Adoption of Agricultural Innovations in Developing Countries: A Survey

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Prepared by: Gershon Feder
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Development Research Center

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This paper reviews various studies which have provided a description and possible explanation to patterns of innovation adoption in the agricultural sector. It therefore covers both empirical and theoretical studies. The discussion highlights the diversity in observed patterns among various farmers' classes as well as differences in results from different studies in different socio-economic environments, and reviews the attempts to rationalize such findings. Special attention is given to the methodologies which are commonly used in studies of innovation adoption, and suggestions for improvements of such work through the use of appropriate econometric methods are provided.

The survey points out that the tendency of many studies to consider innovation adoption in dichotomous terms (adoption/nonadoption) may not be appropriate in many cases where the actual decisions are defined over a more continuous range (such as quantity of fertilizer to be used). More attention needs to be given to the socio-cultural and institutional environment in areas studied so that their interrelation with economic factors affecting adoption can be inferred. The presence of several interrelated innovations (which form a "package") is another aspect that needs to be considered more carefully in future research, since a number of simultaneous decisions may be involved. Furthermore, the possibility of regular sequential patterns in adopting components of a new technological package should be specifically addressed in future studies. Finally, the impact of differential adoption rates on land holding distribution merits attention in future research.

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Adoption of Agricultural Innovations in Developing Countries: A Survey

I. Introduction

Adoption of technological innovations in agriculture has attracted considerable attention among development economists because the majority of the population of less developed countries (LDC) derive their livelihood from agricultural production and because new technology apparently offers opportunity to increase that production substantially. But the introduction of many Green Revolution and other technologies has met with only partial success as measured by observed rates of adoption. The conventional wisdom is that constraints to the adoption process include such things as the lack of credit, limited access to information, inadequate farm size, inadequate incentive associated with farm tenure arrangements, insufficient human capital, absence of equipment to relieve labor shortages (thus preventing timeliness of operations), chaotic supply of complementary inputs (such as seed, chemicals, and water), and inappropriate transportation infrastructure.

Many development projects have sought to remove these constraints by introducing facilities to provide credit, information, orderly supply of necessary and complementary inputs, infrastructure investments and ground leveling, etc. Removal of these constraints was expected to result not only in adoption of the improved practices but also in a change in crop composition which was thought to further increase average farm incomes. Expectations, however, have
been realized only partially. As past experience shows, immediate and uniform adoption of innovations in agriculture are quite rare. In most cases, adoption behavior differs across socioeconomic groups and over time. Some innovations have been well received while other improvements have been adopted by only a very small group of farmers.

The purpose of this paper is to survey the various studies that have attempted to explain these observed differences in adoption behavior either theoretically or empirically. The next section begins by reviewing empirical studies which have attempted to identify and validate various barriers or deterrents to adoption, and it is followed by a discussion of methodologies which should be used in such studies. The following section then considers conceptual and theoretical developments regarding adoption patterns that have been suggested on the basis of various empirical works. Finally, potential new directions for research are explored. The implications of the survey are indicated in the last section.

While the objective of this paper is to survey the literature involved in explaining the adoption process, the volume of such published research is overwhelming. Hence, the attempt here is simply to review representative works rather than to present an exhaustive discussion of all work to date.

II. Empirical Studies of Innovation Adoption

The introduction of high-yield cultivation techniques in agriculture during the 1960s and the socioeconomic impact of these innovations on agricultural sectors in LDCs have been subjects of considerable
interest in empirical economic research. This section reviews some of the empirical works which investigate factors affecting adoption of new technologies in agriculture. Most of these works refer specifically to Green Revolution innovation. For the purposes of this paper, the Green Revolution and farmers' response to it are relevant as examples of innovations that are divisible and thus neutral to scale (provided no credit and tenure constraints are present).

There are hundreds of empirical studies related to this subject of the Green Revolution, and individual mention of each in this review would be impossible. However, Ruttan has drawn several generalizations from this large body of literature that are as follows:

1. The new high-yielding varieties (HYV) were adopted at exceptionally rapid rates in those areas where they were technically and economically superior to local varieties.

2. Neither farm size nor tenure has been a serious constraint to the adoption of new HYVs of grain. While smaller farmers and tenants tended to lag behind larger farmers in the early years following the introduction of HYVs, these lags have typically disappeared within a few years.

3. Neither farm size nor tenure has been an important source of differential growth in productivity.
4. The introduction of HYVs has resulted in an increase in the demand for labor.

5. Landowners have gained relative to tenants.

Ruttan acknowledges that there are many exceptions to these generalizations because innovations have been introduced in environments with different economic, social, and political institutions. The crucial extent to which these factors act as constraints on adoption of new technologies and the importance of individual farmer characteristics are the subjects of the works reviewed below.

