Z^*] \right\}. \quad (5)
\]

\[ 11 \text{ One maund equals 82.29 pounds.} \]
\[ 12 \text{ Note that this definition of safety-first differs from the one used by Roy (1952).} \]
Designate the resulting risk level as $\alpha^*$. If $\alpha^* < \alpha^*$ then there is some portfolio of activities which satisfies both $Z^*$ and $\alpha^*$, and the farmer is a safety first man. By definition, his acreage is between $A_{\text{min}}$ and $A_{\text{max}}$. If $\alpha^* > \alpha^*$ the farmer gambles by setting $\alpha^* = \alpha^*$ and utilizes the crop allocation pattern specified by (5).

Table 12.2 provides estimates of the means and standard deviations of jute and rice for the eight largest jute growing districts in Bangladesh, using published data on agricultural yields and prices from 1947-70.\(^{13}\) The current retail price of rice per maund is assumed to be 37.5.\(^{14}\) Based on a 1969-70 survey of 142 farms in the Mymensingh district (see Khan, 1970) the cost

\[\begin{array}{|c|c|c|c|c|c|}
\hline
\text{Region} & \text{Rice (} X \text{)} & \text{Jute (} Y \text{)} & \text{Coeficient of } & \text{Correlation} \\
& \mu_x & \sigma_x & \mu_y & \sigma_y \\
\hline
\text{Dacca} & 76 & 9.69 & 1.56 & 9.72 & 3.32 & .53 \\
\text{Faridpur} & 100 & 8.06 & 1.24 & 8.51 & 3.31 & .27 \\
\text{Mymensingh} & 88 & 9.29 & 1.50 & 9.31 & 3.54 & .49 \\
\text{Comilla} & 89 & 9.40 & 1.38 & 9.45 & 3.27 & .22 \\
\text{Rangpur} & 59 & 9.60 & 1.35 & 9.63 & 3.53 & .50 \\
\text{Bogra} & 64 & 9.05 & 1.69 & 9.08 & 3.37 & .61 \\
\text{Pabna} & 100 & 8.55 & 1.68 & 8.72 & 4.31 & .50 \\
\text{Jessore} & 55 & 9.98 & 1.46 & 10.00 & 3.14 & .47 \\
\hline
\end{array}\]

Source: Bureau of Agricultural Statistics in East Pakistan (1947-70).

\(^{a}\)Cost differential of growing jute rather than rice.

\(^{b}\)Maunds of rice per acre.

\(^{c}\)Equivalent maunds of rice per acre.

\(^{13}\) A more detailed discussion of statistical data for analyses of the jute-rice planting decision appears in Kunreuther (1972). Data for the Faridpur district indicate that the normal distribution is a good approximation for $X$ and $Y$ and this assumption will be maintained here for convenience.

\(^{14}\) A 1970 survey of rice prices in Bangladesh (see Efferson, 1971) indicates that farmers in villages were paying anywhere from 35 to 40 rupees per maund for rice. For purposes of this analysis, we utilize a value of $P_r = 37.5$. Since rice prices have followed an upward trend since 1957 we have assumed that only the current price of rice affects the farmer’s crop growing decision. For further discussion on this point, see Kunreuther (1972), p. 15.
differential, $C$, between growing rice and jute was found to range between 28 and 110 rupees, depending on surplus manpower on farms and quality of the land. Setting an upper limit of 100, the value of $C$ for each district was chosen so that the expected return of jute was only slightly higher than for rice. Given the considerably higher variance for jute than rice, there would then be little incentive for risk-averse farmers to grow jute on homogeneous land unless their utility curve had some kinks in it.

Estimates of $Z^*$ were obtained from data assembled by Islam (1966) in his analysis of rural family budgets for seven income groups in Bangladesh based on the 1960 National Sample Survey. Total expenditures for the lowest income group indicate that they required an equivalent of 26.15 maunds of rice per year for survival. This value is utilized as a basis for determining those farmers who are forced to gamble. Safety first farmers, on the other hand, are likely to have minimum consumption levels which increase as a function of acreage size. For these farmers, we have permitted their minimum consumption requirement to increase up to 61.2 maunds of rice per year (the equivalent expenditure for the median income group in Islam’s analysis) so as to obtain a crop allocation of jute and rice which matches the actual distribution based on 1960 agricultural data. The higher value of $Z^*$ is also consistent with the notion of aspiration level as defined by Simon (1955).

The acceptable risk level $\alpha^*$ depends upon the farmer’s options should his returns fall above or below $Z^*$. One possibility is for the tenant to borrow rice from his landlord at a relatively high interest rate, payable in maunds of rice next year. The one-period newsboy model utilized in the inventory theory provides a good approximation for $\alpha^*$ in this case. If the farmer had a good year so that his return per acre exceeded $Z^*$, then he incurs a per unit holding charge ($h$) representing the opportunity cost associated with growing more rice than required. Similarly, if a poor year forced him to borrow rice he incurs a per unit shortage cost ($s$). In the optimal solution to the newsboy model there is a simple correspondence between the acceptable risk level and the ratio, $s/h$. Specifically,

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15 The per capita monthly total expenditure for the lowest income group was 15.42 rupees. Since average family size was 5.3 and $P_r = 37.5$ rupees this is equivalent to household expenditure of 26.15 maunds of rice per year (see Islam, 1966).
The minimal differentials in expected return between jute and rice specified in Table 12.1 and the high costs of borrowing by subsistence farmers imply a large $s/h$ ratio. The subjective “shortage cost” may in fact be very much higher than in this illustration, if the ability to borrow at all is uncertain, or if a shortfall may involve the loss of property or tenure status, or social embarrassment. For this example, $\alpha^*$ has been arbitrarily assumed to be .025.

Based on these estimates of $Z^*$ and $\alpha^*$ and the means and variances in Table 12.2, we determine critical acreage sizes for classifying farmers in Bangladesh. Households whose farm size is less than $A_{\text{min}}$ acres are gamblers while those whose plots range from $A_{\text{min}}$ to $A_{\text{max}}$ are safety-first farmers. Table 12.3 presents the values of $A_{\text{min}}$ and $A_{\text{max}}$ and the corresponding percentage of land in these two categories for each of the eight jute growing districts in Bangladesh. Based on the one-goal model, over eighty per cent of the acreage in all districts except Jessore and Rangpur would be owned by farmers in either the gambling or safety-first regions.

4. APPLICATION TO NINETEENTH CENTURY SOUTHERN AGRICULTURE

The previous section indicated how to classify farms into different regions by specifying values of $Z^*$ and $\alpha^*$. In this section, the lexicographic model is applied to the choice between cotton and corn in the nineteenth century U.S. South. We show that the approach has potential for “explaining” in very simple terms developments which appear paradoxical in terms of standard

\[ \alpha^* = \frac{1}{(1 + s/h)^{16}} \]

To derive this result define the following symbols: $Z = \text{a random variable representing actual return per acre}$; $P(Z) = \text{Probability that return per acre equals}$ $Z$; $I = \text{desired extra rice per acre for emergencies}$; $E(I) = \text{expected cost associated with}$ $I \text{ units of rice per acre}$. The objective is to find $I$ which minimizes

\[ E(I) = S \sum_{Z=0}^{N} (Z^* - I - Z)P(Z) + h \sum_{Z=0}^{N} [Z - (Z^* - I)]P(Z) \]

expected shortage cost expected holding cost

The optimal solution to the problem yields a value of $I$ such that

\[ \alpha^* = \frac{1}{(1 + s/h)^{16}} \]

For a more detailed discussion of the newsvendor model, see any basic operations research text such as Hillier and Lieberman (1967), pp. 370-77 or Wagner (1969), pp. 792-98.
microeconomic theory. The basic historical problem may be outlined as follows:

(a) In 1860, the smaller farms of the South (and those with higher ratios of on-farm population to acreage) grew less cotton (the cash crop) relative to corn (the main food crop);

(b) Between 1860 and 1880, the average farm size declined dramatically, and yet the aggregate ratio of cotton to corn output rose markedly;

(c) In 1880, the smallest farms exhibited very high ratios of cotton to corn outputs, and the medium-scale farms had the lowest ratios;

(d) There was no major difference in the relative prices or profitability of the two crops between 1860 and 1880.

It is possible to construct alternative microeconomic explanations for each of these facts, but we know of no single theory which is consistent with all of them. A more detailed discussion of the historical development in the 19th century South and a comprehensive set of references appear in Wright and Kunreuther (1975).

In fundamental respects, the cotton-corn decision was similar to the choice between jute and rice. Cotton was sold for cash, corn was predominantly consumed on the farm—both directly by humans and indirectly in the form of feed for hogs. (We can assume corn prices and allocation reflect both types of demand.) Most farms grew a mixture of cotton and food crops, of which corn was by far the most important. The choice between cotton and corn was primarily a question of land allocation.

### Table 12.3

<table>
<thead>
<tr>
<th>District</th>
<th>$A_{\text{min}}$</th>
<th>$A_{\text{max}}$</th>
<th>Percentage of land in Gambling region</th>
<th>Percentage of land in Safety-first region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dacca</td>
<td>3.9</td>
<td>9.8</td>
<td>44.7</td>
<td>37.9</td>
</tr>
<tr>
<td>Faridpur</td>
<td>4.6</td>
<td>11.3</td>
<td>46.4</td>
<td>37.9</td>
</tr>
<tr>
<td>Mymensingh</td>
<td>4.1</td>
<td>10.4</td>
<td>41.3</td>
<td>41.1</td>
</tr>
<tr>
<td>Comilla</td>
<td>3.9</td>
<td>9.3</td>
<td>60.0</td>
<td>29.0</td>
</tr>
<tr>
<td>Rangpur</td>
<td>3.8</td>
<td>9.2</td>
<td>32.4</td>
<td>39.7</td>
</tr>
<tr>
<td>Bogra</td>
<td>4.6</td>
<td>11.1</td>
<td>46.6</td>
<td>39.0</td>
</tr>
<tr>
<td>Pabna</td>
<td>5.0</td>
<td>11.1</td>
<td>43.0</td>
<td>37.2</td>
</tr>
<tr>
<td>Jessore</td>
<td>3.7</td>
<td>8.7</td>
<td>21.3</td>
<td>47.0</td>
</tr>
</tbody>
</table>
Prior to the Civil War, many small farmers of the South were largely outside the market economy. We do not have acreage and yield data for the antebellum period, but the evidence is strong that the expected value of cotton acreage was above that of corn.\textsuperscript{17} Many of these farms grew only small amounts of cotton, apparently as a “surplus” crop after household food demands had been met.

We believe that this behavior is well explained by the “safety first” model, without the “gambling region” at the lower tail of the distribution; even the “small” farmer of 1860 could ensure, with reasonable confidence, that his family would not fall below intolerable levels of subsistence. There is now considerable evidence that almost all farms in the antebellum South attempted to achieve self-sufficiency in food at the farm level.\textsuperscript{18} The simplest way of viewing the matter is to postulate “self-sufficiency” as a target in its own right. This would require small farmers to plant a larger share of their acreage in corn. Available figures on relative outputs by farm size support this pattern, as shown in Table 12.4.

### Table 12.4

<table>
<thead>
<tr>
<th>Improved Acreage</th>
<th>0-49</th>
<th>50-99</th>
<th>100-199</th>
<th>200-299</th>
<th>300-499</th>
<th>500-999</th>
<th>over 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn/Cotton Ratio</td>
<td>76.71</td>
<td>62.82</td>
<td>45.81</td>
<td>34.16</td>
<td>28.46</td>
<td>24.41</td>
<td>18.74</td>
</tr>
</tbody>
</table>

Source: U.S. Census sample (1860).

A slightly different way of interpreting the same data is to view self-sufficiency not as an independently postulated goal but as a target derived from the “subsistence” constraint that real income (i.e., in corn-bushel equivalents) does not fall below $Z^*$ per acre. Typical small farms of 1860 could expect to achieve $Z^*$ with reasonable confidence by specializing in corn.\textsuperscript{19}

\textsuperscript{17} Using market prices, the value of total output per worker or per acre is positively correlated with the cotton-corn ratio in every part of the cotton growing South and for every farm size-class in 1860.

\textsuperscript{18} See, especially, Gallman, 1970.

