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The dynamic theory of production with special reference to agricultural production

John Tate Harle
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THE DYNAMIC THEORY OF PRODUCTION WITH SPECIAL
REFERENCE TO AGRICULTURAL PRODUCTION

by

John Tate Harle

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
MASTER OF SCIENCE

Major Subject: Agricultural Economics

Approved:

Iowa State University
Of Science and Technology
Ames, Iowa

1966
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. INTRODUCTION.</td>
<td>1</td>
</tr>
<tr>
<td>II. A COMPARISON OF THE STATIC AND NONSTATIC THEORIES OF PRODUCTION.</td>
<td>3</td>
</tr>
<tr>
<td>III. THE FRAMEWORK OF A DYNAMIC THEORY OF PRODUCTION.</td>
<td>17</td>
</tr>
<tr>
<td>A. The Role of Decision Theory</td>
<td>17</td>
</tr>
<tr>
<td>B. A Definitive Statement of the Problem</td>
<td>20</td>
</tr>
<tr>
<td>1. The meaning of utility maximization</td>
<td>21</td>
</tr>
<tr>
<td>2. The conditions under which maximization must be carried out</td>
<td>21</td>
</tr>
<tr>
<td>C. The Case of Subjective Risk</td>
<td>24</td>
</tr>
<tr>
<td>D. The Case of Subjective Uncertainty</td>
<td>29</td>
</tr>
<tr>
<td>E. Flexibility and Adaptability</td>
<td>31</td>
</tr>
<tr>
<td>IV. DECISION THEORY</td>
<td>39</td>
</tr>
<tr>
<td>A. The Motivation Behind the Decision-Making Process</td>
<td>40</td>
</tr>
<tr>
<td>B. Decision-Making as a Satisficing Procedure.</td>
<td>41</td>
</tr>
<tr>
<td>C. The Framework of the Theory of Decision-Making</td>
<td>44</td>
</tr>
<tr>
<td>V. THE DYNAMIC THEORY AND AGRICULTURAL PRODUCTION.</td>
<td>60</td>
</tr>
<tr>
<td>A. The Effects of Uncertainty on Agricultural Production</td>
<td>60</td>
</tr>
<tr>
<td>1. Capital rationing</td>
<td>61</td>
</tr>
<tr>
<td>2. The choice of production methods</td>
<td>62</td>
</tr>
<tr>
<td>3. The importance of management</td>
<td>63</td>
</tr>
<tr>
<td>B. The Implications of the Dynamic Theories for Agricultural Economics</td>
<td>64</td>
</tr>
<tr>
<td>VI. A METHOD FOR COMPARING TWO ALTERNATIVE SYSTEMS OF PRODUCTION</td>
<td>68</td>
</tr>
<tr>
<td>VII. SUMMARY</td>
<td>84</td>
</tr>
<tr>
<td>VIII. LITERATURE CITED.</td>
<td>88</td>
</tr>
<tr>
<td>-------------------------</td>
<td>----</td>
</tr>
<tr>
<td>IX. ACKNOWLEDGEMENTS.</td>
<td>93</td>
</tr>
</tbody>
</table>
I. INTRODUCTION

A fundamental characteristic of the development of any science is that its theories yield successively better approximations of the true state of things which lie within its domain. That is to say, as its constituent theories develop, their defining assumptions become less restricting, thus broadening the set of phenomena which they may explain. Thus for example in physics, we find that Newton's laws of the universe, developed using a Euclidean geometry, and the assumption of the independence of time and space, may explain the majority of the physical phenomena which may be observed in, or from, the world today. However, Einstein and Minkowski showed that these explanations were, in reality, only approximations. By relaxing the assumption of the independence of time and space, and using a Riemannian geometry, Einstein was able to extend the list of natural physical phenomena which could be explained by the science of physics.

Economics has a much less legitimate claim to the description of "a science" than has physics. However, in some manner, we may regard the development of the dynamic theories of economics as an analogous development to the example given above. Of course this is a somewhat bizarre analogy, but it is true that the development of a sound dynamic theory of economics will greatly expand the domain of the science.
Hence the objective of this thesis is to consider, approximately at the level required for the master's degree, and with special reference to agriculture, the development and implications of the dynamic theories of production. The thesis is concluded with the description of a method for comparing two systems of production. It is hoped that this method will be seen to follow logically from the line of exposition followed in the prior chapters, and will meet, to a reasonable degree, the requirements of any such method which are inferred in these chapters.
II. A COMPARISON OF THE STATIC AND NONSTATIC THEORIES OF PRODUCTION

Analytically, the theory of choice and the theories of production are basically similar. In fact it is reasonable to assert that the latter are actually subsumed in the former, since we may regard the general theory of choice as an abstract, uninterpreted, system of logic; and the theories of production as those which are obtained by making a particular interpretation of the terms of this general system. Thus anything which forms a fundamental part of the logic of the theory of choice, will necessarily be a fundamental part of that of the theories of production, and vice versa. Therefore, within this context, we may refer to either system interchangeably.

Traditionally the model of choice is based on an analytical separation of preference and opportunity (39). First of all, it is assumed that the individual is able to arrange into a preference ordering, the choices with which he may be confronted. In order that this assumption of the existence of a preference ordering be tenable, it is necessary that the underlying choice function satisfy certain conditions. By assuming that these conditions will be satisfied, the basic axioms of the theory are defined. Thus for example, if it is assumed that the underlying choice function satisfies Samuelson's generalized strong axiom of revealed preference, this is suf-
icient for it to be representable by a preference ordering. As is usual in economic theory, behaviour which conforms to these axioms is said to be rational, and that which does not is called irrational. Secondly, the "power set" is defined to reflect the limitation of the individual to choosing from some subset of the domain of his preference ordering. A familiar example of such a restriction is the simple budget constraint in consumer theory, which limits total expenditures to being less than, or equal to, total income. Another example, which is perhaps more pertinent to the present discussion, is the familiar closed, convex polyhedron which characterizes the feasible set in linear programming problems. With these definitions of a preference ordering and a power set, the rest is analytically quite simple--the rational individual chooses that element from his power set which is highest in his preference ordering.

The theories of production have been described as particular interpretations of the general theory of choice. We are now in a position to enlarge on this description, and consequently to describe the basis which will be used to compare the various theories of production. Quite obviously there are two basic interpretations to be made. These are, an interpretation of the preference ordering; and an interpretation of the power set. They will be discussed in turn.

In the discussion of the theories of production, the
unit of control will be assumed to be a single entrepreneur; and the domain of his preference ordering to be the set of all possible courses of action which he could follow in running his business. A "course of action" is defined as a contemplated time-path of business activity, the length of which will depend upon the length of the planning horizon. Thus for example, a young farmer with a short planning horizon of say two years, may contemplate the two alternative courses of action of yard-fattening hogs in the first year, then switching to yard-fattening steers in the second year; or of yard-fattening hogs over both years. To each course of action the entrepreneur will be assumed to attach a range of mutually exclusive and exhaustive possible outcomes, measured in terms of net revenues. By attaching a subjective estimate of a probability distribution defined on the elements of this range of outcomes, he will determine the position of each course of action in his preference ordering (29, 53). In this manner we give recognition to the facts that, to a significant extent, the entrepreneur's business activity is a means by which the "private consumption" of such things as a family car, children's education, and so on, may be made possible; and that the weighting of uncertain profits and losses is essentially a subjective matter.

Having defined the preference ordering, the definition of the power set follows quite easily. Thus the power set
of the entrepreneur is simply that part of the domain of his preference ordering which is currently available to him.

The above definition of the domain of the preference ordering in the theories of production provides a convenient basis for comparing these theories, since they are definitely characterized by the degree of knowledge which is assumed available on the probability of the outcomes attached to the courses of action which constitute the domain of the preference ordering. Using a similar basis of classification, Johnson (32, p. 1151) describes three categories of theories of economics. These are:

- **(a)** Static theories, which assume perfect knowledge of all the relevant economic variables and their relationships.
- **(b)** Risk-trend theories, which assume that there exists a known probability distribution of the possible relationships between the economic variables.
- **(c)** Dynamic theories which recognize that subjective estimates of their probability distributions change over time, through the learning process.

We will follow this classification in the following discussion, but we will first re-define it according to the domain of the preference ordering which is inferred in Johnson's classification. However, since there is a definite ambiguity possible in the interpretation of the word "probability", it is necessary first to describe the interpretation of it which will be made here, and to define a set of terms which will be used in conjunction with it.
There are two schools of thought on the concept of probability, the objectivist school, which defines probability in terms of relative frequencies of observations; and the subjectivist school, which defines probability in terms of "degree of belief". In this thesis, we will subscribe to the latter school, thus following Arrow in accepting the Keynesian interpretation that probability is a subjective estimate and opinion of the individual (2). Hence we may draw on the theory developed from the axioms of subjective probability and conditional probability in considering the learning process. Thus for example, we may make use of the theorem that a concave functional, defined on a subjective probability distribution, follows a lower semi-martingale process. Since the range, variance and mean deviation about the mean are all concave functionals, this theorem implies that a given probability distribution will tend to converge to the mean, over time. This point will prove useful in the later discussions.

In interpreting probability in this manner, the concept is obviously an extremely subjective, or personal thing, and is very closely linked with the state of knowledge of the individual with respect to the topics in question. Hence we will need to use terms which define different states of knowledge in which the entrepreneur may find himself. For the present it will suffice to describe three. These are the states of subjective certainty, subjective risk, and subjec-
tive uncertainty. In the subjectively certain state, the individual's anticipations are single valued. This is obviously an extremely confident state of mind, and in agriculture we may rarely expect to observe it. However, in the following discussion of dynamic theories it will only be assumed that the entrepreneur will feel subjectively certain in his estimates of the parameters of the probability distribution of outcomes, and not of the outcome itself. This latter assumption characterizes the state of subjective risk, where it is assumed that the entrepreneur holds subjectively certain estimates of the parameters of the probability distribution of outcomes (53, p. 99). In the case of subjective uncertainty the parameters of the probability distribution are no longer assumed known with certainty but only with a likelihood depending upon past experience (53, p. 102).

We are now in a position to re-state Johnson's classification in terms of the definitions of the domains of the preference orderings. If we define the set $S$ as the domain of a preference ordering; and the elements $x_i, p \in S$ as the elements of this set, where $x_i$ represents the range of possible outcomes associated with the $i$th course of action, and $p$ represents the probability distribution defined on this range, we may re-write the classification as follows:

(a) Static theories, which deal with choice from the set $S_1$, where:
\[ S_1 = (x_1, p \mid x_1 = v_1 \text{ and } p(v_1) = 1) \]

where \( v_1 \) is a single valued outcome, and not a range of outcomes.