A. Farm Size

An often-mentioned impediment to adoption of new technology relates to fixed costs attached to implementation. For example, new machinery or animal power requires an obvious pecuniary expense. In addition, adoption of a new technology requires a fixed investment of time for learning, locating, and developing markets as well as for training hired labor. These fixed expenses tend to discourage adoption by small farms and suggest a different pattern of adoption among farms of different scale.

Several empirical studies in Africa have confirmed the notion that adoption of ox cultivation is more likely on larger farms. Gemmil found in Malawi that adopters of ox cultivation cropped larger areas and significantly larger farms. Weil found, similarly, for Gambia that farmers employing ox plow had 24 percent more acreage than those using hand cultivation.
However, the study by Weil indicates that the interaction of technology lumpiness and limited access to land may not be the root of the negative relationship between farm size and adoption. He suggests that capital may be more available for large farms so that, even though all farms may wish to adopt (and may increase short-run profit by adopting), larger farms are more likely to do so. An additional reason for adoption, beyond the profit motive, is that farmers apparently prefer to replace heavy demands on human power with ox cultivation to improve working conditions. But again, greater credit availability and wealth for larger farms can lead to a negative relationship between farm size and adoption.

Several studies reviewed by Binswanger have found a strong positive relationship between farm size and adoption of tractor power in south Asia.

It is important to note, however, that the relative lumpiness of early tractor technology is somewhat mitigated by the variety of designs presently available and by the emergence of markets for hired tractor services. Greene found that smaller farms in Thailand overcame an initial lag fairly fast and eventually used (hired) tractor services as much as did larger farms. Similar findings are reported for the Philippines by Alviar. In some areas, governmental tractor hire stations have been established, but quite often these programs have failed (e.g., in Northern Nigeria) because of poor maintenance.
Other empirical studies have shown that inadequate farm size also impedes an efficient utilization and adoption of certain types of irrigation equipment such as pumps and tube wells.\textsuperscript{9,10,11,12}

The weight of empirical evidence similarly suggests that the use of HYV and some modern variable inputs initially tends to lag behind on smaller farms; but, for other inputs, the evidence is mixed or to the contrary. Moreover, in some cases, land quality differences combine with farm size differences to affect adoption decisions. For example, Burke\textsuperscript{13} found that adopters of Green Revolution technology are more land intensive when soil quality is taken into account in measuring land intensity, whereas they are less land intensive if land quality is not considered and land intensity is simply measured by the land/labor ratio. Gladwin's\textsuperscript{14} findings in Mexico further suggest the importance of considering land quality in explaining adoption decisions.

However, some evidence suggests that the intensity of adoption of HYV on small farms eventually exceeds that of larger farms. For example, Parthasarathy and Prasad\textsuperscript{15} used $\chi^2$ tests to verify a significant relationship between size and HYV seed adoption in an Andhra-Pradesh village in 1971-72 (about 7 years after HYV introduction). Some additional evidence of such instances is cited in the surveys by Vyas\textsuperscript{16} and Perrin and Winkelmann.\textsuperscript{17} Thus, the majority of evidence indicates that the incidence (as opposed to intensity) of adoption of HYV is positively related to farm size. A number of studies support Ruttan's contention above that smaller farms which initially lag behind larger ones in adopting HYV
eventually catch up. However, Mutiah, Schluter, and Sharma found that small- and medium-size farms in India adopted HYV on a larger proportion of acreage than did large farms. Schluter further found that the degree of this relationship increased with the length of time since the introduction of the new varieties.

The studies regarding intensity of fertilizer and pesticide use per unit of land show a more confusing pattern of behavior. While many studies indicate no significant difference in chemical input use per acre between farms of different size, others indicate a positive relationship between the amount of fertilizer applied per hectare of fertilized land and farm size. Perrin and Winkelmann report that there were significant size effects in nearly half of the studies covered by their survey. Similar findings are reported by Clawson and in a number of other studies cited by Singh.

Again the implication is that, once adoption has taken place, small- and medium-size farms employ a higher level of inputs (such as fertilizers) compared to larger farms. Van der Veen, who studied Philippine rice, suggested three possible explanations for this observed phenomenon. First, small farms may farm land more intensively to meet subsistence needs; second, small farms may irrigate more efficiently; and, third, small farms use relatively more low-cost family labor. Some of these factors were shown by Srinivasan to explain the higher variable input per hectare by smaller farms in the framework of a theoretical model. Hodgdon has
also shown that the ability of small farms to use fertilizer and pesticides efficiently may depend on the availability of HYV technology.

These seemingly conflicting results may not be surprising because landholding size is a surrogate for a large number of potentially important factors such as access to credit, capacity to bear risks (see discussion below), access to scarce inputs (water, seeds, fertilizers, insecticides), wealth, access to information, etc. Since the influence of these factors varies in different areas and over time, so does the relationship between landholding size and adoption behavior.