\textsuperscript{19} Even if standards of “tolerable” food consumption are higher on large farms, $Z^*$ will be lower as farm size increases as long as the “elasticity of minimum standards with respect to farm size” is less than unity, and in any case, because there are generally more household members per acre on small farms. For evidence that the elasticity of the “poverty line” with respect to income is about 0.6, see Kippatrick (1973).
This minimum-income target is clearly not the same as a "subsistence constraint" in any biological sense, but the interpretation is not altogether different from the case of Bangladesh. As in Masson (1972), the "kink" in the function arises not from biology or from discontinuities in the utility of consumption, but because behavior must change below some income level — specifically, the individual must borrow or sell assets, either of which may pose a threat to the security of the farmholding. A large farm, on the other hand, may share the self-sufficiency target, but — referring back to the newsboy model — the consequences of a shortage are less serious, and hence $\alpha^*$ will be higher. The newsboy model implies (if $s_lh$ exceeds unity) that in a normal year, farmers will grow more than their minimum tolerable level of corn, perhaps even more than they want to consume in any case. Most of the self-sufficiency studies have found that such surpluses were in fact common in 1860. But these surpluses will be viewed as a source of relief and not distress, in much the way that a good hostess is not dismayed to see food left over after a party — at least she did not suffer the embarrassment of running short.

Regression analysis using farm data from the 1860 U.S. Census sample confirms that the share of acreage devoted to cotton is inversely correlated with family members per acre, and positively correlated with improved acreage. An illustrative regression, for the alluvial region, is the following:20

$$CT = .418 + .0049** SQ - .156** PI/A + .0017** IA$$

(3.91) (2.08) (2.41)

$$R^2 = .226$$

where

$CT$ = share of acreage in cotton,

$SQ$ = an index of soil quality,

$PI$ = on-farm population,

$IA$ = improved acreage and

** indicates significance at the 1% level.

The model also predicts the positive correlation between $CT$ and $SQ$, since better land increases the probability of achieving a given $Z^*$ from a given

20 For details of variable definitions and alternative regression procedures, see Wright and Kunreuther (1975).

21 Obtained from output data on assumption that land yields are constant for both cotton and corn.
acreage. Note that the sign of $P/A$ is the reverse of what would be predicted by the labor-constraint hypothesis proposed by Gallman; that is, if cotton output is constrained by the size of the labor force, one would expect a positive correlation between $CT$ and $P/A$.

By 1880, the South was no longer self-sufficient in food, with per capita production of corn and hogs falling to only half of what they were in 1860 (Ransom and Stutch, 1972). Regional concentration on cotton production had markedly increased, despite the fact that relative cotton prices for the period 1876-1880 were not at all unusual compared to the 1850's. True, cotton prices had been high during the immediate post war years 1866-76, but the region never again returned to self-sufficiency, even though relative cotton prices showed no subsequent trend of any significance up to 1900 (DeCanio 1973, pp. 616). Nor do relative yield trends appear to provide an explanation. The price-yield-cost evidence strongly suggests that an acre of cotton land had a significantly higher expected yield in value terms than an acre of corn. These differences are generally larger than the jute-rice differentials of Table 12.2. However, the differences in variance are greater: $\sigma$, (corn) averages 1.6, while $\sigma$, (cotton in corn bushel equivalents) averages 7.4.

Why should the Southerners of 1880 have been more willing to bear risk than those of 1860? Our analysis focuses on the following three historical developments: (1) the drastic fall in average farm size, and specifically the emergence of large numbers of extremely small farms by 1860 standards; (2) the rise of tenancy and associated systems of credit; (3) the rapid fall in the price of cotton during 1866-1875 from its historic highs after the Civil War. Our hypothesis is that these developments combined to create a class of small farmers in the "gambling" region.

The effect of the fall in farm size is to raise the minimum yield $Z^*$ required for any given target; in terms of our model, such a change could shift

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Footnotes:

22 Results like these have considerable relevance for the measurement of total factor productivity and economies of scale in agriculture. For example, Fogel and Engerman (1974) find evidence of major economies of scale under slavery in 1860. But these results are obtained by aggregating outputs at market prices. The higher "efficiency" of plantations can be largely explained by this crop mix effect, rather than the organizational economies stressed by Fogel and Engerman.

23 This statement is based on an extensive analysis of USDA state-level price and yield figures, and the cost-of-production figures in USDA (1999). Even when all of the costs of fertilizer, ginning and pressing, bagging and ties, marketing, implement repair and "other" expenses are assigned to cotton and not to corn, cotton retains an expected yield advantage. See Wright and Kneebarger (1975).
the crop mix in either direction.\textsuperscript{24} The former slaves, however, lacked tangible assets at the time of emancipation, and hence, were enmeshed willy-nilly in the market economy. Under either cash tenancy or sharecropping, two main changes militated against safety-first behavior: first, the contraction of debts raised the amount of cash income which a tenant had to target in order to break even; second, if a basic desire of the tenant farmer was to be an independent farm-owner (essentially the same desire as the safety-firsters of 1860), he now would have to target a much higher $Z^*$ in order to achieve or make progress toward this goal, as opposed to maintaining it. Small farms and high targets necessitate gambling.

These structural characteristics were reinforced by the course of cotton prices. The very high prices of the immediate postwar period coaxed many farmers into cotton. The rapid fall left many of the cotton growers in debt, and these debts made it difficult for them to reverse their decisions.

The model predicts a correlation between cotton growing and the presence of tenancy and very small farms. Table 12.5 uses county averages for 1880 to test these predictions. Regression (7) shows that a positive overall correlation still exists between farm size and the share of acreage in cotton; however, regression (8) through (13) show that the pattern is actually U-shaped since the coefficient associated with small farms is positive. The strong association between tenancy and cotton comes through clearly, but the U-shaped pattern is present whether tenancy is included or not. Regression (13) indicates that owned farms of less than 50 acres were in the gambling region whereas for tenant farmers, the threshold between gambling and safety first behavior was at least 100 acres. The argument of this section could, of course, be translated in terms of a discontinuous utility-of-income schedule, as in Masson (1974). However, to explain the change from 1860 to 1880, one would have to postulate a shift in the utility schedule, whereas, our explanation involves no fundamental change in preferences between the two periods.

5. POLICY IMPLICATIONS OF THE MODEL

If the lexicographic model of choice is a correct description of behavior, then a conflict is likely to arise between the economic status of the individual and optimal resource allocation from the standpoint of economic

\textsuperscript{24} A "standard" microeconomic analysis might also predict that a fall in farm size (with a rise in $P/L$) would reduce corn output, if cotton output is constrained only by the size of the labor force. Such an argument could not, however, explain the U-shaped relationship of 1880, and it is inconsistent with the pattern of 1860. Furthermore, in this instance, even the premise is probably incorrect: in the aggregate, $P/L$ was approximately the same in 1880 as in 1860; and because of the withdrawal of black female labor from field work after emancipation, the ratio of labor to acreage had probably fallen between 1860 and 1880, even on small farms.
Table 12.5

Regression coefficients: Cotton south, 1880
Dependent Variable: Cotton acreage/Total acreage
(Country Data)

<table>
<thead>
<tr>
<th>Variable</th>
<th>(7)</th>
<th>(8)</th>
<th>(9)</th>
<th>(10)</th>
<th>(11)</th>
<th>(12)</th>
<th>(13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>.249</td>
<td>.109</td>
<td>.192</td>
<td>.310</td>
<td>.297</td>
<td>.132</td>
<td>.279</td>
</tr>
<tr>
<td>Cotton yield/Corn yield</td>
<td>3.34**</td>
<td>3.38**</td>
<td>3.25**</td>
<td>2.65**</td>
<td>2.59</td>
<td>3.08**</td>
<td>2.60**</td>
</tr>
<tr>
<td>(5.64)</td>
<td>(6.24)</td>
<td>(6.20)</td>
<td>(4.48)</td>
<td>(4.63)</td>
<td>(5.85)</td>
<td>(4.64)</td>
<td></td>
</tr>
<tr>
<td>POP/1A</td>
<td>.068</td>
<td>- .041</td>
<td>- .041</td>
<td>- .975</td>
<td>- .072</td>
<td>- .038</td>
<td>- .008</td>
</tr>
<tr>
<td>(1.09)</td>
<td>(0.70)</td>
<td>(0.73)</td>
<td>(1.22)</td>
<td>(1.23)</td>
<td>(0.67)</td>
<td>(0.13)</td>
<td></td>
</tr>
<tr>
<td>Average farm size</td>
<td>0.0019**</td>
<td>0.0022**</td>
<td>0.0016**</td>
<td>0.0019**</td>
<td>0.0013**</td>
<td>0.0015**</td>
<td>0.0014**</td>
</tr>
<tr>
<td>(7.75)</td>
<td>(5.65)</td>
<td>(6.68)</td>
<td>(8.11)</td>
<td>(5.63)</td>
<td>(8.36)</td>
<td>(6.21)</td>
<td></td>
</tr>
<tr>
<td>Rate of tenancy*</td>
<td>0.325**</td>
<td>0.390**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(5.44)</td>
<td>(6.76)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of all farms</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 50 acres</td>
<td>0.00038**</td>
<td>0.00020*</td>
<td>0.00011**</td>
<td>0.00005**</td>
<td>0.00027**</td>
<td>0.00007**</td>
<td></td>
</tr>
<tr>
<td>(8.60)</td>
<td>(3.74)</td>
<td>(7.36)</td>
<td>(2.70)</td>
<td>(5.86)</td>
<td>(4.45)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50-100 acres</td>
<td>- .00026**</td>
<td>- .00016**</td>
<td>- .00026**</td>
<td>- .00016**</td>
<td>- .00019**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5.95)</td>
<td>(6.76)</td>
<td>(5.95)</td>
<td>(5.95)</td>
<td>(5.95)</td>
<td>(5.95)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of tenant farms by farm size:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 50 acres</td>
<td>0.190**</td>
<td>0.067</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5.48)</td>
<td>(1.27)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50-100 acres</td>
<td>0.190**</td>
<td>0.067</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5.48)</td>
<td>(1.27)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R²         | .229 | .354 | .401 | .329 | .401 | .401 | .405 |

N = 386 countries; t = ratios in parenthesis; ** indicates significance at 1% level.
*Fraction of all farms which are tenant farms.

development. The group of farmers who follow the safety-first strategy may be
said to have misallocated their resources by planting a substantial portion of
their land with a food crop having a lower expected return than the cash crop.
This misallocation arises from the institutional arrangements of the
agricultural sector rather than from ignorance or technical inefficiency. To
achieve a more efficient allocation of resources, two choices are open: (1)
reduce the safety-first farmers to gamblers, or (2) give them enough security so
that they will focus more on the relative expected returns from their crops and
less on their variance.

The postbellum South did manage to develop institutions which created
a class of very small farmers with little choice but to concentrate on cash crops.
Ironically, these institutions almost certainly hurt the region as a whole. The
South was in the unusual position of possessing substantial unexploited
monopoly power in world cotton markets; hence, the shift depressed the cotton price while having no effect on world corn and hog prices.  

The reverse irony may be true in Bangladesh due to their monopoly power in jute. Specifically, a policy of pushing gamblers to safety-first farmers would effectively limit jute production, and hence, would likely increase aggregate returns in the short run. The resulting high jute prices could have long-run detrimental effects causing consumers to switch to other products such as synthetic fibers, thus shifting the demand curve for jute to the left.

Even for the more usual case in which a country actively desires to expand its foreign exchange earnings by increasing cash-crop production, strategy (1) seems indefensible from the standpoint of equity. Turning to strategy (2), one obvious device would be for the government to provide a minimum guarantee of enough food to feed the family in case of a bad harvest. Through surveys of individual farmers, it should be possible to determine these minimum requirements (i.e., $Z^*$) as a function of family size and age distribution. Another way of reducing the importance of variance in the crop allocation decision would be for the government to provide easy credit to farmers at market rates of interest during poor harvests. Other things being equal, such an arrangement would raise the farmer’s acceptable risk level by reducing his $s/h$ ratio. The extent that such individual risk reduction is desirable will of course be tempered by whatever social preference exists for reducing the dependence of foreign exchange earnings on a small number of commodities, as discussed by Brainard and Cooper (1968).

The lexicographic model also makes a case for land reform, but only of generous proportions; mild land reform directed toward the very poorest class may have some resource allocation costs by shifting them from gamblers to safety-first farmers.

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25 For documentation of this assertion, see Wright (1974).

26 A more detailed discussion of the short and long-run effects of limiting jute production in Bangladesh appears in Repetto (1972).

27 Before the 1971 Pakistan War, low interest loans called "tocravi" loans were available to farmers in East Pakistan if there was a bad crop. Procuring them involved considerable red tape, and most small farmers felt they could not be obtained when needed.
Chapter 13

The effect of risk aversion strategies on subsistence and cash crop decisions

Sutti Ortiz*

Hardly anyone would nowadays argue that if a small farmer wants to survive and succeed, he must not only learn to combine resources to obtain high outputs but he must also take into account possible disastrous results. In this essay, I outline the strategies used by a group of Indian farmers in Colombia to assure the survival of their families and their enterprises as they face uncertain incomes.