(b) Risk-trend theories, which deal with choice from the set \( S_2 \), where:
\[ S_2 = (x_1, p \mid p = p(k_1, k_2, \ldots, k_n)) \]
where the \( k_i, i = 1, 2, \ldots, n \), are parameters which are known with subjective certainty.

(c) Dynamic theories, which deal with choice from the set \( S_3 \), where:
\[ S_3 = (x_1, p \mid p = p(k_1(h_{11}, \ldots, h_{1r}, t), \ldots, k_n(h_{n1}, \ldots, h_{ns}, t))) \]
where at any time, \( t \), the \( h_{ij} \) are assumed known with subjective certainty, but are themselves functions of time.

From these definitions it is obvious that \( S_1 \subset S_2 \subset S_3 \), and hence we may clearly see the movement towards increasing generality as we relax the assumptions of perfect knowledge. The choice sets on which the theories are defined are widened successively, and to this extent, they are that much more concerned with reality. Of course it is not necessarily a bad thing that the domain of a theory be far removed from reality (11). However, if we judge the usefulness of a theory according to its ability to explain relevant economic phenomena, we must display dissatisfaction with the static theories because of their inability to explain
... the objective quantities of goods and claims held at any point of time, and the objective market prices at which they are exchanged, given the subjective tastes and expectations of the individuals at this point in time. (43, p. 311)

Similarly, we must display dissatisfaction with both the static and risk-trend theories because of their inability to explain the relevance of the learning process, and the information gathering activities so prevalent in modern economies.

If we define the theory of decision-making as the explanation of a system by which an individual may eventually choose from various alternatives open to him, when he is not certain of the relative positions of these alternatives on his scale of preferences, it is immediately obvious that in the static economy, there is no need for such a theory. Given perfect knowledge of the present and future sets of circumstances, and the relevant preference ordering, everything is actually determined. The entrepreneur has no real choice in the matter but to formulate an initial plan which is consistent with the price mechanism. Thus there is no place in static theory for the dichotomy between "control by the price mechanism", and "control by the entrepreneur" (7, p. 396).

Another immediate result of this assumption of perfect knowledge, is the complete inability of the theory to explain the existence of profit in the real world, since there simply could not be any profit in a static economy. Things are
determined once and for all, so there can be no surplus due to delays in re-adjusting to changes in the data. The final situation is foreseen, and the relevant choices made. In fact we can only allow the theory to consider changes in the data by assuming instantaneous, costless re-adjustments to be made. Thus the use of the device of comparative statics, and the complete inability of the theory to explain the process of change. It may only consider the effects of changes in equilibrium situations. It can say nothing about the rates of adjustments to these changes, and so on.

Thus we see that, because static theories cannot contain any theory of decision-making, or any theory of profit, they are unable to offer any explanation of the maintenance of stocks of goods and monetary claims. These matters may only be explained by a lack of complete information, which is of course, against the fundamental assumption of any static theory.

As we have defined the theory of decision-making, we can see that it has no place in risk-trend theories. Within the theory of choice, there currently exists a set of preference orderings defined on our set $S_2$. That is where:

$$S_2 = (x_1, p \mid p = p(k_1, \ldots, k_n))$$

These of course are the von Neumann-Morgenstern preference orderings, which are representable uniquely up to a linear transformation. The point of relevance here is that, since
we may regard the preference order as being completely defined on \( S_2 \), and since the risk-trend theories assume a 'perfect' knowledge of \( S_2 \), or at least the relevant power set contained in it, we can again see that there is no decision to be made. Everything is again determined. The fundamental difference between this case and the former is that knowledge is not complete. The entrepreneur is merely subjectively certain of a probability distribution of possible outcomes. Given a preference ordering on this choice set, and the basic assumption that he will choose that element from his power set which is highest on this preference ordering, there is again no decision to be made. Of course this does not rule out a theory of profit, since it by no means is assumed that this perfectly confident subjective estimate of the probability distribution will be the correct one; and even if it was, this would not be to say that expectations would be realized.

Thus we may visualize an economy of perfectly confident entrepreneurs, who do not seem to learn by their mistakes. In such a situation it is quite possible to develop a theory of profit (25, p. 170), and, in this light, to rationalize the existence of stocks of goods and monetary claims.

To summarize so far, we have found that we may classify the static, risk-trend, and dynamic theories of production according to the domain of the preference ordering upon which these theories are defined. In doing so, we find that the
static theories are unable to yield a theory of profit; and neither the static nor the dynamic theories are able to consider the decision making process. It is because of their potential ability to do both these things, that we may regard the dynamic theories as being more realistic or general in their applicability.

The set $S_3$ on which the dynamic theories have been defined, has been described as:

$$ S_3 = (x_1, p \mid p = p(k_1(h_{11}, \ldots, h_{1r}, t) \ldots, k_n(h_{n1}, \ldots, h_{ns}, t))) $$

where $x_1$ is the range of mutually exclusive and exhaustive possible outcomes, associated with the $i$th course of action. However, in this case the probability distribution $p$ is not uniquely defined. Rather it is assumed that there exists a probability distribution of possible probability distributions $p$, which are defined on the range $x_1$. Moreover, this former probability distribution is a function of time, and will change according to the experiences of the entrepreneur over time. It is at this point that we may apply the results of the theorem stated earlier. By gathering information on any particular course of action, and modifying his subjective probability estimates according to Bayesian inference, it follows from the stated theorem that all the mentioned measures of dispersion about the mean will tend to decline in magnitude. Thus, as a result of this learning process, we
may regard the subjective estimates of the parameters of the probability distribution $p$, as eventually becoming single-valued. When this occurs, the individual has in effect reached the subjective-risk situation with respect to this $i$th course of action. Hence he may then order it according to his von Neumann-Morgenstern utility index. Thus we have a description of a process whereby the entrepreneur may gather information on the courses of action which may interest him, in order that he may choose from among them, according to his von Neumann-Morgenstern preference ordering. Consequently we have demonstrated that a theory of decision-making must be an essential part of any dynamic theory.

If we call $C$ the relevant power set with which the entrepreneur will be faced at a given time, we have that $C$ is composed of elements of the set $S_3$; and that the entrepreneur is unable to completely order these elements according to his von Neumann-Morgenstern preference ordering, since he has insufficient information to do so. It is quite reasonable to expect that he may be able to classify some subset, say $I$, of the power set $C$, as containing elements which are definitely preferred to the remaining elements in $C$, that is those in $(C - I)$. However it is not possible to order the elements of this "efficient set" without further information. Moreover, it is not reasonable to admit the assumption that the individual might simultaneously gather information on all
the elements of C, since to do so would be tantamount to assuming perfect knowledge of the parameters of p, which would return us to risk-trend theory. Neither can we reason-ably turn the problem into a risk-trend problem by compounding probability distributions, since to do so would be to obscure relevant information (15). Thus it is necessary that decisions be made concerning on which subset of C to gather further information, and therefore we can see that a theory of decision making under conditions of incomplete knowledge must be an essential part of any dynamic theory.

From this, it immediately follows that dynamic theories must handle the learning process (3), since this must form an integral part of any process by which a rational decision is reached. Also, with the introduction of decision theory, the role of the decision-maker (the entrepreneur in production theory, the consumer in consumption theory) becomes so much more meaningful. Thus in a dynamic theory of the firm, full recognition may be given to the role of management in apportioning expenditure amongst the factors of production, and in maximizing net revenue under the given market conditions. From here it logically follows that "the quality of management" is a major and discrete factor of production (28, p. 153). In recognition of this fact, much work has, and is, being done on the tricky problem of estimating the management factor (e.g. 9, 34, 47, 48, 57), although its obvious impor-
tance, especially in the field of agricultural production, where the lack of relevant information is perhaps greatest, has been recognized for years. Thus the tremendous amount of work by agricultural economists and agronomists in developing information to aid the farmer in his decision-making. However the point to be made here is that this work has had to be carried out without the guide of any general theory of production which had, as a fundamental part incorporated within it, a theory of decision-making under incomplete knowledge. In the next two chapters, an attempt will be made to indicate the basic position of decision-making in a dynamic theory of production, and to describe the framework of the decision-making process.
III. THE FRAMEWORK OF A DYNAMIC THEORY OF PRODUCTION

A. The Role of Decision Theory

Fundamentally, the objective of any theory of production must be to explain a process by which the rational entrepreneur may maximize his utility under the conditions of environment set by the area of definition of the theory. This area of definition is, of course, described by the assumptions made, and is correspondingly narrower or broader, according as the assumptions are more or less restrictive. The wider the area of definition, the greater the number of relevant phenomena which will need to be incorporated within the theory, and to this extent the more complex the theory is likely to become.

We have seen in the previous chapter that the area of definition of dynamic theories is the most broad of the three categories compared, and that it is correspondingly more complicated by the necessary inclusion of the theory of decision-making. Essentially, the objective of this latter theory is to explain the process by which the individual moves from a state of subjective uncertainty, to one of subjective risk. Once this position has been reached, the problem has been, in effect, converted into one of risk-trend, and the individual may choose from his "transformed" power set, $C' \subset S_2$, according to a von Neumann-Morgenstern preference ordering. Thus,
to this extent, we may regard the theory of decision-making as providing a device by which the theoretical problem of utility maximization under subjective uncertainty, is transformed into one of subjective risk. This point may be illustrated with the aid of a simple diagram (Figure 1).

The entrepreneur narrows down his initial power set, C, by first choosing a subset I ⊂ C, on which to gather further information. By obtaining more information on the probability distributions of the elements of I, he finally reaches the position of subjective certainty in his estimate of the parameters of the probability distributions of the elements of I. That is, his power set is transformed to $C' \subset S_2$. Here we may say the decision-making process is finished, and choice is automatically made according to his preference ordering defined on $C'$.

This diagram also serves to illustrate that it is somewhat an over-simplification to state that the problem is merely converted into a risk-trend situation: The sets C, I, and $C'$ have been drawn on a time axis, to illustrate that time is required for the process of decision-making. The fact that an interval of time elapses between C and $C'$ has important effects upon the optimal time-path of resource use for the entrepreneur,¹ as will be shown below. However, with this

¹The optimal time path is a subjective thing.
Figure 1. The changes in the power set brought about by the decision-making process.
qualification in mind, this does seem to be a reasonable
description of the role of decision theory in the dynamic
theory of production.

Having so described the position of decision-theory, we
may leave its detailed discussion until the next chapter,
since we are presently concerned with describing the frame-
work of the dynamic theory, and not the details of its funda-
mental parts.