To summarize, the following statement by Schutjer and Van der Veen seems to reflect the state of the art:

"The available literature does not indicate a consistent pattern of size of landholding per se as a barrier to technology adoption by farmers in the developing nations. The range of technology design and the emergence of institutional mechanisms to overcome indivisibilities contribute significantly to that finding. However, more critical is the fact that most studies do not provide evidence regarding the factors which relate to farmsize such as wealth, access to market, etc., which may, in turn, account for variation in adoption across land sizes. Finally, the majority of the studies provide little information regarding the effectiveness of on-farm use of
improved technology and how use effectiveness might be influenced by size of holding or one of the related variables."

8. **Tenure**

A number of studies have considered the effects of tenure arrangements and the proportion of farms rented on the adoption of HYV technology.\(^{32,33,34,35,36}\) In each study, tenure was not a significant variable in accounting for variation in adoption. Vyas\(^ {37}\) cites studies referring to HYV wheat adoption in India which show that tenants were not only as innovative as landowners but sometimes used more fertilizer per hectare than did owners. It was pointed out by some observers, however, that a distinction should be drawn between pure tenants and tenant-owners—where the latter can be expected to be more receptive to innovation. One reason for this behavior may be that tenant-owners are less affected by credit constraints than are pure tenants.

Evidence from a village in Andhra-Pradesh is reported by Parthasarathy and Prasad. Using \(x^2\) tests, they conclude that tenants had a lower tendency to adopt HYV compared to owners. On the other hand, nitrogen fertilizer use levels were the same for tenants and owners. But use of less familiar fertilizers, such as phosphates, and use of insecticides by both smaller farms and tenants was lower. The evidence is somewhat confusing as the authors emphasize that the landlord is the decision-maker regarding the variety of crops to be grown on leased land. It would have been
interesting to verify whether landlords use more HYV on their self-cultivated plots than on the leased-out plots.

Empirical evidence on the relationship between tenancy and adoption of less-divisible innovation is scant, and proper emphasis on intensity of use rather than on the adoption/nonadoption dichotomy is lacking. Lipton\(^\text{38}\) concludes that:

"The limited 'available' empirical work regarding the relationship between tenancy and technology adoption, however, indicates no consistent relationship between tenancy and either adoption or the production of cultivated land, to which the recommended practices have been applied."

Schutjer and Van der Veen further suggest that any observed effect of tenancy may be indirectly due to accessability to credit, input markets, product markets, and technical information.

C. Labor Availability

Labor availability is another often-mentioned variable which affects farmers' decisions regarding adoption of new agricultural practices or inputs. Some new technologies are relatively laborsaving, and others are labor using. For example, ox cultivation technology is laborsaving, and its adoption might be encouraged by labor shortage. HYV technology generally requires more labor input so labor shortages may prevent adoption. Moreover, new technologies may increase the seasonal demand of labor so that adoption is less
attractive for those with limited family labor or those operating in areas with less access to labor markets.

Hicks and Johnson\(^3\) found that higher rural labor supply led to greater adoption of labor-intensive rice varieties in Taiwan, and Harris\(^4\) found that shortages of family labor explained nonadoption of HYV in India. Most of the studies seem to agree that the operative constraint in African farming systems is the peak-season labor scarcity.\(^4\) Specific evidence to that effect for the North Central region of Nigeria is provided by Norman.\(^4\) The seasonal peak labor shortage may be overcome, however, if neighboring regions peak at different times thus allowing temporary labor migration.

One of the major purposes of farm mechanization is to alleviate labor bottlenecks. For example, ox power and tractor power can make possible more timely farming operations and allow increased production and reduced labor demand and, sometimes, more double and multiple cropping. These arguments are confirmed by the empirical works of Alviar\(^4\) in Laguna, Spenser and Byerlee\(^4\) in Sierra Leone, and Weil\(^4\) in Gambia.

It is possible, however, that a labor market may develop in an area previously characterized as a family-farm subsistence type of agriculture if the innovation creates effective demand which may induce changes in the income-leisure equilibrium. For example, in Israel the intensification of agriculture in the south has produced incentives for the nomadic Bedouins to become hired farmhands.
D. Credit Constraints

Some of the studies mentioned above argue that the need to undertake fixed investments may prevent small farms from adopting new innovations quickly. Similarly, the need to finance these fixed investments may cause a crucial dependence of adoption on credit availability. Here, again, scale, as well as accumulated wealth, may play an important role in access to credit markets and in determining the cost of credit.