Although the information here presented is based on very limited information, and a small sample, the richness of the details and the dramatic quality of the case serve to highlight processes that often go unnoticed, despite their relevancy. I have chosen first to review the uncertain world of the farmer from his own vantage point, and later contrast it with some of the formal descriptions offered in existing literature. I hope it will not be disregarded as yet another peculiar case. The plight of these peasant farmers can speak loudly and serve to clarify unwanted and unnecessary constructs. The juxtaposition of the real decision process of few farmers, regardless of their peculiarity, with formal model of such processes is bound to give new insights to economists with imagination. It is in this spirit that the conclusions presented here should be read.

*Many of the conclusions of this paper I owe to the insight of the Indian peasants whose activities I followed closely for a period of a year. Subsequently, and thanks to the cooperation of another anthropologist, Miss Ann Osborn, I was able to confront some of the same Indians with constructs derived from my early field experience. Miss Osborn also questioned them with regards to expectations of prices and outputs.
1. ECONOMIC AND POLITICAL HISTORY OF TIERRADENTRO

In the eastern part of the department of Cauca, Colombia, highly steeped and eroded mountain ranges face each other barely separated by narrow valleys. Only at higher altitudes (around 3,000 meters) do the mountains slope more gently and retain some of the virgin forest. These higher slopes are adequate for grazing cattle and planting potatoes and wheat. The lower slopes, on the other hand, can be planted with a larger variety of crops, yet they are so eroded that the yield is quite low. The few fertile lowland narrow valleys can be planted with coffee and sugar cane. This region is known as *tierradentro* (hinterland), a name that clearly portrays the history of its isolation. On the southern lower slopes of *Tierradentro*, there are a number of small Indian reservations surrounded by rural Colombian settlers.

Since colonial times, the Indian farmers of *Tierradentro* have had to bear a number of economic and political changes; with each change, their freedom of choice has been curtailed and their chance for economic growth hampered. Once conquered, each one of the Indian population clusters received from the Spanish Crown a grant of land and recognition as a semi-independent political corporation. Such a status implied an obligation to pay tribute to the Crown; the tribute was to be paid in labor and crops, including a newly introduced grain: *wheat*.

Although the burden of tribute was lifted after independence and Indians were exempted from tax payments on their land grants, they were forced to face a new economic crisis: shortage of land due to the immigration of Colombians who rapidly claimed the territory surrounding each reservation, including holdings rightfully owned by Indians. By 1916, 2,800 farmers had settled in one of the two municipalities of *Tierradentro*. Twenty-two years later, 6,000 more Colombians came to share whatever land was still available or could be easily usurped. Each Indian family saw their holdings shrink in size and no chance of acquiring more land outside reservation boundaries as they could not compete in the market with the better capitalized newcomers. For the past 40 years, expansions have been rare and difficult.

These new immigrant farmers were attracted to land suitable for cattle and coffee, the new major cash crop of Colombia. They were interested not only in planting it but also in marketing it. *Tierradentro* Indians responded to the incentive by becoming, whenever possible, part-time coffee farmers. Thus, the new immigrants changed the character of the area from a basically Indian potato and wheat producing region to a peasant coffee region with a high Indian population.

In summary, the farming population of this rural area consists presently of two sectors: a better informed and politically more influential population of Colombian farmers and traders with holdings ranging from 1 ha to 500 ha; a less influential sector of Indian farmers with holdings ranging from 1 ha to 70
ha. The Colombian farmers have easier access to credit, technical aid, and market information. It was not so difficult for them to be the first to plant coffee in the 1930’s and to be the first to buy suitable land for cattle raising in the late 1960’s and 1970’s.

The Indians, on the other hand, devote their efforts entirely to farming and cattle raising, with one single exception: a well-to-do Indian farmer who, for a short time, became a supplier of meat and a butcher in the market place. None of them holds as much land as the wealthiest of the non-Indian farmers, but there is a wide range of variation in the size of holdings which range from 1 ha to 70 ha, with most of them having 3-10 ha (see Appendix 13.1). Some of these holdings are within the coffee growing area or sugar cane area; others are good only for the less desirable cash crops (wheat and potatoes). Still other holdings are high enough to provide good, safe pasture for cattle. All of them, however, have land that yield a reasonable variety of local staples — manioc, arracacha, plantains, beans, and mountain maize.

2. THE INDIAN FARMER’S INSURANCE STRATEGY

In 1961, I spent over a year in one of the two municipalities of Tierradentro1 and was able to follow closely the farming activities of 26 Indian families with land suitable for coffee, sugar cane, and/or cattle. It soon became evident that the Indians with land suitable for coffee or sugar cane expanded their plantations as far as they considered feasible and safe; that is, as far as it did not endanger food production for their own subsistence. It was obvious that they also wanted to avoid indebtedness or any other contractual arrangement that may limit their freedom of action or their bargaining power. The income earned was not necessarily spent on ceremonial activities or luxury purchases (see Appendix 13.4). The overall picture was that of a group of farmers with a varying degree of competence and stamina, but who allocated resources carefully in order to increase their income and the productivity of their farms without, of course, endangering their families. These Indian producers could not be characterized as Indian farmers burdened by traditional rules and social demands, but they were thoughtful farmers in distress.

They handle distress by following a traditional wisdom: you can be sure to have enough to eat if you can produce the food yourself or perhaps borrow some from a close kinsman or friend. Food is to be shared with those who may

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1The field work was financed with a grant from the Organization of American States. Some of the farmers studied in 1961 have since died; the few surviving, whose farms are large enough to allow subsistence and expansions without having to primarily rely on wage earning, have been interviewed by Miss Ann Oshorn in 1975.
help you in crisis but not grown to be marketed, as you are likely to be paid unprofitable below-market rates by Colombian neighbors. In many respects, they behave like the suboptimizing model suggested by Day: in both cases, safety zones are delineated. But the Indian farmer does not define his zone in terms of a combination of activities with a corresponding range of returns, but in terms of two noncomparable ventures — each one requiring a specific land allotment: subsistence and market production. Such managerial procedure is also probably used by peasants in other parts of the world, who, like the Tierradentro Indians, do not consume their own cash crop. In such cases, economists must program not only for costs and returns but also for adequacy of crops for subsistence and market. Models which can integrate such information with ease are most suitable to analyze the behavior of the peasants.

The farmer, whose subsistence farming can be interpreted as a rational reaction to potential disaster, can be expected to place less reliance on that strategy as he gains confidence on the range of yields and the adequacy of cash returns. If the price of his cash crop (as coffee in Colombia) does not greatly fluctuate either seasonally or annually, he will slowly commercialize his enterprise and eventually give up inefficient subsistence practices. The point at which such a transformation will occur can, I believe, be estimated with existing models.

Uncertain outputs and incomes force farmers to continue to produce for their own subsistence and to accept innovation slowly. This relation between uncertainty and innovation has already been clarified by Lipton (1968). However, some apparently contradictory data and some discouraging experiences have thrust economists back to old constructs discriminating between risk-taking and risk-averting farmers. Such retrogressive moves are unnecessary if we examine more carefully how peasants arrive at allocating decisions. It then becomes clear that peasants accept the risk of cash cropping, even when this is high, but do so only after subsistence is assured (see the contribution in this volume by Scandizzo and Dillon for a similar conclusion). Such suboptimizing peasants neither fit the category of risk averter nor risk taker; they fit both classes. Furthermore, as explained later, the willingness of peasants to accept risky ventures depends on income and ability to insure a minimal fund of operation. Lastly, it becomes clear that certain decision processes hamper cost evaluations and the comparability of the costs of safe

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2If an Indian was able to harvest more than the food he needed for subsistence, except for fields where corn or beans were specifically planted for sale, he would not sell the excess in the market but save it in case others requested a loan. The only time that food was brought to the market in very small quantities was when an Indian was in urgent need for a small amount of cash to buy something for his family. If no one requested food, he would spend it on informal feasts.
decisions with risky decisions. The peasant's preference for subsistence over starvation cannot be rephrased into a preference for \( X \) chance of \( Y \) income over \( X-n \) chance of \( Y-m \) income; such paraphrasing totally misrepresents his options and it is unnecessary. I return to this point after a discussion of how peasants allocate resources for subsistence and for profit, when faced with uncertain outcomes and uncertain availability of inputs (an uncertainty often disregarded in analyses).

The managerial technique of allocating land for a purpose, either by conversion into cash or as the family food supply, does not imply that each farmer either plants a fixed amount of a variety of staples or that a farmer plants the same combination of crops year after year. The 26 families interviewed insisted that they wanted to plant as much as they needed for subsistence and whatever ceremonial obligations they had to discharge that particular year. They would not commit themselves to a fixed combination, as they were aware that a variety of combinations was suitable and that they could do with less food if they had a sudden opportunity to earn some cash to buy bread or meat. The farmer is also aware that if, at the time of planting the bulk of his food supply, his existing maize field is not progressing satisfactorily, he should increase the amount of another desirable though perhaps more risky crop like beans, while expanding as well his existing manioc field (a safe but less preferred staple).

The behavior of farmers and the reasons for their behavior can be outlined in more formal terms following Shackle's (1961) intuitive description of decision process. In his terms, an Indian farmer would be expected to be able to decide what to plant and in what quantities once he is able to formulate expectations regarding possible outcomes, as well as once he is able to determine the degree of surprise attached to each outcome. A farmer is then expected to focus on the outcomes which he regards most likely to occur and which will bring him greatest satisfaction or greatest distress. An experienced Indian farmer has no trouble formulating possible yields or the likelihood of a particular range of yields. What a farmer cannot determine ahead of time is the satisfaction he will feel from a particular yield of food; he is too aware that in order to obtain a given yield, he has to forego other “satisfaction” (e.g., comforts, luxury foods, medicine and clothing). In other words, the Indian farmer finds it difficult to evaluate the desirability of an outcome (food yield) when the desirability is relative to the desirability of other outcomes (cash for family expenses). Shackle suggests that, when faced with complex decisions, the decision maker will envisage a number of different mutually exclusive circumstances which will insure the focus gain and focus loss of each one.

But our Indian farmer, all set to plant his food crops, still faces another set of difficulties. Not only must he decide what yields or satisfaction he will gain and will prefer, but when will he be free to work in his own fields. This dilemma is particularly serious not only for poor Indians with insufficient acreage of land suitable for cash crops or for Indians who may have suffered
heavy losses, but also for Indians who may have misjudged their ability to repay a loan or complete payment for equipment purchased on credit. The Indian farmer who owes money has to work for wages. He is thus confronted when planting subsistence crops with a similar situation to that of Carter's decision maker (Carter, 1957). According to Carter, when a decision maker is in doubt, he will look more carefully into the matter and, by so doing, increase the number of opportunities or events he can perceive; the decision will become so complex that evaluation will become impossible. Carter suggests that when an individual is faced with opportunities (or outcomes) which he cannot rank, he will either lower his aspirations or look for another course of action or hedge between undecided possibilities or trust to chance. Carter's comments are perceptive and are supported by Hayes' experiments which suggest that the decisions' time relates to the number of variables and attributes to be considered. What Carter seems to overlook is that, under the circumstances mentioned, the farmer may delay decisions until he absolutely has to make them (see Kunreuther's paper in this volume for comparative insurance problems); that is, he delays them until he must start planting. Or, as the Indian farmer himself conveyed it to me, he plants until he knows he has enough and that depends on too many things to be able to evaluate beforehand. He only knows what is considered by all to be a fair supply of food. When it is time to plant, he begins to plant; he decides when to stop depending on how much money he has been able to earn up to that moment, how much time he has available, and so on. In other words, during the course of planting, his decision will be defined not so much by expected gains but by likely losses, immediate expected demands for food and labor, and estimates of annual needs. The Indian farmer is, in fact, willing to accept a low focus gain in subsistence production and unlikely to favor yields that are much higher than what he needs to offer friends and feed his family. The resulting range of variations in amounts planted and harvested defy, I believe, the ingenuity of any economist who wants to devise a predictive model of subsistence production. One possible solution is to integrate the consequence of various decision timing in the model. Another possible and more simple solution is to calculate the amount of land required for an undetermined combination of food crops for family subsistence, then concentrate on determining the combination of cash crops to be planted in the remainder of the land.