B. A Definitive Statement of the Problem

We have already stated that the problem to be solved by
any dynamic theory of production must be to explain a pro-
cess by which the rational entrepreneur may maximize his
utility, under the conditions of environment set by the area
of definition of the theory. However, this is a broad and
nebulous statement, and therefore, by first considering its
various implications in greater detail, we may achieve a more
precise definition of the task of the theory, and consequently
a better idea of the fundamental problems to be faced. Thus
we will now consider the following points:

1. In what respect is utility to be maximized.

2. Under what conditions must this maximization take
place.

These will be dealt with in turn.
1. The meaning of utility maximization

In the history of economic thought, "utility", has been given many connotations (49, p. 80), and therefore so has "utility maximization". We will follow current practice and assume a "level of utility", to represent nothing more than a position in a preference ordering. Thus "utility maximization" is defined as the achievement of the highest attainable position on the preference order. Given this definition, the possible ambiguity between maximization of experienced, as opposed to anticipated, utility is removed (49, p. 81). Thus we assume that the entrepreneur is faced with a set of possible choices, which he arranges in a preference ordering according to the preferability of their anticipated consequences, and from which he makes the corresponding choice. That is to say, we consider the maximization of anticipated utility, as it has been defined above.

2. The conditions under which maximization must be carried out

We have established that the entrepreneur will seek to choose the element of choice from his power set, $C \subseteq S_3$, which is highest on his preference ordering, where $S_3$ is the set:

$$S_3 = \{x_1, p \mid p = p(k_1(h_{11}, \ldots h_{1r}, t) \ldots k_n(h_{n1}, \ldots h_{ns}, t))\}$$

Since time is a very relevant factor, it follows that inaction is itself a choice, since it is equivalent to the
rejection of all the elements of C which are immediately available (39). Thus following Koopmans,

We can therefore look upon economic choice at any one time as an inevitable choice between several or many specific subopportunities, i.e., subsets of the opportunity set that are available at that time, provided choice is made right then. (39, p. 245)

Moreover, we do not have independence between the choice made now, and those which may become available at some future date. Thus the conditions of present choice from the current power set, are such that the choice actually made from this current power set will determine the future power sets from which subsequent choices may be made. Figure 2 may aid in clarifying this point (39, p. 245).

Suppose at time $t_0$ the entrepreneur is considering choice between the nine alternative courses of action described by time paths $CC_2', C_2'^n, Z_1$, $CC_2, C_2'n, Z_2$, $CC_2'C_2'n, Z_3$ etc. Essentially he will choose only between the two initial alternative courses of action $A_1$ and $A_2$. Thus for example, we could regard $A_2$ as investment in adapting an old barn for beef production, whereas $A_1$ might be investment in a highly specialized feedlot system. These alternatives $A_1$ and $A_2$ are what Koopmans calls "subopportunities", since they each in effect define subsets of the initial power set. The courses of action which constitute these subsets each have in common the time path from $t_0$ to $t_1$. 
Figure 2. The constitution of the power set
Quite obviously, as the power set $C$ is defined, it contains a large number of elements. Koopmans' device provides an ingenious method of reducing the number of relevant choices in a manner which is intuitively very appealing, since it does describe a logical method which one would expect to be observed in real life. It also brings out clearly the dependence of future power sets on current choices, and provides an excellent illustration of the fundamental difference between flexible and specialized methods of production.

We may now make a definitive statement of the problem to be answered: The process must be explained, by which the rational entrepreneur may maximize his utility under conditions in which choice is inevitable, and there is a definite dependence between current and future choices.

C. The Case of Subjective Risk

By assuming that there existed a joint probability distribution of possible prices and interest rates, the parameters of which were supposed to be known with subjective certainty; and by also assuming that the transformation function was known with subjective certainty, Tintner (53) defined the probability distribution of anticipated discounted net profit, $W$. He then assumed that the maximand was a "risk-preference functional", $F$, where:

$$F = F(Q(W))$$
and where $Q(W)$ was the probability distribution of anticipated net discounted profit. He used a functional, rather than a function, to stress the opinion that the value of $F$ depended upon the whole probability distribution of $W$, and not simply upon its expected value.\(^1\) He thus obtained the conditions necessary for this functional to be a maximum, and from there, obtained an expression for the demand or supply differentials.\(^2\) However, in the light of current theory, it would appear that his conclusion that a functional should be the maximand, caused him to consider too general a problem \((12, \text{pp. 60-61})\).

To draw a parallel with the current exposition, $F$ would be a functional representing the von Neumann-Morgenstern preference ordering defined on the set $S_2$. However, since we are using such a preference ordering, we need only consider $F$ as a function, not as a functional, since, according to the von Neumann-Morgenstern hypothesis, the utility of a probability distribution of choices is equal to the expected utility of its components. Thus the maximand which need be considered here is simply:

$$F = F(Q(W)) = G(W), \text{ say.}$$

---

\(^1\) In this he was following Marschak \((42, \text{p. 261})\).

\(^2\) The writer does not mean to infer that his present knowledge of the calculus of variations is sufficient for a complete comprehension of Tintner's results.
With this qualification, Tintner's procedure will be followed in the treatment of the risk-trend case. Let \( x_u,t \) be the anticipated production of product \( u \), or the negative of factor \( u \) used at time \( t \), \( i_t \) be the anticipated interest rate at time \( t \), \( P_{u,t} \) be the anticipated price of the product or factor \( u \), at the time \( t \), and also let \( q_{u,t} \) be the anticipated discounted price. That is to say,

\[
q_{u,t} = \frac{P_{u,t}}{r_1 r_2 \ldots r_t}
\]

where \( r_i = (1 + i_t), i = 1, 2, \ldots, t \).

Then the net discounted profit for the firm is

\[
W = \sum_{v=1}^{m} \sum_{s=1}^{n} x_v,s q_v,s.
\]

Assume that the probability distribution which expresses the "subjective risk anticipations" of the firm, be given by:

\[
P(dP_{11}, \ldots dP_{mn}, dr, \ldots dr_n) = P(P_{11}, \ldots P_{mn}, i_1, \ldots i_n; k_1, \ldots k_u) dP_{11}, \ldots dP_{mn}, di_1, \ldots di_n.
\]

In this case of risk-trend, the \( k \) parameters are assumed known with subjective certainty. This probability distribution gives the probability that simultaneously, \( P_{11} \) will be in the interval \( P_{11} \) and \( P_{11} + dP_{11}, \ldots \). \( P_{mn} \) will lie in the interval \( P_{mn} + dP_{mn}, \ldots \). \( i_n \) will lie between \( i_n \) and \( i_n + di_n \). Given this probability distribution, the probability distribution of anticipated net profit \( W \) can be found. Thus we may obtain:
\[ q \Delta W = Q(W; x_{11}, \ldots, x_{mn}; k_1, \ldots, k_n) \Delta W. \]

Therefore, if we assume the transformation function \( \varphi \), where

\[ \varphi(x_{11}, \ldots, x_{mn}) = 0 \]

the problem is to maximize:

\[ F = G(W) = F(Q(W)) \]

subject to \( g(x_{11}, \ldots, x_{mn}) = 0 \). This yields the Lagrangian:

Maximize:

\[ F^* = G(W) - \nu g(x_{11}, \ldots, x_{mn}) \]

whence the necessary conditions:

\[ \frac{\partial F^*}{\partial x_{u,t}} = \frac{\partial G}{\partial Q} \cdot \frac{\partial Q}{\partial x_{u,t}} - \nu \frac{\partial F_u}{\partial t} = 0 \quad u = 1, 2 \ldots m, \quad t = 1, 2 \ldots n \quad (1) \]

\[ \frac{\partial F^*}{\partial \nu} = \varphi(x_{11}, \ldots, x_{mn}) = 0. \quad (2) \]

We may re-write (1) as:

\[ \frac{\partial G}{\partial Q} = \nu \cdot \frac{\partial F_u}{\partial t} \quad u = 1, 2 \ldots m, \quad t = 1, 2 \ldots n \quad (3) \]

and we may call \( \frac{\partial G}{\partial Q} \) the marginal utility of discounted anticipated net profits; \( \frac{\partial F_u}{\partial t} \) is the partial of \( \varphi \) with respect to \( x_{u,t} \); \( Q_{u,t} \) may be called the marginal effect of \( x_{u,t} \) on the probability that discounted net profit, \( W \), will be in some specified interval. To abbreviate, call this the "mar-

\[ 1 \text{This term is used bearing in mind Arrow's point, "... the utilities assigned (by the von Neumann-Morgenstern index) are not in any sense to be interpreted as some intrinsic amount of good in the outcome .... Therefore, ... we are free to assume that marginal utility (may be) is increasing." (2, p. 425).} \]
original probability effect". The necessary conditions (1) are equivalent to:

\[
\frac{f_{v,s}}{q_{v,s}} = \frac{f_{u,t}}{q_{u,t}} \quad v,u = 1,2,\ldots,m \quad s,t = 1,2,\ldots,n
\]

Very crudely, conditions (4) could be called "the ratios of marginal productivities to the marginal probability effects, of all factors and products, should be equal." This is not really a very satisfactory expression, but it has some small amount of intuitive appeal in that it seems reasonable that entrepreneurs should balance effects of factor and product changes with their anticipated effects on the probability of achieving some level of profit.

The above treatment of the utility maximization problem under conditions of subjective risk, may be regarded as yielding the solution to the problem of the dynamic theory of the firm, since we have assumed that, through the decision-making process, the entrepreneur reaches the position of subjective risk, from which he chooses according to a von Neumann-Morgenstern preference ordering. However, for the purposes of the present chapter this approach is unsatisfactory, since it has in no way explained the relevance of the dependence of future power sets on current choices. This topic will indeed be dealt with in the next chapter in the discussion of the decision-making process, but in order that we may develop a framework for this discussion we will briefly describe Tint-
D. The Case of Subjective Uncertainty

First of all, assume that the transformation function is known with certainty. In this case, Tintner (53, p. 102) again assumed that there existed a joint probability distribution of anticipated prices and interest rates, characterized by k parameters $k_1, \ldots k_k$. However, this time these parameters are not supposed known with subjective certainty, but are supposed to be jointly distributed according to a "likelihood function", $L$, where:

$$L(k_1, \ldots k_k; h_1, \ldots h_h) dk_1, \ldots dk_u.$$  

The characteristics of this likelihood function are assumed to depend upon the past experience of the entrepreneur, whom we now may regard as being less supremely self-confident, and more enlightened concerning his own fallibility. Given this likelihood function, and the probability of the anticipated net profit, $Q$, where

$$Q = Q(W; x_{11}, \ldots x_{nm}; k_1, \ldots k_k),$$  

as before, he then defines the likelihood of the anticipated net profit, $W$,

$$MdW = M(W; h_1, \ldots h_h) dW$$  

which expresses the likelihood that expected profit, $W$, will be between $W$ and $W + dW$. He then assumes the maximand to be a preference functional, $S$, which expresses the preference
for subjective uncertainty. Thus:

\[ S = S(M(w)) \]

and from here he derives the necessary conditions for this to be maximized.