I have explained that, as the goal of subsistence production is maximum insurance rather than maximum food production, the farmer does not force himself to make decisions until he is sure that inputs are available and that the demands for planting of food crops do not conflict with other demands. This is not a consciously devised procedure, but one that emerges from a situation where inputs and outputs are uncertain. It is a procedure well adapted to gain maximum insurance; at the same time, one must not lose sight of the fact that unplanned decisions, coupled with harvesting procedure geared for consumption rather than for sale, hamper simple accounting calculations.
Farmers are not constantly reminded of the time spent planting, harvesting, and of the yield derived from such efforts. They can reconstruct cost calculations, but they are not forced to do so. They are often unaware of how inefficient their techniques in subsistence production are and can only slowly evaluate the impact of new technology when it is to be integrated into this sphere of their agricultural activities.

3. PERCEPTION OF FOCUS-LOSS AND FOCUS-GAIN IN CASH CROP DECISIONS

The same Indian farmer, who begins to plant subsistence crops before he has carefully determined what crops or how much he will plant, is very careful when he plans his cash crop strategy. He considers new information he receives about prices and techniques, as well as the state of the market. He decides, accordingly, what crop to plant and what capital investment to make. Such decision can be modeled using Shackle's concept of focus-loss and focus-gain. He will choose an opportunity or further invest in it if the focus-loss estimate is acceptable and the focus-gain is higher than other equivalent prospects. Such calculations are not so cumbersome as in subsistence production; hence, they can be made ahead of time. Although the Indian farmer may easily formulate and evaluate expectations, it is not so easy for the economist to determine those same estimates. The few cases here examined can be used to explore why and when some estimating procedures used by economists may diverge from the actual practices of peasant farmers.

Boussard, when incorporating Shackle's notion into his own model, defines the permissible loss "as the difference between the inflow of normal receipts (i.e., the receipts corresponding to the foci of gain) and the inescapable expenses" (1971, pp. 473-4). In other words, a tolerable loss is an income which, though below normal receipts, does not fall below inescapable expenses that must be covered. In the case here examined, with receipts from coffee, sugar cane, or cattle (the three major local cash activities), the following expenses must be covered: replacement of tools or purchase of more efficient equipment; repayment of loans; marketing costs; and in some cases, purchase of seeds; fertilizers; and wages; as well as a cash income estimated to cover needed consumer goods.

For Boussard, the permissible loss can be calculated from the following mathematical expression:

$$L_0 = \sum_i (m_i - e_i) x_i - (C_m + F_m)$$
where \( m_i \) = the unitary gross receipts on the \( i \)th activity at the focus gain level,
\( e \) = the corresponding current expenses,
\( C \) = the farmers' vital consumption,
\( F \) = all the compulsory payments not included in the \( e \)'s,
\( i \) = the number of activities.

A clarification must be made before the applicability of Boussard's mathematical definition of focus-loss is considered. As expressed in the formula, focus-loss is not necessarily a matter of avoiding starvation but about avoiding undesired incomes. Furthermore, the distinction between ruin and focus-loss becomes clearer as the intensity and net return of activity increases. For example, an Indian farmer with 2,000 coffee trees in production during 1961 would have been fearful, according to Boussard, of the possibility of not having enough cash for basic needs; yet, fifteen years later, that same farmer would be cheered by Boussard's focus-loss calculations as price increases had brought up expected return well above the inescapable expenses (see Appendix 13.2). In 1961, that farmer was thinking along the lines of a consumer who needs a job; during 1975, he is thinking like a producer who compares the generating power of alternative activities. Can we suddenly really expect him to formulate a focus that is considerably higher than a return required to cover needs and expenses? Is it likely that a producer who has faced at one time a disastrous income would, 15 years later, reject enticing prospects just because of a high chance of dangerously low income? Is such a formulation useful for small farmers in marginal areas where price changes may affect the impact of low incomes? Should its applicability be limited to commercial farmers in developed or underdeveloped areas? Without a theory to explain how expectations are formulated and what experiences affect them, we have to rely on observation and empirical confirmations.

The data from Tierradentro Indian peasants can be used to examine focus-loss calculations offered by Indians and those derived from economists' formulations. However, unlike Kennedy's and Boussard's commercial farmers, poor peasants do not conceptualize their activities in terms of a single strategy with an annual income but as a set of separate though related activities, each one of them having corresponding potential loss and gain points. Boussard's formulation must then be rephrased; instead of attempting to determine the total permissible focus-loss, a similar accounting can be used for a single activity. Such a simplification is warranted only because comparison with empirical findings for peasant producer is potentially useful at this stage of our knowledge; but, in no way, questions the validity of Boussard's focus-loss summation.

During 1975-76, as an initial exploration for an eventual study on formulation of expectations, some of the surviving farmers whose activities
had been carefully followed in 1961 were interviewed. The farmers were urged to discuss expected outcomes, in terms of hypothetical units, to avoid the usual reluctance to talk about personal wealth and biased judgments to cover income received. The hypothetical units were approximations of what I knew or expected present holdings to be. Farmers who preferred to talk in terms of their own holdings were encouraged to do so; nevertheless, an occasional game was introduced to contrast answers. The interviews were open-ended, as this is only a feasible technique with local farmers. Farmers were asked to specify the range of expected return; the degree of surprise was checked by noting their reaction when figures mentioned by them were increased or decreased.

All of them, without exception, chose at first to answer in terms of a standard expected return rather than a range of returns. In other words, initially they conceptualize a choice problem in terms of a standard expected return. It is only when encouraged to think in terms of ranges that focus-loss and most optimistic returns are expressed by farmers.

The interviews brought to light a considerable difference in the range of incomes expected by each farmer. For the same crop, some expected the possibility of an income two-thirds less than the expressed standard; others, only one-third less. All of them clearly explained that they based their estimates on weather conditions, as well as seasonal demand fluctuations and annual price changes. As the altitude and, hence, the weather conditions vary greatly from farm to farm, range of yields, as well as focus-loss estimates, are correspondingly different from case to case. Furthermore, with altitude change, time of harvest varies and hence the range of prices each farmer is likely to experience. Personal experience is not, however, enough to explain range of variation in focus-loss estimates. As implied by Boussard's conceptualization, the higher the intensity of the activity, the smaller the difference between expected standard profit and focus-loss profit.

Environmental idiosyncrasy and intensity of production may be enough to explain the range of low incomes that different farmers had learned to expect and were prepared to accept. But would we have predicted the same focus-loss points through simple calculations? My estimates matched only the focus-loss expressed by one of the wealthier Indian peasants for a coffee plantation of 4 hectares (Figure 13.1). Poorer farmers are willing to accept much lower gains than I predicted. Such a disparity can be explained by the fact that poorer farmers had experienced during the sixties, when prices were much lower, focus-loss incomes that were just barely high enough to cover the most immediate cash needs. These same farmers, not surprisingly, are now quite willing to accept for the same plantation an occasional similarly low income. There is yet another explanation for the disparity. A poor farmer with only one hectare of coffee can easily substitute factors of production when he realizes that the yields or prices are extremely low; such a substitution is not so easy in larger plantations.
Figure 13.1. Expected focus gain and loss expressed by farmers against estimated values for 1975 coffee prices.
The focus-loss for *panela* (unrefined brown sugar cubes) production reveals another interesting point. All farmers are willing to tolerate lower returns than would have been predicted from our calculations. As it turns out, none of them expected *panela* production, or any activity subsidiary to coffee, to cover basic needs of the family: only costs of production are taken into account in focus-loss calculations. Once family expenses are excluded from focus-loss estimates — Boussard had already suggested that depreciation of equipment should be neglected — the predicted values correspond closely to the farmers’ estimates. Yet, another factor contributes to equivalence: *panela* production requires high labor input during a short period of time so that wage labor must be contracted; it also requires the purchase and maintenance of equipment; the scope for substitution of factors for production is much narrower than with coffee. The appeal of *panela* production, despite the uncertain yields and capital costs, does not lie on a high focus gain but on the fact that cane can be planted, harvested, and processed when farmers are not involved in their coffee plantations. Furthermore, as a complementary cash activity, it is more profitable than wage labor.

The role of each crop within the total scheme of agricultural production is, as illustrated in the previous paragraph, relevant to focus-loss calculations. Among the farmers here studied, coffee has become the pivotal crop, probably because farmers have more experience with it; partly, as well, because coffee offers no major marketing problems and prices have not fluctuated too rapidly. There is no question as to the importance of coffee to the farmers. They mark annual events with reference to the major coffee harvest and insist, incorrectly, that all family expenses are paid with the revenue from coffee. It should be equally simple to determine, for each area to be studied, the relative importance of each cash crop within the accounting cycle of the farmer.

Although some economists may balk at the notion of pivotal crops, it is implied in many of their formulations. For Shackles, for example, focus-loss and focus-gain calculations should envisage not only the circumstances which will insure a particular focus gain or loss (*i.e.*, labor and capital required), but also the conditions to realize such a circumstance (*i.e.*, the security of a certain income to initiate subsequent activities). Boussard, quite correctly, assumes that low income or losses in one venture can be subsidized with the revenue from another; hence, he suggests that it is more accurate to rely on estimates of aggregate focus-loss than the focus-loss estimated for each separate activity.

The notion of pivotal crop is not only very much in the spirit of the thinking of economists but also may help solve one of the problems that emerges from estimates of total permissible focus-loss: how to estimate the fraction of the total loss that each crop must shoulder. Boussard and Petit (1967) are aware of the problem. With some hesitation, they suggest the fraction of one-third as a realistic estimate based, it is true, on intuition and also on considerable experience. If, instead of assuming a purely intuitive fraction, one determines the relative importance of each crop and which, if
any, assumes a pivotal position, then estimates are more likely to be realistic and their model still more convincing. The pivotal crop can be expected to cover most, if not all, of the family's very basic cash needs, as well as a small fund to initiate subsequent activities in their annual cycle. Subsidiary activities will thus tolerate a focus-loss point which is relative not just to costs of production but also to their orders in the annual cycle and whether or not capital has to be borrowed.

Six summary points emerge from the preceding discussion, all of which can only be stated as suggestions since the data is still scanty. First is that focus-loss estimates are more likely to accurately represent the perceived permissible focus-loss of middle-income subsistence farmers than of subsistence farmers close to the line of disaster. Second, the accuracy of the prediction will also depend on capital/labor ratio required for the particular enterprise. Third, the farmers may allow for lower permissible focus-losses when they are not able to earn subsistence wages. Fourth, that on the whole, farmers, unless they have minimal acreage, are not considering ruin but low income. Fifth, the fraction that each enterprise must shoulder of the permitted loss relates to whether or not it occupies a pivotal role, a fact of particular importance to lower income farmers in less developed countries which do not have easy access to loans to cover losses or routine costs. Sixth, depreciation costs or repayment of initial investment is not included by the farmer in his estimates of focus-loss.

Whereas, common sense guides us in our speculation regarding how a farmer may arrive at focus-loss perception, we are at a loss at the moment to determine how focus-gain points are formulated. The farmers interviewed could not themselves verbalize how they decide what yields and what profits to expect. Miss Osborn, who interviewed the Indians in 1975, had the distinct impression that the range and evaluation of prospects were formulated not in terms of accumulated experience regarding price fluctuations but based on how much prices had fluctuated that particular year. But it is hard to tell whether their appreciation of supply/demand relation and of government as a price-setting agent leads them to formulate over pessimistic, optimistic, or accurate evaluations. Whatever factors may influence the range of prospects conceived, focus-loss estimates are not biased by high focus gain.

4. THE ENTICEMENT OF RISKY PROSPECTS

In this paper, I review how uncertainty affects the process of decision, the ability to formulate prospects of gain or loss, as well as value of the lowest permissible return. Risky incomes are responsible for a subsistence-first strategy. The uncertain availability of inputs inhibits the formulation of prospects and any a priori planning of food production.
Yet, as already noted, uncertainty does not thrust the farmer into an overly cautionary stance. Once very basic subsistence requirements are insured, the peasant plants one of the local cash crops even when, as in 1961, the chances were that the return would barely cover costs if weather conditions were not propitious. In fact, about 15 years ago, a peasant with a small coffee plantation of half a hectare had to avoid any cash outlays (i.e., wage payments or acquisition of even basic equipment) to insure a cash revenue from their harvest. Certainly, such a poor peasant was not a risk averter; had he preferred a safe income over a chance of a higher though risky return, he would have instead avoided small scale cash cropping and sold his labor time to a local planter for a wage. It was the peasant with about 3,000 trees who, in 1961, could feel “safe” with a cash income from coffee; at present prices, 1,000 trees are sufficient to insure cost of production and a revenue for family expenses. Only about one per cent of the Indian peasants, in 1961, had enough coffee to be assured of a satisfactory income; yet, none of those who had suitable land refused to plant this cash crop. To some readers, such a risk may appear as unwarranted, but the alternative was an extremely low wage (see Appendix 13.3) or crops with difficult and costly marketing requirements.

A still poorer farmer or one without adequate cash crop land is willing to speculate with other risky ventures. One of them planted an unusual extension with beans (a very risky crop with existing technology) in response to the incentive of a buyer who suddenly offered a high price for beans. Others entertained more dubious ventures; many of which, of course, failed and they were forced back to work as laborers.

The farmer, with one to three hectares of coffee land, who can afford to envisage a revenue high enough to purchase a cow, processing equipment, or even land, if available, has always preferred slower but safer avenues of expansion. His strategy is one of expanding his coffee plantation to the limits set by the adequacy of his land, then invest in processing equipment or, more recently, to convert it to the higher yielding Caturu variety which requires high fertilizer inputs. This same farmer does not entirely avoid risky prospects. His willingness to convert his plantation to an enterprise with higher capital requirements is a case in point (though I am not certain whether they are truly aware of the extent of capital required as they just planted the seedlings in 1975). Another case in point is the willingness to plant a second, more risky, cash crop; sugar cane. This second crop does not compete with coffee for land or labor, hence, it is a complementary venture rather than an alternative. Nevertheless, the farmer had another safer option: to expand his subsistence production. Such tendencies are reflected in permissible focus loss estimates by farmers, as discussed in a previous section.

Notwithstanding the impact of attitude differences, it now is clear that a strict adherence to a categorization of a population of producer into risk and risk averters is counterproductive. Most producers are cautious suboptimizers in the sense that they insure their subsistence and may, to the best of their
knowledge, avoid choosing a prospect where a loss below the bearable minimum is highly likely. Yet, while they are insuring themselves, they are also willing to gamble in another one of their activities (see contribution in this volume by Scandizzo and Dillon, as well as the classic paper of Friedman and Savage, 1948).

There is no doubt that some had more flair than others and that farmers, when young, were more prone to optimism than when they were interviewed 15 years later. Nevertheless, it should be remembered that a willingness to accept a risky prospect does not emerge simply from a personality configuration but from the confrontation of a person who has learned certain strategies with a set of opportunities.

I hope that the trials and tribulations of the peasant Indians of Tierradentro will dissuade economists from the easy appeal of simple classifications. The risk averter is a farmer in distress in a world that presents just too many uncertainties and provides him with too little information. He is no more conservative than the commercial risk-prone farmer; he is simply biding time. Our task is to determine what landholding pattern, what marketing opportunities, and price stabilization policies may trigger their transformation.
Appendix 13.1

Land distribution (1960-70)

<table>
<thead>
<tr>
<th>Land ownership</th>
<th>Indian</th>
<th>Non-Indian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landless</td>
<td>22</td>
<td>4</td>
</tr>
<tr>
<td>Less than 1 ha</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>1-5 ha</td>
<td>100</td>
<td>6</td>
</tr>
<tr>
<td>5-10 ha</td>
<td>48</td>
<td>2</td>
</tr>
<tr>
<td>10-30 ha</td>
<td>23</td>
<td>3</td>
</tr>
<tr>
<td>30-50 ha</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>50-70 ha</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Over 100 ha</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>206</td>
<td>27</td>
</tr>
</tbody>
</table>

Appendix 13.2

Coffee prices in the interior

Prices in Colombian pesos per arroba (25 lbs.) of coffee

<table>
<thead>
<tr>
<th>Year</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>$19.88</td>
</tr>
<tr>
<td>1955</td>
<td>31.98</td>
</tr>
<tr>
<td>1960</td>
<td>42.93</td>
</tr>
<tr>
<td>1965</td>
<td>71.70</td>
</tr>
<tr>
<td>1970</td>
<td>126.00</td>
</tr>
<tr>
<td>1975</td>
<td>330.00</td>
</tr>
</tbody>
</table>

The above figures are indicative of the trend in coffee prices. There have been no major fluctuations during intervening years.

Appendix 13.3

Wage labor

In 1961, Indians received a wage of $3 for unskilled agricultural labor, $5 a day for labor in panela production. Non-Indians received $5 for unskilled labor and $10-20 for skilled labor. The minimum necessary for subsistence if fully dependent on wage labor. The minimum necessary for subsistence if fully dependent on wage labor would have been $15 a day. About 50 per cent of the male Indian population worked about three months a year; the rest, less or none at all.

In 1975, Indians received from $10-15 a day, and according to a DANE census, 21 per cent of the male Indian population are wage earners. Wage rates are expressed in Colombian pesos.
### Appendix 13.4

**Cash income, expenditures, and capital investments for twenty-four Indian families (1961)**

<table>
<thead>
<tr>
<th>Net income</th>
<th>Tools</th>
<th>Animals</th>
<th>Land improvement</th>
<th>Ceremonial expenditures</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ 320</td>
<td>$ 25</td>
<td>$ —</td>
<td>$ —</td>
<td>$ 25</td>
</tr>
<tr>
<td>350</td>
<td>20</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>400</td>
<td>25</td>
<td>—</td>
<td>5</td>
<td>—</td>
</tr>
<tr>
<td>420</td>
<td>—</td>
<td>330</td>
<td>—</td>
<td>—</td>
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<tr>
<td>480</td>
<td>240</td>
<td>150</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>500</td>
<td>—</td>
<td>—</td>
<td>160</td>
<td>20</td>
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<td>500</td>
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<td>—</td>
<td>50</td>
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<td>320</td>
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<td>700</td>
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<tr>
<td>800</td>
<td>260</td>
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<td>860</td>
<td>220</td>
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<td>—</td>
<td>10</td>
</tr>
<tr>
<td>1,000</td>
<td>25</td>
<td>—</td>
<td>—</td>
<td>15</td>
</tr>
<tr>
<td>1,000</td>
<td>—</td>
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<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1,200</td>
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<td>—</td>
</tr>
<tr>
<td>1,300</td>
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<td>250</td>
<td>10</td>
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<td>0</td>
<td>600</td>
<td>—</td>
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<td>2,200</td>
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<td>(?)</td>
</tr>
<tr>
<td>2,500</td>
<td>200</td>
<td>900</td>
<td>160</td>
<td>—</td>
</tr>
</tbody>
</table>

Income from wages is not included; none of the families with net incomes over $1,000 earned wages. Income and expenses expressed in Colombian pesos.
Part VI

Implications of uncertainty for crop breeding and varietal selection
Chapter 14

Risk and uncertainty as factors in crop improvement research

Robert E. Evenson, John C. O'Toole, Robert W. Herdt, W.R. Coffman and Harold E. Kauffman*

The principal focus of much of the risk and uncertainty literature in agriculture is on the behavior of farm producers in the light of the variability of natural and market events. This chapter, in contrast, is concerned with the organization, operation and productivity of a crop improvement system in the light of environmental variability.¹

Crop improvement activities respond to and partly determine the consequences of environmental uncertainty. That is, research directed toward developing improved crop varieties and related agronomic and economic practices is itself guided by the degree of uncertainty in the natural environment and by the response of producers to that uncertainty. And, existing technology partially determines the economic instability associated with variability in natural environmental factors. Part I of this chapter briefly reviews the relevant concepts of environment, stability and adaptability. Part II sketches the outlines of some economic principles for crop improvement and the implications of environmental variability for crop improvement in the light of different kinds of environmental variability that appear to exist. In part III, we review some techniques that have been used and suggested for evaluating multilocation genetic trials and present the results of some of our own efforts to evaluate recent international rice yield trials.

¹The judgments and conclusions reached in this chapter are those of the authors and do not represent those of their organizations.

¹The word environment has come into common use in the last decade. Misuse has also increased. Perhaps the most common misuse is equating environment with climate. For a general treatment of the “environmental complex” see Billings (1952). An abbreviated treatment of environmental elements appears in O'Toole, et al.
1. ENVIRONMENTAL FACTORS IN CROP IMPROVEMENT RESEARCH

Crop improvement activities would be immensely simplified were it not for "genotype-environment interactions,"\(^2\) which cause a genotype or variety to perform differently in different environments. Each genotype performs at its biological maximum in a particular environment. As environmental elements depart from the biologically optimal state for a given genotype, negative genotype-environment interactions reduce performance. The nature of this reduction differs by genotype so it is possible to develop genotypes suited for different environments.

A new crop variety tailored for a given environment will be superior to existing crop varieties only over a limited range of similar neighboring environments. This range of neighboring environments will be quite narrow if few resources are directed toward crop improvement for neighboring environments and will be broader if many resources are devoted to crop improvement for different environments.

Environments can most conveniently be defined in terms of their separate elements. Among the more important are soil and geographic elements which are fixed at a location but highly variable between locations. Climatic and biotic elements vary both across locations and within locations from time to time. Economic and social elements affect the economic performance of genotypes and vary among locations, seasons and years. These various elements all affect the degree to which genotypes perform well over a range of environments.

One issue facing a crop improvement system is determining the optimal allocation of resources between tailoring genotypes to given environments and designing genotypes well adapted to a wide range of environments (wide adaptability). Environmental variability over time within a location confronts producers, while environmental variability across locations does not result in risk or uncertainty to producers, but does have implications for crop improvement research. The problem becomes more complex when one recognizes that a crop improvement system comprises institutions at the international, regional, national, provincial and even the local level.

\(^2\)This could be termed phenotype-environment interactions. The crop genotype is its true genetic attributes, while its phenotype is its revealed characteristics which are affected by the environment. The genotype is by definition fixed. We use genotype here because it is possible to view the phenotype as the sum of genotype component, an environmental component and an interaction effect.
1.1. Tolerance, Adaptability and Stability

The concept of tolerance, used by plant geographers to explain plant movement and migration, is relevant to the problem of developing well adapted genotypes. Good's tolerance theory says that "each and every plant species is able to exist and reproduce successfully only within a definite range of environmental conditions" (Wilsie, 1962). Shelford's earlier general law of tolerance included observations on the relationship of plant performance to environmental variability (Wilsie, 1962). The concept of tolerance is schematically represented in Figure 14.1 where performance of alternative genotypes A, B and C are related to one environmental factor, temperature. The point illustrated in the figure is that tolerance is not a constant trait but is a characteristic for which plant breeders can systematically search in their research programs.

Figure 14.1. Comparison of organisms with narrow limits to low and to high temperature to those having broad limits of tolerance (Source: Wilsie)

The concept of tolerance has been replaced in the modern literature by the related concepts of stability and adaptability. Stability as used in this chapter refers to the performance of a genotype with respect to changing environmental factors over time within a given location. The more stable a variety, the less sensitive its performance is to environmental changes within a location. Adaptability refers to the performance of a genotype with respect to environmental factors that change across locations.
Existing literature on the measurement of stability and adaptability does not make a clear distinction between the two concepts (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Goldsworthy, 1974; Laing and Fischer, 1973). In fact, there is a presumption in much of the literature that adaptability and stability are highly correlated. In Section 3, we provide some evidence that they may not be. This is important to crop improvement strategies because these traits are subject to selection by plant breeders. The breeder can, usually by sacrificing other traits, achieve higher stability or wider adaptability. This selection process, then, is the primary means by which crop improvement programs respond to risk and uncertainty.

2. OPTIMIZING PRINCIPLES IN CROP IMPROVEMENT RESEARCH

Crop improvement research entails the improvement of genotypes, agronomic practices and the economizing behavior of farmers. Genotype improvement can be accorded a primary role since when new genotypes are developed, they provide scope for improvements in agronomic and economic or managerial practices. Accordingly, we focus on genotype improvement as the primary focus of optimal crop improvement system organization vis-à-vis environmental factors.

We develop a conceptual framework that has implications to selection for genotype stability and adaptability as a response to uncertain environmental changes affecting producers. Research to improve agronomic techniques and economizing techniques may be guided by similar considerations.

2.1. The Search Principle in Research

Consider a set of research activities to improve the genotype of a particular crop in the context of a search model. Suppose the crop has only one important trait of economic value, say yield per hectare. Suppose that a set of plant breeders, with a given stock of genetic materials and a given set of methods and resources for screening and testing, attempt to produce new genotypes which are economically better than existing genotypes. Also, initially assume only one environment.