We may now again draw a parallel with Tintner's treatment of the problem and the current exposition:

The assumption of the existence of the functional \( S \) is not equivalent to assuming the existence of a preference ordering over the set \( S_3 \). According to our present terminology, Tintner assumed the decision-making process to be completed in forming the likelihood function for \( M \) from the likelihood function, \( L \), and the probability distribution of anticipated net profits \( Q \). Thus again \( S \) would represent a von Neumann-Morgenstern preference ordering defined on the set \( S_2 \). As will be pointed out later, this assumption that there exists in the entrepreneur's mind an \textit{a priori} known distribution of the relevant parameters has important implications in the decision-making process (29, p. 109). The point of interest here is that again it does not seem necessary to assume that \( S \) is a functional, and therefore we may expect to derive exactly analogous results to those obtained in the risk-trend case.

Thus we may regard Tintner's treatment of this case of subjective uncertainty as providing the framework of a theory of the firm in a dynamic situation. However, it is not yet
quite satisfactory on two counts:

(i) It does not contain a procedure for dealing with the dependence of future power sets on current choices.

(ii) Although the role and position of decision theory, as it has been defined here, is quite compatible with this framework, the actual process of decision-making is not at all dealt with, and to this extent, is attributed too little importance in the theory.

The first point gives no real problem, since Tintner did expand the case of uncertainty to include flexibility and adaptability, and we will do likewise before completing this chapter. The second point is not really a valid criticism considering that his development is being used in this chapter to sketch the framework of the theory. As was stated earlier, we will discuss decision-theory in the next chapter.

E. Flexibility and Adaptability

We have seen that the expected effect of his current choice on his future set of choices, is a relevant factor influencing the entrepreneur in making this current choice. He must make some choice, since inaction is itself a choice, and he must make this choice without complete knowledge. Thus it is reasonable to postulate that he will tend to make that choice which will leave him a degree of maneuverability, in order that he might take advantage of future information.
This is the reasoning of Hart (14, p. 59) and Stigler (51, p. 305), when they discuss the importance of flexibility and adaptability in business planning under uncertainty. These two properties of a business plan have this "degree of maneuverability" in common. (To return to Koopmans' diagram on page 23, alternative A₂ would represent the flexible or adaptable plan, since it leaves a greater choice of future alternatives.) Stigler distinguishes between them as follows. The property of adaptability is attributed to a fixed plant which is fundamentally designed to produce a given output in the most efficient manner, as defined by existing technology. If this plant can be adapted to the efficient use of other than the optimal combination of variable factors, it is said to be adaptable. On the other hand, the property of flexibility is attributed to a fixed plant which is not designed to produce a given output in a most efficient manner. Rather it is designed to approximate the most efficient plants over a range of outputs.

Tintner treats both flexibility and adaptability together, in recognition of their fundamentally similar nature. We will complete this chapter with a description of his treatment, and return in a later chapter to expand on this important topic, and to discuss its special relevance to agricultural production.

Thus far, Tintner has assumed that there exists one
transformation function which was assumed known with subjective certainty. Now this assumption must be dropped. Thus we begin with the assumption of a number, \( m' \), of transformation functions, \( f^{(1)}, \ldots, f^{(m')} \), which are known with subjective certainty.

\[
\begin{align*}
(1) \quad f^{(j)}(x_{11}, x_{21}, \ldots, x_{mn}; t_1^{(j)}, t_2^{(j)}, \ldots, t_{T_j}^{(j)}) &= 0 \\
& \quad j = 1, 2, \ldots, m'
\end{align*}
\]

As before we have a joint probability distribution, \( P \), of anticipated prices and interest rates, and a likelihood function, \( L \), expressing the likelihood of the parameters of this probability distribution \( P \). However, to express the assumption that the individual believes he may improve his forecasts in the future, Tintner introduces a "second-order likelihood function", \( N \), for the parameters of \( L \). Thus we now have:

\[
N = N(h_1, \ldots, h_{H}; a_1, \ldots, a_A).
\]

From this, in the usual manner, the likelihood function, \( B \), for expected discounted net profit is derived, thus yielding:

\[
BdW = B(W; a_1, \ldots, a_A) \, dW
\]

and the new preference function, \( X \), from which the necessary conditions for a maximum may again be found.

The procedure which Tintner follows in this situation is briefly described below.\(^1\) Since he and A. G. Hart seem to

\(^1\)More correctly, this is an interpretation of the joint implications of the two works by Tintner cited above. Thus any anomalies should not be attributed to Professor Tintner.
have concurred in their opinions on this matter, a diagram constructed by Hart is then used to illustrate Tintner's procedure.

Again the individual is assumed to have a fixed planning horizon of n intervals of time. His immediate problem is to decide on production over the period 1, 2, ... n' < n (assuming that he is at time zero). We begin by assuming an arbitrary choice of inputs for this period. That is to say, we make no assumptions about the initial plan of production for this period. The first part of the problem is then to maximize anticipated discounted net profit, J, over the interval n'+1, n'+2, ... n. This is equivalent to maximizing:

$$J^* = J + \sum_{j=1}^{m'} v_j f(j)$$

and thus a set of necessary conditions may be obtained, and a set of maximum solutions, $\bar{x}_{vs}$, be found. These inputs will be a function of expected prices, interest rates, and the technological factors $t^{(1)}_1, ... t^{(m')}_{m'}$, which characterize the $m'$ transformation functions. Thus we obtain what might be called a set of first-order conditions on the optimum choice of quantities of inputs and products for the period 1, 2, ... n' < n.

These conditions are then imposed by substituting the quantities $\bar{x}_{vs}$ into the definition of anticipated discounted net profit, i.e.,
Thus we now have \( J \) as a function of the anticipated prices and interest rates as usual. However it now also depends upon the technological parameters and initial arbitrary inputs. From here, the usual procedure is followed to yield the uncertainty preference function. However this now depends upon the initial set of inputs and outputs over the interval \( 1, 2, \ldots, n' \), as well as the parameters of the second order likelihood function, \( B \). That is, we now have:

\[
X = f(x_{11}, \ldots, x_{mn'}, a_1, \ldots, a_A)
\]

This is now maximized with respect to the anticipated quantities \( x_{vs} \) to be used or produced over the period \( 1, 2, \ldots, n' \). Thus the optimal inputs and outputs over this period may be found, and we obtain

\[
\bar{x}_{vs} = \bar{x}_{vs} (a_1, \ldots, a_A) \quad s = 1, 2, \ldots, n'
\]

which therefore depends upon the parameters of the likelihood function.

The diagram, illustrated on page 36, constructed by Professor Hart (14, p. 58) is used to illustrate the implications of the above analysis.

To construct this diagram, Hart assumed:

(a) The firm sells only one product.

(b) There is no uncertainty of technology, buying-prices or interest-rates.
Total receipts and total outlays

Output = sales
physical units available
at $t_k$

Figure 3. The choice of plant when further knowledge is expected (Hart)
(c) The amount of goods available at a given future time is independent of expectations of sales at other dates.

(d) The selling market at a given future time is unaffected by sales or purchases at other dates.

(e) The firm is not subject to capital rationing.

He later removed these assumptions, and showed that their absence did not affect the fundamental implications which may be drawn from the diagram.

TC is the locus of the minimum possible total costs for each level of output. CC' is the cost curve resulting when operations are adapted to producing an output \( x_m \) at minimum cost. Thus, by definition, it must touch TC at \( P \), and lie above it elsewhere. \( r_1, r_2, r_3 \) represent revenue curves, showing receipts under the three mutually exclusive and exhaustive conditions assumed possible.

The diagram is constructed with respect to time \( t_k \). It is now assumed that at some intermediate time \( t_f \), \( t_0 < t_f < t_k \), the entrepreneur expects to be quite certain which revenue curve will actually occur. (Thus we may regard \( t_f \) to be equal to \( n' \) in Tintner's analysis.) The problem is therefore to choose a provisional output, \( x_m \), in order that the greatest advantage may be taken of the final situation, \( r_1, r_2, \) or \( r_3 \). Tintner's "first order" conditions may be regarded as being equivalent to requiring the choice of any
provisional output $x_m$, such that the resulting cost curve $CC'$ is nowhere below $TC$, and touches it at the point where output is equal to $x_m$. The remainder of the problem is to choose $x_m$, taking into account the entrepreneur's uncertainty about the likelihoods of the respective market situations, and his willingness to take long or short chances.

We have seen above that, following the development of the von Neumann-Morgenstern theory, in retrospect, it seems that Tintner considered too general a problem when he assumed that the maximand must be a functional. In view of this, we may now use Hart's diagram to illustrate the full solution to the problem.

Following the procedure described on page 24 above, the entrepreneur may be regarded as estimating the expectation function of receipts, $ER$, from his likelihood function $B$. He then chooses $x_m$ so that the distance, $(PP')$ between $ER$ and $TC$ is greatest.
IV. DECISION THEORY

With the developments in statistical and mathematical maximizing techniques which have occurred over the last two decades, the title of this chapter may suggest a variety of possible discussions, ranging through statistical decision procedures and various programming methods, to explanations of the process by which the rational entrepreneur may move from a position of subjective uncertainty, to one of subjective risk. However the objective of this chapter will be limited to a description of the latter process.

As is common to most problems in economics, the theoretical analysis of such a subjective process infers the need to become involved in the theory of the sociological and psychological processes which govern human behavior. However, the economist may circumvent the need to become so involved by either:

(a) Simply observing entrepreneurial activity, and from such observations, developing a framework of explanation by defining the various situations in which the entrepreneur finds himself, and by then classifying the stimuli which cause him to move into these situations. That is to say, adopting the empirical approach.

Or, (b) postulating fundamental axioms of behavior, and from there, theoretically developing a process which the "rational" entrepreneur would follow.
The first approach is that of Johnson and Haver (35), in their discussion of the decision-making process in agriculture. The second approach is suggested by Koopmans (39). The procedure which will be followed here will be to first describe Johnson and Haver's framework, then to attempt to develop an axiomatic explanation, based on Professor Koopmans' work, which will fit into this framework.