The problem can then be set up as follows: the plant breeders search in a distribution of potential genotypes for those that are superior to existing genotypes. The stock of genetic materials and the known breeding and screening methods determine the parameters of the distribution of potential genotypes. The breeders determine the number of crosses and the volume of material screened. This now becomes a “statistics of extreme” problem.
Crop improvement research

To illustrate analytically, let the distribution searched on the simple exponential, with mean \( \theta \):

\[
f(x) = \lambda e^{-\lambda(x-\theta)}, \quad \theta \leq x.
\]

For this distribution, the expected value of the maximum \( X \), denoted as \( Z \), in a sample of \( n \) searches or observations is:

\[
E_n(Z) = \theta + \frac{1}{\lambda} \sum_{i=1}^{n} \frac{1}{i}.
\]

One can readily see that the expected value of the maximum rises with \( n \), but at a diminishing rate. That is, there are diminishing returns to search. This property of diminishing returns holds for virtually all distributional forms.\(^3\)

If the current technological level or best genotype is \( Y \), the expected technological change \( \Delta Y \), as a function of \( n \) is:

\[
E_n(\Delta Y) = \theta + \frac{1}{\lambda} \sum_{i=1}^{n} \frac{1}{i} - Y.
\]

\( E_n(\Delta Y) \) increases (at a diminishing rate) as \( n \) increases, but decreases as \( Y \) increases.\(^4\)

Figure 14.2 illustrates the relationship between \( \theta \), \( Y \) and \( \Delta Y \) for the exponential distribution. As \( Y \) shifts to the right, it becomes progressively more difficult to discover improvements, \( \Delta Y \). Optimal \( n \) in any given time period is that \( n \) in which the diminishing marginal product of search is equal to the rising marginal cost of search.

This formulation indicates first, that the difficulty of finding better genotypes may be represented by \( (Y - \theta) \) which is the gap between the best genotype \( Y \) and the mean of the existing distribution (\( \theta \)). The smaller the difference \( (Y - \theta) \), the larger the technological gap and the more fruitful is search. Second, as search continues, \( Y \) is shifted to the right, the technological gap closes and the scope for improvement decreases (the potential of the technology is exhausted). If the distribution searched is not altered, the marginal cost of research will eventually exceed its marginal return. Third, the

\(^3\)The Cauchy distributions represent distributional forms where this is not true. See Evenson and Kislev (1976) and Kislev and Rabiner (1976) for a more complete discussion of the application of search models to research processes.

\(^4\)This can also be expressed as:

\[
E_n(\Delta Y) = \int_{y}^{\infty} [1 - F^n(Z)] \, dZ
\]

where \( F(Z) \) is the cumulative probability distribution of \( X \).
greater the variance of the distribution of potential genotypes (holding the mean content), the higher the productivity of plant breeding research. Similarly, the higher the mean of the distribution of potential genotypes, the higher the productivity of plant breeding research.

![Graph showing the probability of discovering improved genotypes for a given distribution of potential genotypes.](image)

**Figure 14.2.** The probability of discovering improved genotypes for a given distribution of potential genotypes

One important implication from this model is obtained by considering how the mean and variance of the distribution of potential genotypes can be changed. This can be done by incorporating new genetic material into the research system, by developing more precise screening and testing procedures, and by developing new methods of research. As the model is expanded to consider several traits, such as disease and insect resistance, fertilizer responsiveness, photoperiod response, the roles of the related sciences such as entomology, physiology and soil chemistry become clearer. Work in these areas changes the distribution of potential genotypes and therefore is productive even though it does not produce new genotypes directly.

### 2.2. The Effect of Environmental Variation

We now introduce alternative crop production environments to deal with the basic issues of stability and adaptability. Suppose the research system is producing genotypes for several locations, each of which has several
Crop improvement research

environmental states. Should the research system “target” its genotypes for one environment or for many environments, and if many, how many? If there were no added costs to producing added genotypes, the solution to the problem faced by the crop improvement system would be simple: a genotype should be produced for every type of environment. But it is not the case that one can expand the number of genotypes without added costs. It costs more to organize a crossing and screening program for several types than for one type. Each may require the development of its own different field trial and screening setup. On the other hand, there are scale economies to the conduct of research. Thus, the unit costs of additional genotypes may be lower than the initial types.

The benefits from tailoring technology to produce more types occur because negative genotype-environment interactions reduce the productivity of research outside its primary target environments. This interaction is minimized when technology is perfectly tailored to each environment. But this is unlikely to be optimal except in cases where the technology “potential” is almost completely “exhausted.”

Suppose that there are $e$ discrete environments. Define a set of weights, $W_e$, to be the shares of total crop area in each environment. Then,

$$V = \sum_{e=1}^{T} W_e E_n (\Delta Y_e) - C_n (T)$$

expresses the total expected value of the improved technology less the total costs (including social costs) during a particular period. The research system can attempt to maximize this expression by varying $n$, the intensity of research activity for a given type of environment, and $T$, the number of types of environments for which genotypes are targeted. More appropriately, the present value of a stream of $V$'s over time should be maximized, and in each period, $n$ and $T$ should be chosen so that the present marginal value of the expected yield increase in each type should be equal to the present value of marginal costs for the entire system. These costs are a function of both $n$ and $T$.

The choice of $T$, however, is not a simple matter. One cannot simply handle the problem by saying that the research system should select the

---

5 In spite of scale economies, few research systems are capable of producing more than a few types. Even large systems would find it very costly to produce, say 15 types.

6 This is due to the search process. The payoff to tailoring may be low relative to the payoff to improving on tailored material in the early stages of search. But as diminishing returns to this process set in, it becomes more attractive to tailor. The history of sugar cane improvement shows a clear pattern of just achieving basic gains, then of tailoring the high yielding material to environmental niches. Similarly, the high yielding rice and wheat varieties are now being tailored.
environments for which varieties are to be tailored on the basis of the weights. The importance of the environment is one factor, but a further consideration is required. As long as \( T \) is less than \( e \), "spillover" effects have to be considered and the fundamental research strategy will differ in that adaptability will become a valuable characteristic.

### 2.2.1. Spillover and clustering principles

The spillover effect is related to the genotype-environment interaction. An improvement in a genotype will have maximum value in one particular environment. But it may well represent an improvement for neighboring environments as well, that is, "spillover." Since there are many components to a technology, it is quite possible that the environment interaction effects and hence, the spillover effects will differ by component. Disease and insect resistance, for example, may represent components of technology with large spillover effects. International centers and large national systems may be able to specialize in the production of these components, leaving to local or branch stations the task of concentrating on the components with higher environment interaction effects.

In general, an optimal research system will include a grouping or clustering of environments into niches and a program directed to each niche. A program may specialize in improving only a subset of the components of the final technology. Other institutions and programs producing other components will also be organized according to a clustering of environments. Several layers of clustering may make sense, depending on the decomposability of technology and differing environmental effects.

Optimal clustering of environments could be based on statistical grouping concepts. Suppose that one formed \( T \) groups from \( e \) environments. The variance in environmental factors can be decomposed as: the sum of squared deviations from the group means and the sum of squared group mean deviations from the overall mean.

\[
\sum_j \sum_i (e_{ij} - \bar{e}_j)^2 = \sum_j \sum_i (e_{ij} - \bar{e}_j)^2 + \sum_i (\bar{e}_i - \bar{e})^2.
\]  \( (5) \)

By selection of groups to minimize within group variance, the between group variance will be maximized and spillover effects will be maximized. Now, consider:

\( \text{Decomposability is itself an important factor in crop improvement research. With modern procedures for identification of traits and screening, crop technology is probably more decomposable than in the past.} \)
\[
\sum_{e} \sum_{f} (W_{ef} E_{n} (\Delta Y_{ef}) - E_{n} (\Delta Y))^{2}
\]

\[
= \sum_{e} \sum_{f} (W_{ef} E_{n} (\Delta Y_{ef}) - W_{e} E_{n} (\Delta Y_{f}))^{2} + \sum_{f} (W_{f} E_{n} (\Delta Y_{f}) - E_{n} (\Delta Y))^{2}.
\]

To minimize within group variance, groups will be chosen so as to equate the weighted group variances.\(^8\) The role of the weights can be seen in this case. More technology types will be produced to a given range of environments, the more economic activity there is in the environments.

We can only approximate the optimizing principle here. We have not considered spillover effects across groups which may alter the picture. But, most importantly, we have not considered the effect of unstable environments over time.

2.2.2. The effect of variable environments

Once a grouping of environments is chosen, it will no longer be optimal to establish screening criteria and related research methods to produce technology tailored to a single environment within the group. Instead, it will be optimal to design or tailor a technology for the total group. This means that tradeoff will be made between genotypes with desirable characteristics for one environment and high environment interaction effects and genotypes with less desirable characteristics for any single environment but which are more widely adaptable. Figure 14.3 illustrates this proposition. The vertical axis measures the expected yield increment from alternative research programs. The horizontal axis measures a generalized environmental variable. Research programs 1, 2, 3, 4 and 5 produce expected yield increments represented by 11', 22', ... , 55'. These technologies have high environment interaction effects as depicted by the curvature and, thus, are highly tailored to particular environments. The curve \( AA' \) reflects the expected yield increment from a program that selects for lower environment interaction effect, i.e., wider adaptability. Each of the highly tailored programs has a higher expected yield increment for its local environment while \( AA' \) has a higher yield increment over a broader range of environment.\(^9\)

\(^8\)See Johnston (1960) for a discussion of clustering techniques.

\(^9\)The tradeoff between yielding ability and adaptability is part of the more general nature of crop characteristics. In the selection process, one cannot simply select for one trait while also obtaining other characteristics as well. "Linkages" between traits can be broken with some breeding techniques but this is incomplete. Thus, to get more of a desirable trait, one also obtains more of some undesirable traits and less of other desirable traits.
Figure 14.3. Expected yield increments from alternative research programs

If the range of environments, $E_1$ to $E_p$, represents a group the optimal program will depend on the distribution of the crop by environment. If most of the production is concentrated around $E_3$, for example, the program producing $3'$ will be optimal. If production is evenly distributed from $E_1$ to $E_p$, the program producing $AA'$ is clearly superior.

Now suppose that in a certain location the environment could range from $E_1$ to $E_p$ over time with a uniform probability distribution of occurrence of each environment. Under these circumstances, the wide adaptability program $(AA')$ would be optimal for the location being considered.

But, if the distribution is not uniform across $E_1$ to $E_p$, then $AA'$ may not be optimal, so one of the tailored programs would be preferred. Clearly, the value of wide adaptability depends on whether variability in environmental conditions across locations is similar to variability in environments within locations. Not all environmental factors vary by location and the variance of, say rainfall, across locations may not be highly correlated with the variance over time for some areas. Thus, it is likely that wide adaptability may not, in general, be optimal. We examine some empirical evidence related to this issue in the next section.
3. SOME EMPIRICAL EVIDENCE ON STABILITY
AND ADAPTABILITY

Much of the success of the semidwarf wheat varieties in areas outside
their initial development (Mexico) has been attributed to the benefits of multi-
location testing and the resulting wide adaptability. International yield trials
have been conducted for a number of other commodities, including rice and
maize. These trials, it should be noted, have not generally been utilized by
breeders to identify phenotype characteristics except for yield. Average yields
across locations, ranking of the yield of varieties within locations, and average
ranks across locations are generally the only routinely calculated statistics. In
this section, we review some alternative procedures for analysis of these data
and apply one procedure.

3.1. The Stability Index Concept and Modifications

To characterize the yield stability of hybrids, Yates and Cochran (1938)
suggested the regression of yield on an “environmental index” measured by
the mean yield of all varieties in a particular environment. Finlay and
Wilkinson (1963) used a logarithmic transformation of yield data and fitted the
model:

$$\log (Y_{ij}) = a + b_i \log (X_{ij}) + u_{ij}$$  \hspace{1cm} (7)

where $Y_{ij} = \text{yield of variety } i \text{ at site } j$ and $X_{ij} = \text{mean yield of all tested}$
varieties at site $j$. These authors paid greatest attention to the biological
interpretation of the stability parameters and its inference for a plant breeding
program. The parameter $b_i$ was used as an index of stability. This stability
index was then plotted against variety mean yield. Their generalized
interpretation is intuitively compelling (Figure 14.4) especially when large
numbers of diverse genetic materials are being categorized. Subsequently,
Eberhart and Russell (1966), Laing and Fisher (1973), and Strobe and
Johnson (1972) used similar models to estimate indices of “stability” for multi-
location variety trials.

Recently, Matsuo, et al. (1975) published an analysis on yields of 75 rice
varieties grown at 45 locations, initially using the Finlay and Wilkinson
method of analysis. Subsequent treatments of the data involved principal
component analysis and orthogonal polynomial regression on environmental
factors and utilization of Wricke’s (1962) “ecovalence” concept.10

10The reader is also referred to this publication for discussions on the physiological and
genetic basis of adaptability and the implications of breeding for adaptability and productivity.
Goldsworthy (1974) discussed an approach being developed (Munogomery, et al., 1974) that is related to the concepts of groups discussed above in which "cluster" or "pattern" procedures reduce the complexity of responses to environments. Initial testing of his procedures with wheat yield nursery data were superior to linear regression analysis. Anderson (1974) has experimented with the use of stochastic dominance to evaluate data from international wheat improvement trials of CIMMYT. His technique gives primary weight to risk consideration so that varieties that have a very small frequency of poor performance are rejected in favor of varieties that may have a higher potential performance under appropriate environments.

3.2. The Measurement of Stability and Adaptability

As the above review indicates, most of the existing literature do not distinguish between adaptability and stability as we have in this chapter. In this section, we report relatively simple measures of stability and adaptability for
22 rice varieties from the International Rice Yield Nursery (IRYN) trials for three years and from similar trials conducted as part of the All India Coordinated Rice Improvement Program (AICRIP) in India for several years.

Our procedure is relatively simple. Each variety in the IRYN and the AICRIP set was planted in several locations (22 in the case of IRYN, and from 20 to 25 in the case of AICRIP) for 2 or more time periods. (In the case of IRYN, replications for each site were included in the analysis.) The following models were fit:

\[ Y_{jit} = a_1 + b_{ij}^M + \sum_{i=1}^{m} d_{1i} L_i + e_{1ijit} \]  
\[ Y_{jit} = a_2 + c_{ij}^M + \sum_{i=1}^{n} d_{2i} T_i + e_{2ijit} \]

The conceptual basis for these relationships is based on the standard analysis of covariance formulas. The variable \( M \) is an index of environment in each location \( i \) and time period \( t \). Maximum yields (the average of the two highest yields at each location) are used as the index of environment. In expression 8, the yield of variety \( j \) in location \( i \) and time period \( t \) is regressed on the environment index for that location and period and on a set of location dummy variables. This removes systematic location effects and uses the within-location variance to estimate the parameters of the equation. The \( b \) coefficient is interpreted as a stability parameter measuring stability within a location across time.

Equation 9 includes time period dummy variables and the relationship is estimated utilizing across location variance. We interpret the estimated parameter \( c \), as an adaptability parameter measuring adaptability across locations.

We acknowledge that the error structure may not be fully consistent with this procedure and that alternatives exist (Binswanger, 1976). But, we believe that these estimates will serve to at least initiate a more systematic investigation of these data.

Table 14.1 reports the estimates of the \( b \) and \( c \) parameters for the IRYN and AICRIP data. Figure 14.5 shows the relationship between the estimated stability and adaptability indices for the two sets of data. The results have important policy implications for the design of crop improvement research. They show that for the IRYN locations involved in these trials, adaptability and stability are not closely related. Breeders cannot rely on screening across these locations to select for stability. This raises some critical questions about present crop improvement systems which to some degree are based on the presumption that adaptability and stability are closely related. The AICRIP locations do, however, show positive correlation. The set of locations in the Indian program is apparently better suited to the joint selection for stability.
Table 14.1

Measure of stability and adaptability of yields

<table>
<thead>
<tr>
<th>Variety name</th>
<th>1st, 2nd and 3rd IRYN Data</th>
<th>AICRIP Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stability Coefficients Yield on Maximum Yield + Location Dummies ( \beta )</td>
<td>Adaptable Coefficients Yield on Maximum Yield + Time Dummies ( \gamma )</td>
</tr>
<tr>
<td>1</td>
<td>PBM-6634-257-1</td>
<td>0.58</td>
</tr>
<tr>
<td>2</td>
<td>RP4 14</td>
<td>0.68</td>
</tr>
<tr>
<td>3</td>
<td>BCI-90-2</td>
<td>0.657</td>
</tr>
<tr>
<td>4</td>
<td>Chiang Sen. Yu 6</td>
<td>0.639</td>
</tr>
<tr>
<td>5</td>
<td>C4-63</td>
<td>0.49</td>
</tr>
<tr>
<td>6</td>
<td>B4-36-2</td>
<td>0.190</td>
</tr>
<tr>
<td>7</td>
<td>IR 630-271-1</td>
<td>1.671</td>
</tr>
<tr>
<td>8</td>
<td>IR650-95-1-3</td>
<td>1.250</td>
</tr>
<tr>
<td>9</td>
<td>BKN 6029-74-4</td>
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</tr>
<tr>
<td>10</td>
<td>IR 1529-680-3</td>
<td>0.350</td>
</tr>
<tr>
<td>11</td>
<td>IR 26</td>
<td>0.379</td>
</tr>
<tr>
<td>12</td>
<td>Bujbub</td>
<td>0.372</td>
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<tr>
<td>13</td>
<td>Javaneri</td>
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</tr>
<tr>
<td>14</td>
<td>EFT 2938</td>
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</tr>
<tr>
<td>15</td>
<td>Petia</td>
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</tr>
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<td>Cica 4</td>
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<tr>
<td>22</td>
<td>IR861-253-2-45</td>
<td>0.771</td>
</tr>
</tbody>
</table>

*Standard deviation of the coefficient above it.
and adaptability than are the international locations. Thus, the Indian sites are perhaps a cluster, in the sense discussed in the previous section.

![Graphs showing relationship between stability and adaptability](image)

**Figure 14.5. Relationship of stability and adaptability**

Both these results should, of course, be corroborated by other estimation procedures and by other data sets. One question which deserves explanation is the sensitivity of the results to the locations chosen. If it is possible to select a set of locations from within the IRYN data where the correlation between the two measures is high as it is in the AICRIP data, it will be valuable to plant breeders. Presumably, proper clustering of environments would increase the correlations to achieve this.

Figure 14.6 shows the relationship between the stability and adaptability measures and the relative yielding ability of each variety. Since the performance of the variety in its best environment is most relevant, the figure shows stability and adaptability plotted against the average of the best two relative yields. There is little relationship between stability or adaptability and
the performance in the best two locations. This suggests that these traits may not be too costly in terms of yield performance.

Thus, we conclude that there is little support for the assumption that stability and adaptability are correlated if no attention is paid to appropriate clustering. Adaptability may be correlated with stability within properly clustered locations, but clustering techniques were not investigated. High levels of stability and adaptability do not appear to reduce the performance of varieties in the locations where they are best adapted. All these conclusions are, however, tentative because of the rather small data set supporting them.
Chapter 15

Diversity by breeding for genetic variability on the farmer's field

Douglas Neeley, Wayne McProud, and John Yohe

1. INTRODUCTION

A major source of risk to the farmer is the unpredictability of critical environmental factors. Varietal response to such variability will be a major criterion for the farmer's acceptance of material released by national and international breeding programs. Since it is improbable that a single variety will be able to meet all sources of environmental fluctuation, many genetically diverse varieties should be released to serve as a buffer against abnormal conditions.

Unfortunately, the direction of most breeding programs is toward the development of a few "elite" high yielding varieties, a direction that usually leads to the release of genetically narrow based material. Breeding techniques that permit a greater exploitation of genetic variability do exist and should be adopted more widely in national and international breeding programs. This chapter outlines the philosophy behind some of these techniques as they relate to introducing broad genetic variability to the farmer's field.

2. VARIETAL IMPROVEMENT

There are many traits a genetic line must possess if it is to become a successful variety. However, three of the most important traits are (1) its ability to maximize producer profit, (2) stability at a particular location over years, and (3) less importantly, adaptability over a wide range of environments.
In a critical analysis of breeding programs for developing these traits, it becomes apparent that three major steps are taken. First, there is the collection or creation of genetic diversity (creation phase). Secondly, there must be a selection process to bring the population down to a manageable size prior to critically examining the above three traits (pretrial selection phase). The third step is to identify which selections have the three desired traits (yield trial phase). We look at each of these steps as they relate to breeding and selecting for genetic diversity and stability.

2.1. Creation Phase

One of the major criticisms leveled at current breeding programs is the narrowness of the genetic base from which parental material is drawn. For example, according to Eslick and Hockett (1974), since 1900, at most 11 outside sources of barley germplasm have been introduced into those varieties making up a very substantial proportion of North American barley acreage. Similarly, in the development of malting barley varieties in Japan, only 11 separate genetic sources were represented in varieties released before 1968 (Meguro, 1971). Considering the vast genetic sources of barley available (over 16,000 in the U.S. Department of Agriculture's world barley collection alone), 11 is an appallingly low number to be utilized in modern breeding programs.

This narrow base reflects the nature of most breeding programs which introduce new sources of genetic diversity by crossing them into the established breeding stock. Frequently, crossing methods, such as backcrossing, are used to guarantee that most of the established genetic base remains unaltered. Such conservative breeding methods result in the release of genetically narrow based material.

A reason for this conservative approach is put forward by Ramage (1974) in his "Happy Homes Theory." In order to optimize its expression, a plant characteristic, whether it is simply or complexly inherited, must act in harmony with other genetic systems in the plant. The difficult task of building compatible genetic structures has been continuing for decades. To tear these structures apart and reconstruct new compatible systems, which must be done if there is to be a substantial expansion of genetic diversity, is a formidable task. Breeders tend to take the course of least resistance and work within the existing genetic structures.

One method of broadening the genetic base is through the creation of a genetic reservoir. Several genetic sources can be intercrossed forming what is called a composite. The progenies are then bulked and are themselves intercrossed. This procedure is continued from one generation to the next. From such mass reservoirs, material can be selected for entry into breeding programs. Successful reservoirs do exist and have been sources of material used directly as varieties or as parental material entered into more advanced breeding programs (e.g., barley composites maintained at the University of California at Davis).
A reservoir can serve, not only as a means of pooling sources with measurably useful characteristics, but also for entering germplasm having no apparent direct use as breeding material. Such germplasm may eventually find useful expression through recombination within the pool.

2.2. Pretrial Selection Phase

The amount of genetic variability generated from a given cross or cross combination is so immense that it must be substantially reduced to a manageable size before it is possible to critically evaluate the material.

Under most breeding programs, the method of reduction is to impose stringent, purposeful selection in early generations. The major reason for this conservative approach is that most breeders have consciously or unconsciously established in their mind the idea of a desirable plant. Usually, this picture of the "elite" type closely approximates those varieties that have historically been most successful in the breeder's experience. Taking barley as an example, in a region that grows two-rowed barleys, the breeder will tend to call his "elite" type two-rowed rather than six-rowed, because two-rowed barleys have historically been successful. This assumption could be wrong. The problem that arises is that, by sticking to the morphologically "elite" types, potential sources of genetic diversity introduced at the creation phase are discarded in this second step before they can even be tested for yield, stability and adaptability.

Recently, new pretrial techniques have been introduced which encourage the advancement of diverse genetic material into the third phase of varietal development. Reinberg, et al. (1975) reported on a comparison of three pretrial selection techniques in barley: (1) pedigree selection (conscious selection), (2) single seed descent (random zygotic selection), and (3) double haploid method (random gametic selection). Their findings indicated that the two random selection procedures were just as effective in advancing material to the yield tests as was the conscious selection effort. Similar evidence exists in soybeans (Brim, 1966).

Such random procedures are less laborious than conscious selection techniques, and they permit an increased exploitation of genetic diversity. Through random selection, certain genotypes which would have been discarded in a conscious pretrial selection process may be found which successfully compete in yield trials. Further, random selection methods generally require less space for maintaining individual lines. This permits the breeder to advance more lines into the yield trial phase, which further increases the probability of realizing genetically diverse, useful recombinants.

2.3. Yield Trial Phase

With more material available, the observational or preliminary yield trial (the early part of this third and final phase) should be expanded, and
rigorous selection imposed at this point. Selected material can then be carried into advanced yield trials for a more critical evaluation.

Selection should be confined to important characteristics such as yield, quality and resistance or tolerance to relevant pests or adverse climatic and edaphic conditions. Selection for an “elite” plant type, if not directly related to essential traits from the farm management standpoint, can severely and unnecessarily restrict the genetic variability created and preserved in the previous steps.

The most promising lines should be grown in regional trials at various locations to assess general adaptability. Although this is a standard component of most breeding programs, the locations chosen are often regional experiment stations; therefore, adaptability is often tested under yield maximizing conditions which do not reflect the situation at the farm level. Instead, testing sites should be chosen or conditions created to simulate, as nearly as possible, the environmental variability to which a variety might be subjected if released.