A. The Motivation Behind the Decision-Making Process

We have seen in the previous chapter that the fundamental objective of the entrepreneur is to maximize his utility. Thus we may regard his business activity as an intermediate activity necessary for the achievement of this goal. 1 The more successful he is in running his business, the greater will be his power set, and consequently the further he may move up his preference ordering. In static theories, where knowledge is perfect, the motive to enlarge the power set by increasing profit is all that it is necessary to consider. 2 Thus the profit function and the utility function are in a one-to-one relationship, and when the former is maximized, so is the latter. However, when the assumption of perfect knowledge is dropped, this relationship no longer holds and it is no longer possible to utilize this extremely

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1 This same business activity will, of course, for its own sake, enter into the preference ordering.

2 Assuming that this enlargement does not involve excess amounts of entrepreneurial effort.
objective measure of entrepreneurial utility. Hence the utility maximizing choices of the entrepreneur no longer simply depend upon profit maximization. With each level of profit which is anticipated to follow from a particular choice of action, there must be associated an anticipated probability of its realization. Thus the utility maximizing choice becomes an extremely subjective thing, and will depend, inter alia, on the anticipated consequences of failure (37). As a result of this, the willingness of an entrepreneur to take long or short chances, will not simply depend upon his intrinsic psychological characteristics, but will also depend upon the current state of the business.\^1 Since the willingness to take a chance and the amount of knowledge required to make a decision will be inversely related, we may regard such factors as the current state of the business as determining the efficiency with which decisions may be made.

B. Decision-Making as a Satisficing Procedure.

In Chapter II the theory of decision-making was described as a device by which the theoretical problem of utility maximization under subjective uncertainty was transformed to the more simple one of utility maximization under subjective risk. However it was so described with the qualification

\^1This was clearly demonstrated by a study by Hady et al. (18).
that since time was needed for decisions to be made, this description must be regarded as an oversimplification, since it did not infer the relevance of flexibility in the choice of actions of the entrepreneur.

The qualification mentioned above may be dealt with if we now describe the process of decision-making as a satisficing procedure. That is to say, the entrepreneur realizes that he has not enough information to identify that element in his power set, \( C \subseteq S_3 \), which is highest in his preference ordering. Thus he sets himself some level of aspiration, and regards the achievement of this level as being nearly enough equivalent to maximizing his utility. Thus in using the theory of decision-making as a device to convert a dynamic problem into a risk-trend problem, we do not assume that the element of choice, which, given adequate information, would be seen to be the optimum choice, will necessarily be found by the decision-making process. This point may be clarified with the aid of the diagram on page 43.

In Chapter I we saw that \( S_2 \subseteq S_3 \), and we now consider choice from the power set \( C \subseteq S_3 \). We have seen that the first part of the decision-making process was to choose a subset, \( I \subseteq C \) on which to gather further information. These sets are represented in part A of the diagram, and the
Figure 4. Diagrammatic representation of the subdivisions of the power set
"partitioning" of C is enlarged in B. Define $\bar{x}_{i,p}$ as that unidentified element belonging to C which actually is the highest on the preference ordering, and which would therefore be chosen if the entrepreneur had adequate information. We do not assume that $\bar{x}_{i,p}$ belongs to $I \cap S_2 \cap C$, and even if it does we do not assume that it is chosen.

C. The Framework of the Theory of Decision-Making

In this section, the discussion of decision-making will be restricted to a consideration of the process by which a major entrepreneurial decision may be made. (Thus for example we could apply the discussion to the choice of the type of plant to use in producing some already chosen product.) However, in the dynamic economy, as in the real world, we have a state of things where, "change is normal, partial ignorance is universal" (35, p. 1) and consequently where entrepreneurs must continually learn and adjust. Thus the following points should be borne in mind throughout such a restricted discussion:

1. We are discussing the process whereby the choice of a possible course of action is made. The actual business activities of the entrepreneur during the time he is involved in this process will affect his final choice through the

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1 The diagram infers that C is distinctly partitioned by $S_2$ and I. This is not the case, and the inference is allowed only to facilitate the demonstration.
effect of their outcomes on his consequent power sets.

(2) In most cases the entrepreneur will be attempting to co-ordinate the various enterprises which together constitute his business. Thus he simultaneously may be in various stages of the decision-making process with respect to different enterprises.

In Section A we saw the importance of anticipated consequences in the choice of actions. Following the line of analysis established in Chapter II, we may say that, for the most part, this point is taken care of in the construction of the relevant von Neumann-Morgenstern preference ordering. However, as we have seen in section B of this chapter, it is not dealt with completely in this process, since a choice is made in the decision-making process itself. We may regard this latter choice as the fundamental part of the decision-making process, representing the basic distinction between the dynamic and risk-trend theories. Once the choice of the subset I has been made, we may regard the information gathering process as a matter of course, leading finally to the position of subjective risk. Of course this is not to say that the information gathering process is attributed minor importance, since, as will become clear below, the efficiency with which this procedure is carried out will fundamentally determine the efficacy of the decisions made.

Johnson and Haver (35) described the essential functions
of the entrepreneur as follows:

(a) To observe those factors which affect his business environment.
(b) To analyze the data so obtained.
(c) To decide on a course of action indicated to him by this analysis.
(d) To act on this decision and put the course of action into effect.
(e) To accept responsibility for the consequences following this course of action.

They enumerated five fields which the entrepreneur must study. These were: prices; production methods and responses (including weather); potential technological changes; the personalities of the people directly or indirectly involved in their business activities; and the general economic and political situation. These areas may be regarded as together determining the environment in which the entrepreneur's business must be conducted. We may regard him as being involved in performing the above functions in this environment, with the aim of maximizing his utility. While so involved, he may find himself in one of the following knowledge situations with respect to a particular course of action:

(a) The Inactive Situation.
(b) The Learning Situation.
(c) The Forced Action Situation.
(d) The Subjective Risk Situation.

(e) The Subjective Certainty Situation.

The first three are situations of subjective uncertainty, while we may regard the last two as being essentially similar. The entrepreneur is regarded as first being in the inactive situation with respect to a particular course of action. He then may move into the learning situation, from which he may reach any one of the last three classifications. The diagram on page 48 illustrates the possible sequences.

With this sequence in mind, we will define these situations, according to Johnson and Haver, and at the same time, describe the process by which they conceive the entrepreneur to reach a decision concerning a particular course of action.

The inactive situation may be regarded as that situation in which the entrepreneur finds himself before he chooses the subset I, from his power set C. This latter set must now be regarded as that part of his sphere of awareness which seems attainable to him. That is to say, his power set may actually be larger than he is aware, but of course that part of which he is not aware is irrelevant to the discussion.¹ While he is in this situation, he may be regarded as lacking adequate knowledge to choose any course of action, and as being uninterested in gaining more. If he continues in this state over

¹Of course it may also be smaller than he believes it to be.
Figure 5. Johnson and Naver's classification of the states of knowledge
time, this in itself will contribute a choice.

The movement from the inactive situation into the learning situation is equivalent to the choice of the subset I from the power set C. This choice has been described as representing the fundamental distinction between dynamic and non-dynamic theories, and is thus obviously a very important step in the decision-making process. We will return to discuss it later, since at present it will suffice merely to assume that the entrepreneur becomes sufficiently interested in a set of possible courses of action to decide if it is worth while to gather further information on the implications of choosing to implement any element of this set. Thus he enters the learning situation, in which he feels he does not know enough about the probabilities and magnitudes of the various possible consequences of choosing the different courses of action, but feels it sufficiently worth his while to gather information on these things. Quite obviously this process will take time, but since it is essentially a very subjective matter, we can say nothing about the length of time necessary, but can only bear in mind the points made in Section A of this chapter. From the learning situation, the entrepreneur may move into any one of the last three knowledge situations. It is in these situations that a decision is made.

The forced action situation arises when the emergent
circumstances are such that the entrepreneur must choose a particular course of action, regardless of whether he feels that he has sufficient information to make this choice rationally. Thus a decision in such a case is really little more than a guess or a random choice, and therefore we may generalize and describe this situation as something which all entrepreneurs will wish to avoid.

The subjective risk situation has already been defined as that state of knowledge in which the entrepreneur is subjectively certain of the probability distribution of possible outcomes following choice of a particular course of action. Thus his choice in this situation may be regarded as being made according to a von Neumann-Morgenstern preference ordering, and is therefore fundamentally similar to choice in the situation of subjective certainty, when he holds single valued estimates of the possible outcomes.

This description of the various knowledge situations through which an entrepreneur may move before reaching a decision has been found to be quite useful in analyzing the process of decision-making in farming (34). The axiomatic approach of Professor Koopmans will now be used to develop a theoretical explanation of the process, which fits into the above framework.

We begin by extracting our fundamental axiom of behavior from a quotation by Professor Koopmans. Thus he wrote:
We can confidently assert that almost all choices occurring in real life are sequential "piece-meal" choices between alternative ways of narrowing down the presently existing opportunity, rather than "once and for all" choices between specific programs visualized in full detail. (39, p. 245)

In Chapter II, Koopmans' device for reducing the number of relevant alternatives from which choice must be made was described. Thus the power set was seen to be composed of subopportunities which define sets of courses of action which are jointly available for at least the first time period. We will use this device to define the choice of the subset \( I \subset C \). Thus we will henceforth regard the choice of the subset \( I \) as being equivalent to the choice of a subset of the subopportunities which together constitute the current power set. In other words, we will suppose that the entrepreneur chooses to gather information on only some fraction of the total number of alternative courses of action which he feels open to him.

Thus we will take the view that the entrepreneur will not immediately choose one particular course of action, but rather he will first choose from among the set of subopportunities which together contribute his current power set. This choice will then determine a new power set at a different point in time, from which a similar choice will be made. Thus the choice of the final course of action is in reality a sequence of choices from narrowed power sets. In other
words, we may state as our axiom of entrepreneurial behavior:
"The choice of a particular course of action is the result of a temporal sequence of choices which narrow down the power set." With this axiom and one basic assumption, we may describe a process by which the rational entrepreneur will move from the inactive situation, to the situation of subjective risk, from which he may choose according to a von Neumann-Morgenstern preference ordering.

We begin by assuming the entrepreneur to be in the inactive situation. Thus he may be regarded as being content with his business as it is, and not being interested in considering changes in his policy. By taking this view, we narrow down the area of consideration to that of business planning, and do not consider the "routine" decisions necessary to implement a given plan. As we have seen above, the entrepreneur operates in a changing environment, and it is this constantly changing environment which makes it necessary for him to constantly learn and adjust. Thus we see changes in this environment as being the stimuli which induce him to move into the learning situation.

In Chapter II we say that it was necessary to assume that the entrepreneur would not be able to gather information on all the courses of action open to him, indeed he would not immediately be aware of them all. Thus the necessity of first choosing a subset of his possible choices was seen as the
diagnostic feature of a dynamic theory, and in this section, this choice was subsequently defined as the choice of a subset of subopportunities. We now make a basic assumption: that there exists a preference ordering of all the subsets of subopportunities with which the entrepreneur may be confronted. This seems a reasonable assumption to make, since in effect we are simply assuming that the entrepreneur is able to choose between different ways by which it might be possible for him to maximize his utility. For example, we would assume that the farmer can decide whether he would rather feed cattle and hogs, or produce milk and keep hogs, or feed cattle and sheep, and so on. Quite obviously his economic conditions might be such that he has no choice in this matter, but this does not preclude the possibility that he might have a preference ordering of these things.

Given this assumption, we may explain the transition from the inactive to the learning situation as follows. The current power set of the entrepreneur will have been determined by his previous choices of courses of action, and the subsequent conditions of environment which actually occurred following these choices. That is, we may say his current power set is determined by his past actions and business environments. Thus if he chooses to remain in the inactive situation, we may conclude that his current business activities are those which he most prefers, given his present oppor-
tunity. Furthermore, in this case, his future power sets will be determined solely by his business environment. Thus the movement from the inactive situation into the learning situation occurs when the effects of changes in his environment so alter his power set that he either may no longer be able to continue in his current activities, and will have to choose a less preferred set; or he may find that it is now possible for him to engage in a more preferred set of activities.

Thus we have seen that the entrepreneur chooses a set of subopportunities on which to gather further information. This process will take time, but the length of time required will vary with the individual, according to his experience, circumstances, and willingness to take chances. Eventually he will recognize these initial subopportunities as themselves leading to future subopportunities. In this way he finally builds up a picture of the various alternative courses of action which he expects will constitute the subopportunity. We may expand on this point with the aid of the diagram in Figure 6. This represents a highly simplified case, where it is assumed that the power set of the farmer is initially composed of four subopportunities, to feed cattle, hogs, sheep, or keep dairy cows. Thus he has a choice of \(2^4\), that is, 16 sets of subopportunities. We suppose that he chooses to investigate cattle feeding or milk producing, and
Figure 6. Alternative subopportunities

- Feed cattle
  - Feed hogs
  - Feed sheep
  - Dairy herd
  - Use old barn
  - Yard and parlour

- Specialized system
  - Adapt old barn
  - Finish steers
  - Calves
    - Finish steers
    - Steers
    - Calves
      - Finish steers
      - Steers
      - Calves
        - Finish steers
        - Steers
          - Calves
            - Finish steers
            - Steers
              - Calves
                - Finish steers
                - Steers
                  - Calves
                    - Finish steers
                    - Steers
                      - Calves
                        - Finish steers
                        - Steers

Planning horizon for the non-specialized system of cattle feeding
Planning horizon for the special system
Time in production periods
we use the cattle feeding subopportunity to indicate how he may break down a subopportunity into its constituent courses of action.

In this simplified case, we assume that there would be only two alternative feeding systems, namely to adapt an existing barn, or to invest in a new specialized system. We also assume that there is only a choice of feeding one type of calves or finishing one type of steers. Finally we assume that if the specialized system is chosen, it may only be used to finish steers. Thus we may suppose that the farmer recognizes these alternatives, and hence the alternative courses of action, as shown in Figure 6, which constitute this subopportunity. We suppose that he estimates that the non-specialized method would involve a planning horizon of two years, while the specialized method would involve one of \( n \) years. Given the development of this estimate of the constituent courses of action which compare the subopportunities which interest him, we may describe the remaining parts of the process of decision-making which our rational entrepreneur would follow.

To each possible course of action we may assume that the entrepreneur formulates an estimate of a probability distribution of profits, or losses. Thus, for example, he would estimate a probability distribution of profits or losses from feeding calves over the first period; and he would also attach a probability distribution of profits or losses from
discontinuing operation of the specialized feeding system over the second period, and so on. We may also assume that he would attach an estimate of the probability that his economic environment would be such that he would choose these respective courses of action. Since, according to the von Neumann-Morgenstern theorem, the utility of a probability distribution is equal to its expected utility, we therefore have a probability distribution of expected outcomes for each subopportunity. Thus the entrepreneur would choose among these according to the relevant von Neumann-Morgenstern utility index. In our example, he would thus choose between cattle feeding and milk production; and by the same token he would choose between the alternative methods of production. In so doing, we see that he is simply choosing a set of possible alternative courses of action, and not a single course of action. We can also see that this result is quite compatible with the analysis of flexibility, where the problem was to choose the best method of planning inputs when further information was expected. In fact we may fit the above analysis into this latter analysis, since we may regard it as being simply an explanation of the process whereby the relevant information is gathered.

Before ending this chapter, it is necessary to consider briefly the possible position of another set of theories of choice in the above framework. This set is composed of the
game theoretic models which have been developed by such workers as Wold, Savage and others.

The assumption that the entrepreneur will formulate a subjective estimate of the probability distribution of profits or losses resulting from following a particular course of action, is very broad. For example, subsumed in it are the possibilities that the entrepreneur may use any one or group of a regular spectrum of estimating methods, ranging from the most sophisticated econometric methods at the one extreme, to simple intuition or guess-work at the other. Thus it would seem difficult to reasonably deny this assumption on the grounds of it being so narrow in its applicability as to be virtually useless in practice. However the common characteristic of the game theoretic models would seem to represent such a denial of this assumption, since they are based on the assumption of absolute uncertainty (8).

The tenability of this objection must depend upon the view taken with respect to the possible accuracy of these estimations of the probability distribution. If we take the view that the entrepreneur simply cannot make consistently accurate estimations of the relevant parameters, a logical alternative is to drop the whole procedure, and simply to recognize that pertinent events have occurred, and therefore may occur again. This is the course taken in the game theoretic models of choice. There is no assumption of probabil-
ity estimations, and the decision is made using only the data which have been observed to occur, and the appropriate choice criterion. To the extent that economic systems are composed of sets of simultaneous relationships, and hence the relevant parameters may only be estimated if the pertinent relationships are identified,\(^1\) this view may seem reasonable. Thus it may be suggested that if these parameters can only be estimated by the most judicious use of econometric methods, there seems little chance that the entrepreneur, especially the farmer, will make a reasonable estimate on his own.

To some degree there is validity in this argument, and to this extent we may regard these theories as a substitute for the above framework, in that the various choice criteria may be used to approximate different types of utility functions. However they do seem to be fundamentally defeatist in their attitude towards probability estimation. This point, together with their pessimistic attitude on the abilities of the human mind, seem sufficient to make seem quite reasonable the suggestion that this substitution should not take place.

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\(^1\)See for example Johnston (36).
V. THE DYNAMIC THEORY AND AGRICULTURAL PRODUCTION

In this chapter we will first consider the importance of the dynamic theory of production to the economics of agriculture. We will then consider the implications of this theory with respect to agricultural economic research and extension programs.

A. The Effects of Uncertainty on Agricultural Production

We have seen in Chapter I that the common diagnostic feature of dynamic theories is that they handle choice under uncertainty. Thus the importance of these theories to the economics of agricultural production depends upon the extent to which uncertainty exists in the economic environment of the agricultural entrepreneur. It is very well known that this environment is one of the most uncertain of all areas of production. Hence there is no need here to demonstrate this fact in detail, and we may assume any dynamic theory of production to be potentially very important to agriculture. However it is quite relevant to the continuity of the discussion to consider the effects of this uncertain environment on agricultural production.

Perhaps the most important causes of uncertainty in agriculture are price fluctuations, which arise as the effect of the interaction between an inelastic demand and variable
production coefficients caused by variations in weather, disease effects, and so on. There are numerous examples where this point has been demonstrated. For example, Brown and Heady (4) attributed most importance to price fluctuations in causing income variability in livestock production. This income variation caused by fluctuating prices has various important effects on agricultural production. We may classify these effects into three broad groups:

(a) Capital-rationing.
(b) The choice of production methods.
(c) Increasing the importance of management.

These groups are not, of course, completely distinct, since factors in any one group may partially determine results observed in either of the other two. However for the present purpose they will suffice as a rough classification of the effects of uncertainty.

1. Capital rationing

Capital rationing is said to occur when the use of capital is restricted to the extent that its value at the margin is significantly greater than its cost at the margin. This may be brought about by a restriction in supply from the lending firm (external capital rationing), or by a restriction in use by the borrower (internal capital rationing) (16, p. 550). An example of the latter case was provided by a study by Heady et al. (20), who found that the equity ratio and the
risk discount factor were significant in explaining variations in planned investment. They also found that the farmers in the sample were little affected by external capital rationing. The reason for the observed internal capital rationing was uncertainty, and practically all the farmers were found to describe one hundred percent equity as an ultimate goal.

2. The choice of production methods

Quite obviously internal capital rationing will have a significant effect on the choice of production methods. However, at this point we are more interested in the effect of uncertainty on the way in which a given amount of capital will be fixed for productive use, rather than how much of it will actually be used.

As an extreme effect of uncertainty on production plans, we may cite a study on Kentucky stock feeding and dairying farms made by Nesius (46). In the area studied, there had been five disastrous droughts over a period of fifty years. It was shown that the farms tended to carry only a few more livestock than it was expected the pastures would carry in dry years. However this extreme Wald type maxi-min approach seems to be more characteristic of older and less educated farmers (8, p. 926). More usually, the effect of uncertainty on choice of production methods will be that "the (farmer) may prefer flexibility to the extent that marginal rates of
substitution between enterprises is sufficiently greater" (17). Thus, in our current terminology, the farmer usually prefers not to narrow down his power set in too rapid a manner, since this leaves him with too little maneuverability in the face of his uncertain future business environments. For similar reasons, diversification of production, and the use of "safe", "time-proved" methods are often preferred (16, p. 468). The net effect of these preferences is that, generally speaking, the cost structure in agriculture will be higher than the current technology of the industry would suggest.

3. The importance of management

In the previous chapter we saw that the fundamental role of the entrepreneur in managing his business was to observe, analyze and make decisions in his uncertain business environment. In agriculture, the ranges of total possible outcomes are considerably greater than those which are likely to be experienced by any one entrepreneur working within his own micro-environment. Thus it is necessary that farmers should have "mental capacities to 'think outside' of the narrow environment of their own experiences" (16, p. 468), if they are to have any reasonable chance of success. Moreover they must be capable of continuing this process after a primary decision has been made, since, as we have seen above, they must continually learn and adjust to their changing environ-
ment. Thus we may generalize and state that the successful farmer will have an analytical approach to his task of management, and hence will use both inductive and deductive reasoning in reaching his decisions.