3. BREEDING FOR STABILITY IN PEST RESISTANCE

Whereas, simulating climatic or edaphic variability is usually possible, simulating the range in pest variability is usually impossible because pest populations can genetically shift in response to the introduction of new varieties. Therefore, special consideration must be given to breeding technologies for incorporating into varieties resistant genes that can curb such shifts.

Two major types of resistance have been defined in plants — vertical and horizontal, and the difference between these types closely relates to the genetic structure of resistance and to breeding techniques necessary for stability in resistance.

3.1. Vertical Resistance

Genes for vertical resistance function against epidemic development by completely resisting the pest’s establishment. This type of resistance is usually controlled by only one gene (Nelson, 1973). The major problem with single gene resistance is that new pest biotypes are likely to evolve because all that is usually required is a single genetic change in the pest to overcome the single gene source of host resistance. The genetic compositions of pest populations are not static; and since most pest populations are large, such biotypes are probably present and their frequency will increase in the presence of single gene resistance.

If it were possible to incorporate several genes for complete resistance into the same variety, this problem would be reduced or eliminated because there would probably have to be several genetic changes in the pest population in
order to neutralize multigenic resistance. And since such genetic changes are likely to occur independently, the probability that a biotype can acquire all the necessary changes is nil.

Unfortunately, it is extremely difficult to combine and then identify different genes for vertical resistance in the same plant; however, vertical resistance can be exploited in another way — through the development of isogenic multilines. An isogenic multiline is a blend of different genotypes, each containing a different gene for resistance to a specific pest. Isogenic multilines are established by making several crosses, each involving a different parental source of resistance and a common parent having desired agronomic traits. Each of these crosses are selected for the agronomic characteristics of the common parent and the resistant genes from the different sources. The selected progeny is eventually bulked together producing a line uniform in all characteristics except sources of resistance.

Although an individual component’s resistance may be neutralized by a new pest biotype, it is unlikely that all components in the isogenic multiline would be susceptible. Further, the susceptible component’s resistant neighbors may present a physically inhibiting barrier to an epidemic spread.

Nonetheless, the creation of multilines components differing in single gene sources of resistance is a conservative method of exploiting genetic variability (Browning and Frey, 1969). Several biotypes could evolve which were specific to different components. Further, over several generations, a stepwise evolution of a superbiotype, overcoming all sources of resistance in the multiline, could take place. Resistance to such a superbiotype could be all but impossible to breed for.

3.2. Horizontal Resistance

Unlike vertical resistance, horizontal resistance, which impedes the pest development and growth rate subsequent to infection, is usually controlled by several genes; consequently, horizontal resistance tends to be stable over long periods of time. Therefore, stability in resistance can be developed by incorporating genes from several horizontally resistant sources into the same variety.

Development of genetic lines with horizontal resistance is not easy. The individual genes may act in an additive fashion, and their contribution may be difficult to detect and incorporate into acceptable cultivars. To breed for horizontal resistance, single gene sources of complete resistance should be excluded so as not to mask the effect of horizontally resistant genes (Van der Plank, 1968). Parental material showing moderate resistance of a nonspecific nature can be entered into a composite cross. In the initial generation, plants should be selected that demonstrate an intermediate reaction to the pest, and in each successive generation, recombination should be facilitated, followed by selection for higher levels of resistance. In time, a genetically diverse
population would be created in which each individual carried a resistance conditioned by several genes. In order to recover desirable agronomic traits along with horizontal sources of resistance, much larger populations are required than is necessary in conventional breeding programs for single gene resistance (Nelson, 1963). Multilines can also be developed using sources of horizontal resistance. Each component line would have several genes for resistance, and at least some of the genes would differ over lines. The International Maize and Wheat Improvement Center (CIMMYT) is developing multilines which could have multigenic sources of resistance within component lines (CIMMYT, 1976). However, CIMMYT employs only three parental lines through a double cross and, consequently, does not tap the genetic reservoir to the extent that a composite cross would.

4. THE POTENTIAL OF MIXTURES

The multiline approach has at least one serious drawback. It introduces genetic variability with respect to one trait only, and the breeder still strives for uniformity in all other characteristics. Undoubtedly, it is necessary to have a relatively high degree of uniformity in some characteristics; however, phenotypic uniformity in the crop has been overemphasized in most breeding programs.

Genetic diversification, if appropriately selected for, could buffer the crop against a wider range of stresses. In recent years, increasing attention has been given to developing varietal mixtures with the objective of increasing yield and imparting more stability. In certain crops, the advances have been rapid, taking mixtures from the domain of research in the 1960's to varietal blends released by commercial seed companies at the present time. Unfortunately, most of the current commercial effort has been directed toward developing unique blends based on existing varieties. In the words of R.W. Allard (Allard and Adams, 1969):

It is probably too much to expect that a set of varieties selected for high yielding ability in pure stand should have the biological properties that will lead to favorable interaction in mixture. It seems more likely that genotypes with such properties should be found in populations with a history of mutual selection.

Such populations should be identified and/or created, and breeding and screening techniques developed to exploit these populations for the selection of varietal mixtures.

Some of the techniques discussed earlier could form the base for such a program. Genetic reservoirs represent genotypically diverse competitive populations. Promising individuals could be selected from these populations, multiplied, and critically evaluated in terms of their potential either as components to mixtures or as parental material for mixture development.
The question which immediately arises is how should the material be evaluated in mixtures. The evaluation procedure, by nature, will be more complicated than selection for pure stand performance because the breeder is not only concerned with the performance of a given line, but also with the effect of that line on the performance of the other component or components in the mixture.

Consider the simplest mixture, one comprised of two genetic lines of an inbred crop. In terms of a breeding program, a line should be selected based on, not only its performance as a competitor, but also as a contributor; i.e., a line would be selected if it did well when grown with other lines, and other lines did well when grown with it. Such selection criteria would result in an interdependence that would reduce or eliminate the frequency with which mixtures would have to be reconstituted. In order to assure a stable composition of two lines, the fitness of one component grown in association with the other would have to exceed that of the other when grown in association with itself; this would have to hold for both lines (Cockerham and Burrows, 1971).

In developing an evaluation system for the identification of parental material to be used in a breeding program for mixtures, the material should be evaluated in terms of average performances when grown in various pairwise mixtures. This technique could be modified and applied to selection systems in which specific plant characteristic associations were thought to be mutually beneficial. For example, a breeder may have evidence that a mixture of low tillering and high tillering varieties of barley will behave in a synergistic fashion. He could select a low tillering variety based both on its average performance when grown in pairwise mixture with several high tillering varieties and on the average performance of those high tillering varieties when grown in pairwise mixture with it. High tillering varieties could be selected in an analogous fashion. Field and analytical techniques have been suggested and should be further explored (e.g., see Shultz and Brim, 1967; Griffing, 1969; Akihama, 1974; and Rawlings, 1974).

Up to this point, the situation has been oversimplified. What we are interested in is introducing genetic variability into a crop so that it can respond to changes in environmental conditions. If a mixture is developed that does impart such stability, it is doubtful that the proportions of the components that optimize yield under one set of environmental conditions would be the same as the proportions that optimize yield under another set of conditions. What is required is flexibility in the component that permits the crop to perform adequately over a range in the proportions of its components under various relevant environmental conditions.

Evidence suggests that mixtures can act as a stabilizing force with respect to degree of disease incidence. And in many crops, mixtures have been produced which increase yield. The evidence of increased stability with adequate performance over locations has not been as strong, but this
may reflect the fact that most mixtures involve material originally selected for pure stand performance. Studies by Allard (1961) tend to support this contention. However, one can visualize situations in which improperly constituted mixtures could act as a destabilizing force. For example, during a period of moisture stress, if, because of a high transpiration rate, one component of a mixture is substantially less tolerant to a lower level of soil moisture than the other, then the less tolerant variety could reduce soil moisture to such a low level that neither component could be productive in mixture; whereas, the more tolerant component could have produced in pure stand. This emphasizes the need for rational combinations of components and for careful and adequate testing of mixtures under relevant environmental stresses.

5. ROLE OF INTERNATIONAL INSTITUTIONS IN BREEDING FOR DIVERSITY

The international agricultural research institutions play a major role in the collection, identification, and distribution of genetic materials throughout the world. CIMMYT draws liberally from the U.S. Department of Agriculture’s seed collection of wheat, barley and rye. IRRI is developing a rice seed bank which already contains well over 30,000 accessions. Up to now, IRRI has tapped only a minute fraction of its available material. CIMMYT has large working collections of diverse germplasm, but these collections still represent a small fraction of the total.

Major efforts at tapping these resources have been directed toward the introduction of specific traits into existing high yielding material. CIMMYT has pointed out that their outstanding material was genetically narrow-based (CIMMYT, 1972). It rationalized this situation by stating “land races must be used indirectly to improve the gene pool, but generally they will not directly produce superior commercial varieties.” This statement implies that advanced material must continue to serve as the breeding base for varietal development. This contention is difficult to understand since all commercial varieties were, at some point in their history, derived from traditional land races.

The philosophy at IRRI has been similar to CIMMYT’s; i.e., to “identify and evaluate rice which are genetically adapted to the most pressing constraints to rice production . . . (and) incorporate combinations of these favorable genetic characteristics into a large number of high yielding breeding lines and varieties” (IRRI, 1974). Unfortunately, most of IRRI’s high yielding lines and varieties are already genetically related. This is exemplified in the pedigree of IRRI’s varietal releases (Figure 15.1). All releases have the variety

1 Actually, IRRI officially stopped releasing varieties toward the end of 1975 and has left the responsibility of selection of IRRI developed material to national research programs (IRRI, 1976). However, most of IRRI’s advanced material still reflects this narrow base.
Peta as a common ancestor, and all but one, IR5, have Dee-geo-woo-gen in their pedigree (IRRI, 1975).

Figure 15.1. Schematic diagram of pedigree of IRRI varietal release (Numbers in parenthesis indicate number of backcrosses involved.)

The dangers of such a narrow genetic base are obvious. The material generated from international institutions is distributed throughout the world and used as varieties or breeding stock by national programs. With a large portion of the world’s material having common genetic background, there is an inherent danger that an unknown pest biotype could evolve specific to that common genetic base. Thus, an epidemic, international in scope, could result. Therefore, international institutions may well be contributing to risk in
proportion to the amount of this narrow based material entering national breeding programs.

The total environment under which a given crop is grown is usually extremely diverse, and the specific development of material to meet the specific sets of conditions can be met only at the national or regional level. Attempts by international research institutions to meet a crop's general requirements severely limit the genetic diversity. For example, one IRRI varietal release, IR28, is resistant or moderately resistant to no less than four diseases, three insect pests, and four soil problems (IRRI, 1975). The only effective way that resistance and tolerance to such a myriad of pest species and edaphic problems can be built into a single variety is through the predominant use of single gene sources of resistance which, as mentioned earlier, will eventually prove susceptible to new pest biotypes.

Even if a crop is subject to a wide range of environmental stresses, the stress complex differs from one region to another. For example, gall midge may be a critical insect pest to rice in one region, and brown plant hopper in another region. The question centers on whether international agricultural research institutions should even expend their energy and resources to develop high yielding material with such a range of resistances when it would be virtually impossible to develop varieties which would meet all the requirements of the rice growing world.

An alternative method would be a component character approach. The available germplasm could be evaluated for single gene and multigenic effects on each separate character of interest; reservoirs specific to each of these characters could then be created and distributed to national programs. National programs could request sets of reservoirs for particular sets of characteristics relevant to their specific regional requirements. It would then be up to the national programs to bring these components together in their breeding programs. The total approach can be visualized in Figure 15.2 based on a diagram presented by Simmonds (1962).

The existing international testing networks could provide an excellent mechanism for evaluating material in the germplasm bank and genetic reservoirs, as well as a mechanism for testing the stability and adaptability of varieties developed by national programs.

Most national programs lack the facilities or resources to test some of the breeding and selection methods discussed in this paper. The international institutions could evaluate the potential of applicable techniques in their specific crop areas. For example, since single seed descent appears to have merit in such inbred crops as soybeans and barley, CIMMYT and IRRI could test its application to wheat and rice, respectively. As another example, the potential of multilines and mixtures for resistance to rice blast, a highly genetically variable fungus, could be investigated at IRRI. Methods found to have merit at the international institutions could then be used by the national programs.
Figure 15.2. Relation between proposed international genetic reservoirs (above the broken line) and national varietal improvement programs (below the broken line)

The basic direction of the program as presented here is to encourage the buildup and use of genetic diversity at international research institutions and to channel this diversity to national breeding stocks and down through regional varietal development programs. The ultimate objective is to substantially increase genetic diversity on farmers' fields as a means of reducing risk and uncertainty in agricultural production.