The above discussion suggests that "the management factor" will be significantly important in determining farm income. Thus Wilcox (57, p. 119) points out that most differences in net farm income have been explained in terms of the technical efficiency of production and marketing, and stresses his belief that variations in management are at the root of the matter. Since we may regard the above characteristics of the successful farmer as being definitely human characteristics, and since these latter phenomena are generally normally distributed, we may regard the fact that, in all studies on income dispersions, the array is ogive (57), as a possible support of this hypothesis.

B. The Implications of the Dynamic Theories for Agricultural Economics

We have seen above that the general effect of the uncertainty in the agricultural economic environment is that costs of production will invariably be significantly higher than they would be under conditions of more nearly perfect knowledge. Thus an important role of agricultural economic research is to eliminate this uncertainty as much as the economic use of national resources will allow, since any sig-
significant achievements made in this direction are bound to yield long-run benefits to both the agricultural sector and the economy as a whole.

Of course agricultural economic and extension work has always been directed to this end. However, as was recognized in Chapter II, this work has generally been carried out without the guidance of a theory of production which had, as a fundamental part incorporated within it, a theory of decision-making under incomplete knowledge. The initial discussion in Chapter II showed that one immediate effect of admitting uncertainty into the domain of the theory of production was the loss of the correspondence between profits and utility. Thus was lost almost all of the objectivity possible under the assumption of perfect knowledge, where the axiom of profit maximization was quite tenable. Consequently it became necessary to discuss how a particular entrepreneur might maximize his utility, given his own, subjective, preference ordering, and his current power set. This last requirement might, at first view, seem to carry with it enormous problems for extension and research work, due to the seeming loss of the general applicability of research findings, which are invariably obtained via the assumption of profit maximization. However this does not at all seem to be the case, since all that seems necessary is a slight shift in emphasis in research, and a few changes in the method of presentation of
the results.

Usually farm system and enterprise research results are published and communicated in the form of averages. The more sophisticated the report, the more data will be included on the dispersion, skewness, and other characteristics of the sample studied. From the data gathered in these studies, the important economic variables are found, and recommendations made. However, in the light of our discussion in Chapter IV, we may criticize a large number of research reports on two important points:

(1) Invariably no attempt is made to formulate an objective probability distribution of profits.

(2) The study is made, and recommendations given, under the assumption that the farmers studied were attempting to maximize profits.

This is not by any means to suggest that the majority of workers are unaware of the need to recognize these points. Invariably they may be well aware of such shortcomings in their work, but, in the absence of a well established dynamic theory of production; and in the presence of overwhelming computational and statistical difficulties with limited information, they feel that this is all that can be done with existing tools. This view is entirely reasonable especially with respect to the second point. However so is the above criticism of such work in the context of the present dis-
cussion, where we are simply giving recognition to the im-
plications of the dynamic theories of production, for agri-
cultural economics.

The interstate study (34) generally confirmed the use-
fullness of Johnson and Haver's (35) classification of the
states of knowledge in which a farmer finds himself during
the decision-making process. Thus, whether or not the ex-
planation of the process developed from Koopmans' approach
is accepted, it is obvious that information on the probabil-
ity distribution of profits and losses will be an important
aid to the farmer in this movement from subjective uncer-
tainty to subjective certainty. If the above explanation is
accepted, investigations of the different courses of action
which constitute the respective subopportunities will become
of relevance. These would then provide a framework of pos-
sible outcomes which could be presented to the farmer, and
from which he would choose according to his preference. How-
ever, it may not be necessary to describe in detail each pos-
sible course of action and its probability distribution of
outcomes, since it seems that it may be possible to use pro-
gramming methods to consider the problem as a whole. We will
now move to the final chapter with this objective in mind.
VI. A METHOD FOR COMPARING TWO ALTERNATIVE SYSTEMS OF PRODUCTION

In this chapter an attempt will be made to meet the suggestions put forward in the last chapter. That is to say, a possible method for comparing the likely profitabilities of two alternative methods of production will be described. Since we have seen that an important effect of uncertainty in agricultural production is to cause a higher industrial cost structure than present technology would allow under more certain conditions, we will choose to develop a theoretical framework for comparing specialized and flexible systems of production, since by definition, the former systems will be more technologically efficient than the latter.

First of all we must consider further the meaning of "specialization" and "flexibility". In Chapter III we saw that flexibility is a property of a business plan. This property was attributed to a fixed plant which was not designed to produce a given output in the most efficient manner possible, given the amount of capital available, and present technology; but which was designed to approximate the most efficient plants over a range of outputs. Thus we may regard the degree of flexibility exhibited by a given plant as being directly proportional to the size of this range. Hence we may regard flexibility as being a reasonably continuously variable property, and therefore there will be
no absolute distinction between the two properties. Thus a specialized plant is essentially only specialized relative to some other plant which will have a greater range of outputs over which it approximates best technologies. This distinction should be borne in mind during the following exposition.

In the previous chapter it was suggested that there were two important criticisms which should be met by system and enterprise research methods. These were, that importance should be given to determining objective probability distributions of profits; and that the assumption of profit maximization is not really tenable. Thus any research method developed here should be able to meet these criticisms to some reasonable degree. It was also recognized that the second criticism would be the most difficult to meet directly. Hence the procedure followed will be to first describe a method in which profit maximization is assumed, in order to simplify the exposition. This method will then be expanded in an attempt to meet the second criticism.

In Chapter IV it was shown that we could regard a choice of a particular course of action over time, as the result of a series of choices which successively narrowed down the opportunities associated with a particular line of investment. However, at the beginning of each production period, we saw that there would essentially be a recurring set of possible activities in which it was possible to become
engaged over that period. That is to say, the financial results of the previous periods would tend more to limit the level of these activities, rather than to cause the exclusion of any of them from subsequent possible sets from which choice could be made. To return to the example given in Figure 6 on page 55, suppose the subopportunity, "adapt the barn to cattle feeding" were chosen, and the necessary investment made. With the barn so adapted, at the beginning of each production period, it may still be used to feed calves or steers. However the success or failure of the farm system as a whole will determine the level at which either of these activities may be operated.

Due to this recurring set of activities associated with each subopportunity, or line of investment; and since we are currently making the assumption of profit maximization, the problem of estimating the probability distribution of profits associated with a particular farm system may readily be tackled using linear programming methods. We must compare farm systems, rather than enterprises, since as is well known, the basic profit maximization problem involves the best use of the scarce resources of the farm, and hence the harmonious combination of the various enterprises which may utilize these resources. Of course the specialized farm system would be built around one important enterprise, and of course may simply consist of only one enterprise. However
in this latter case, we are simply saying that the levels of all other enterprises, which could make use of the scarce resources of the farm, are set at zero. It is quite conceivable that circumstances could arise where the profit maximizing combination of these activities would actually require the level of this specialized enterprise to be set at zero, and the specialized equipment left idle. Thus for example, if a farm system was built around a cattle feedlot system, where a maximum amount of corn was grown to feed the cattle. It would be quite possible for the fat cattle and corn prices to vary in such a way that it was more profitable to sell all the corn, and feed no cattle, thus leaving the specialized feedlot equipment idle.

We have seen above that an essential requirement of our method is that it recognizes the dependence of the present power set on the outcomes of past undertakings. In Chapter II we recognized the feasible set of the linear programming method as defining a power set. Thus we must require that the model used to compare the performance of two systems over time, contain a method for simulating the adjustments in restraints which would be necessary at the end of each production period. In this manner, we may regard the requirement

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1This is the procedure used by L. P. Apeadele, in his work on his doctor’s thesis, and who suggested the method to the present writer.
as being reasonably satisfied, and may proceed with the general description.

If we define any variable which varies in a chance, or unpredictable manner, as a random variable, it is quite obvious that agricultural commodity prices most certainly qualify to be called random variables. Since net farm incomes are functions of these prices, we can see that net farm income is itself a random variable. Hence, by taking samples from the various series of observed agricultural product prices, and using them with the simulated linear programming model, we may generate a sample of net farm incomes which will have been generated by some parent distribution which is peculiar to the system and price expectation model under consideration. The longer the series which may be used, the more information will be available on this distribution, and the better the estimate which may be made of it. By programming different farm systems, samples from different probability distributions will be generated, and consequently comparison may be made between them. As will be recognized below in the detailed description of the method, it may not be reasonable to attempt sophisticated statistical comparisons. However it will at least be possible to compare estimates of such parameters as the mean, range, variance, mode and so on.

Thus the procedure used for estimating the probability distribution of profits for a particular system (say, for
example, the system centered on the specialized feed lot) would be as follows: A set of resource restraints and activities would be defined, according to the area and class of farms to which the results were to be applied. Obviously the greater the number of farms which would be characterized by the defined set of restraints and input-output coefficients, the greater would tend to be the applicability of the results. The simplifying assumption of constant input-output coefficients could be made if the period of sample was short, or if the indications were that such an assumption would be tenable. To simplify the exposition, we will assume that it is tenable.

Having so defined the farm at the beginning of the period, it would then be assumed that the farmer would use these resources to set up the system under consideration. This would then simulate the choice of a subopportunity, and narrow down the power set, by the necessary adjustment in the restrictions. Thus, for example, by making a heavy investment in specialized feedlot equipment, the farmer would lower the amount of capital at his disposal for other uses. This effect is illustrated in the very simplified diagram in Figure 7. The farmer is then regarded as planning his program of outputs for the first period of production, according to some price expectation model, and then implementing this plan for that first period. The actual result of that plan
Restraint (1) reflects the capital availability before investment in the specialized feedlot system.

Restraint (2) reflects the capital availability after the investment.

Thus the narrowing down of the power set is, in a sense, represented by the shaded area.

Figure 7. Diagrammatic representation of the narrowing of the power set.
would then be evaluated according to the prices which actually did occur. For example, suppose the period of sampling was 1950-65. The farmer is regarded as using his expectation model to evaluate his estimates of product prices for the first year, that is 1950, and he then derives his production plan for this year, by linear programming. This plan is assumed put into effect, and its yield is evaluated according to prices which actually materialized during that year. Given this evaluation, the resource restraints would be re-adjusted according to changes in inventory and liquid financial resources. This process would then be repeated for each period in the series, so yielding the sample of annual net incomes.

By using different price expectation models for the same system, the method would yield a comparison of the relative efficiencies of these different models. However it should be noted that the assumption that the farmer correctly anticipates prices for each single production period in turn, would not necessarily yield a measure of the maximum possible profits attainable from that system, over the period observed. The readjustments in the restraints would tend to prevent wide fluctuations in successive production plans from being very profitable. Thus we can only compare system probability distributions which involve the same price expectation model. Since the net incomes generated by each system are random
variables, so will be these differences. Hence an estimate of the probability distribution of these differences may be obtained. This would yield an idea of the probability that an annual difference would be greater than or equal to zero, as illustrated in the hypothetical example shown in Figure 8 on page 78. The above arguments may be illustrated algebraically as follows. First we define the following terms:

- $P_{i,t}$ is the observed net price of the $i$th output for the $t$th period,
- $P_{i,t}^*$ is the expected net price of the $i$th output for the $t$th period,
- $x_{i,t}$ is the optimum output (according to the expected prices) of the $i$th product for the $t$th period.

Then, if we consider $n$ products, we have

$$N_t = \sum_{i=1}^{n} P_{i,t} x_{i,t}$$

as the net revenue for the $t$th period. This will contain the return on fixed assets, and profit. We have seen that product prices must be regarded as randomly distributed. Theoretically this is so because we cannot fully explain the process of price determination, but can only pick out the major factors in the process, and must confine the effects of the remaining determining factors to a residual term. Thus we may write:
Figure 8. A hypothetical example of two samples of annual net incomes generated by two different systems.
Possible time-paths of net incomes for two different systems

Estimate of the probability distribution of these differences
\[ P_{i,t} = B Z_{i,t} + e_{i,t} \quad 1 = 1, 2 \ldots n \]

where we regard the residuals \( e_{i,t} \) and hence the \( P_{i,t} \) as being randomly distributed.

As a very general representation of the expectation model, we may write:

\[ P_{i,t}^* = E(P, G) \quad 1 = 1, 2 \ldots n \]

where \( P \) would be a matrix of observations on the lagged prices of the \( i^{th} \), and other related product prices; and \( G \) would be a matrix of observations on other factors thought relevant to the process of determining the \( i^{th} \) price. Obviously \( P \) would be randomly distributed, while \( G \) may or may not be. Hence we can see that \( P_{i,t}^* \) would also be randomly distributed. Also we have:

\[ x_{i,t} = x_{i}(P_{1,t}^*, P_{2,t}^*, \ldots P_{n,t}^*) \quad 1 = 1, 2 \ldots n \]

Hence \( x_{i,t} \) is also randomly distributed. Therefore we can see that \( N_t \), which is a function of two random variables, will itself be a random variable; and we note that this distribution depends upon \( E \), the expectation model.

Given the structural forms of the above relationships, and assumptions on the distribution of the \( e_{i,t} \), by determining the relevant Jacobians, the distribution of \( N_t \) could be found. However the necessary compounding of any assumptions made would undoubtedly render this procedure impracticable. Hence it is felt more reasonable to propose that observations on the \( N_t \) should be used to estimate this dis-
If we define $N^j_t$ as the net income from the $j$th system for the $t$th period, then
\[ D_t = N^S_t - N^F_t \]
would represent the difference in net incomes from two different systems, where the same expectation model was used. By analogous reasoning to that used above, we can see that $D_t$ would also be randomly distributed.

The above procedure would yield an estimate of the parameters of the probability distribution of annual yields which an efficient farmer following a profit maximizing procedure, and using a particular expectation model, could expect from a particular system of enterprise. In view of the theoretical discussions in the earlier chapters, it is suggested that all these results be presented to farmers in order that they may make their own subjective evaluations of the various systems and expectation models studied.

Before concluding this chapter, there remains the task of modifying the above method, in order that the criticism of the non-tenability of the assumption of profit maximization may be met to some extent. The fundamental argument against the above method, which this latter criticism raises,

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1The author is indebted to Dr. W. A. Fuller for his advice on this matter.
is that the $x_{i,t}$ variables depend upon this assumption in a crucial manner. Thus the feasible set of points in the programming problem, is not at all determined by any objective measure of the risk associated with each solution vector. Hence the optimum solution may yield net incomes which have prohibitively high variances. By phrasing the problem in this manner, we can see that, to some extent, the above method does meet this second criticism, since it may be expected that the estimates of the parameters of the distributions of $N_t$, obtained under this assumption, would allow the farmer to take into account this variability. Also, downward biased price expectation models would tend to reduce the effect of the profit maximization assumption. However, the fact remains that it seems unlikely that farmers act according to this assumption. Hence we will complete this chapter by describing a modification of the above method, which may better enable it to meet this second criticism.

The procedure suggested is simply to define a "risk restraint", which would be included into the restraints defined in the above problem. Thus for each period, the farmer would be regarded as maximizing net income, subject to an additional restraint that the variance of this net income, should be less than some specified value. We have defined $N_t$ such that:
\[ N_t = \sum_{i=1}^{n} x_{i,t} P_{i,t} \]

Thus, for any given set of values for the \( x_{i,t} \), \( i = 1, 2 \ldots n \), at a time \( t \), we have that:

\[
\text{Variance of } N_t = \text{Var.}(N_t) = \sum_{i=1}^{n} x_{i,t} \text{Var. } P_i + 2\sum_{i<j} \sum_{1}^{n} x_i x_j \text{cov.}(P_i P_j).
\]

Hence \( \frac{\partial}{\partial x_{i,t}} (\text{Var.}(N_t)) = \text{Var.}(P_1) + 2\sum_{j=1+1}^{n} x_j \text{cov.}(P_i P_j) \), \( i = 1, 2 \ldots n \)

In order that the restraint may be made to fit into a linear programming problem, the assumption that \( \text{cov.}(P_i P_j) = 0 \), for all \( i \) not equal to \( j \), is required. If tests proved this to be tenable, we may proceed with this method. Hence we could assume:

\[
\frac{\partial}{\partial x_{i,t}} (\text{Var.}(N_t)) = \text{Var.}(P_1) \quad i = 1, 2 \ldots n
\]

Given estimates of these variances, the restraint added to the program would be:

\[
\sum_{i=1}^{n} x_i \text{Var.}(P_i) \leq K
\]

where \( K \) would be a value reflecting the willingness of the farmer to involve himself in a plan having widely variable outcomes.

By adding this restraint to the first method, and by using various levels of \( K \), there would be generated a set of
results which should approximately meet the second criticism. In view of the extremely subjective nature of the utility maximization process, these results would be presented to farmers in a manner which would describe to them as fully as possible, the estimated probability distributions of net incomes of the systems compared. Thus, for example, they could be presented diagrammatically as in Figure 8, which would provide a simple comparison of the variability in the levels of net income which the different systems might be expected to yield. Given this information, the farmer might then be better able to plan his farming system. Moreover, there is currently a definite trend towards greater specialization in agricultural production. If this method could be used to objectively demonstrate that an efficiently managed specialized farming system would not yield such a greatly fluctuating annual net income as is commonly supposed, it would aid in increasing the efficiency of agricultural resource use, by helping to strengthen this trend towards specialization.
VII. SUMMARY

In the second chapter, the theories of production are recognized as defining particular interpretations of the general theory of choice. Hence they are divided into three categories, according to the domain of the preference ordering on which they are defined. Thus the fundamental characteristics of the static, risk-trend, and dynamic theories, are described and compared, and it is seen that the area of definition of these theories increases as we move from the static to the dynamic cases. Consequently the list of natural economic phenomena which may be explained by economic theory, is lengthened as the assumptions on the degree of knowledge is relaxed. Thus we see that static theories cannot explain the existence of profit and the maintenance of stocks of goods. Nor can they contain any requirement for a theory of decision-making. The risk-trend theories are similarly unable to require a theory of decision-making, but they may explain the existence of profit and the maintenance of stocks of goods in a production economy. It is the potential ability of the dynamic theories to explain all these phenomena, which is seen to characterize their importance in the development of economic theory.

In the third chapter, the works of Tintner, Hart and Koopmans are compounded to develop a framework for the
dynamic theory of production. The theory of decision-making is regarded as the process whereby the entrepreneur, finding himself in a situation of inadequate knowledge, chooses to gather information on certain of the elements of his power set, in order that he may choose from among them according to his von Neumann-Morgenstern preference ordering. Having so defined its position in the framework, the detailed discussion of decision theory is left to the following chapter.

Professor Koopmans' observation that, in a theory of choice over time, choice is inevitable and present choices will influence future sets of possible choices, is recognized as being relevant to the dynamic theory of production. The works of Tintner and Hart are then used to describe the formal maximization of the von Neumann-Morgenstern preference function.

In Chapter IV, the effect of uncertainty is seen to cause the loss of the one-to-one correspondence between the profit maximization and utility maximization processes. This is due to the fact that such factors as the consequences of the failure of a business plan also enter into the utility function. Under conditions of perfect knowledge these considerations are irrelevant, but when knowledge is less than perfect, they become very relevant in the choice of production systems. Another result of uncertainty is that we must regard the decision-making process as a satisficing procedure,
since it may no longer be feasible to identify the utility maximizing element of choice. Thus the decision-making process may be regarded as a search procedure whereby some satisfactory level of utility may be reached. In part C, the discussion is restricted to the process by which a major entrepreneurial decision may be made. In this discussion, Johnson and Haver's classification of the states of knowledge which constitute the decision-making process, is used in conjunction with work by Koopmans, to describe a rational process of decision-making. Thus the process of choice under conditions of inadequate knowledge is seen to be characterized by a sequence of choices which narrow down the existing set of feasible choices.

In Chapter V the effect of the uncertainty in the agricultural economic environment is seen to cause the cost structure of the industry at any given time, to be higher than the state of technology at that time would tend to suggest. Hence it is recognized that an important role of agricultural economic research is to eliminate this uncertainty as much as possible. The theory of dynamic production described in the earlier chapters, indicates that information on objective estimates of the probability distributions of outcomes which may follow various lines of investment, will be very relevant to farmers in aiding them in their decision-making. Hence in Chapter VI, a method is described whereby
these probability distributions might be estimated.

In Chapter VI, it is recognized that the annual net incomes yielded by the use of a particular price expectation model and farm system over a period of time, will be distributed in a random manner. From the discussions in the prior chapters, it is shown that a procedure using linear programming and a model which would simulate changes in resource restraints brought about by the outcomes of previous production plans, may be used to generate a sample of observations from this distribution of net incomes. Thus a process is described, by which comparisons may be made of the characteristics of the distributions of net incomes yielded by different price expectation models and farm systems.
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