Access to capital in the form of either accumulated savings or capital markets is necessary in financing the adoption of many of the new agricultural technologies. Thus, differential access to capital is often cited as a factor affecting differential rates of adoption.46,47 This is, in particular, the case with indivisible technology such as tractors or other machinery that requires a large initial investment.

A number of studies have found that lack of credit is an important factor limiting adoption of HYV technology. For instance, in a study of Indian agriculture, Bhalla48 reported that small and large farms differed in the reasons offered for not using fertilizer in 1970-71. Lack of credit was a major constraint for 48 percent of small farms and for only 6 percent of large farms. Bhalla concludes that "access to credit may be responsible for the gain in income (and HYV area) made by the large farmers." Similarly, in a study of HYV adoption by Pakistani farmers, Lowdermilk49 found that a majority of small farms reported shortage of funds as a major
13.

constraint on fertilizer use. Similar results are reported by Wills, \textsuperscript{50} Hodgdon, \textsuperscript{51} Frankel, \textsuperscript{52} and Khan. \textsuperscript{53}

However, others have argued that lack of credit is not a crucial factor inhibiting adoption of innovations which are scale neutral. Schutjer and Van der Veen \textsuperscript{54} cite a number of scholars who point out that the profitability of HYV adoption will induce even small farms to mobilize (from whatever sources they have access to) the relatively small cash requirements for necessary inputs. Von Pischke \textsuperscript{55} similarly questions the assertions presenting credit availability as a precondition for adoption.

The study by Scobie and Franklin \textsuperscript{56} also concludes that access to credit may not encourage adoption if it entails restrictions on input use (e.g., lower limit on fertilizer and pesticide applications). In fact, evidence suggests that rational farmers will evade the restrictions. In areas where adoption of divisible innovations (such as HYV) is dependent on (or greatly enhanced by) complementary indivisible investment (such as tube wells), lack of credit can impede the uptake of the divisible innovation by smaller farms. \textsuperscript{57}

Evidence that lack of credit and differential access to credit are significant constraints on adoption of lumpy investments is also provided by Gotsch \textsuperscript{58} and Havens and Flinn. \textsuperscript{59} Subsidization of credit does not necessarily circumvent the problem for smaller farms, since in many cases the larger and more influential farms manage to get the bulk of such credit. \textsuperscript{60}
E. Risk and Uncertainty

There is general agreement in the literature that aversion to risk is an important factor in explaining farmers' adoption behavior. Innovations entail, in most cases, a subjective risk (the yield is more uncertain with an unfamiliar technique) and, quite often also, objective risks (due to weather variations, pest susceptibility, uncertainty regarding timely availability of crucial inputs, etc.). Lack of adoption or slow adoption patterns are thus expected where risks are high.

However, empirical studies have quite rarely treated this factor because of measurement difficulties. Thus, Gerhart's study of maize adoption in Kenya used the presence of drought-resistant crops as an indication of especially high risks and found this variable statistically significant in explaining adoption performance. However, this procedure is potentially misleading as the decision to plant drought-resistant crops is an endogenous variable and should not, in general, be included on the right-hand side of the equation. A more appropriate procedure used in a number of studies, which obtained observations from different climatic or topographical areas, was through location-specific dummy variables that were shown to be significant. It should be noted that such dummy variables could also represent other factors relating, for example, to fertility (rainfall, soil quality, etc.). Another approach is to ascertain farmers' perceptions through direct interviews. The only works following this procedure in the context of innovation adoption
are reported by O'Mara\textsuperscript{64} and Binswanger et al.\textsuperscript{65} O'Mara derived for a sample of Mexican farmers the corresponding sets of subjective yield distributions associated with HYV. These were shown to be related to the adoption decisions actually taken, and they were modified over time on the basis of new information. Other possibilities which were suggested relate to proxy variables measuring rainfall variability or indices related to incidence of major disasters (major infestations, severe droughts, floods, etc.).

Binswanger et al. obtained a measure of farmers' risk aversion (from a sample of farmers in India) through gambling experiments. These measures are used as an explanatory variable in a multivariate analysis of fertilizer adoption, with mixed results in terms of statistical significance.

Inferences about the role of risk aversion in explaining adoption behavior could also be derived indirectly. For example, Winkelmann\textsuperscript{66} reports that, for corn, farmers in the Puebla area use three seeding periods 10 days apart: "According to farmers, this plan is followed to take advantage of early or late spring rains and avoid having their entire production tied to the rains of one period." This result suggests that farmers place a low value on the timeliness of operation. On the other hand, it is also possible that, when scale is sufficient, part of the land will be devoted to a risk-minimizing cultivation procedure (such as the one described by Winkelman above) while the rest is assigned to a double-cropping cultivation practice which entails both higher risks and higher expected profits.
Farmers' technology choices are based on their subjective probabilities and, hence, on their exposure to information regarding new technology. As Gafsi and Roe\textsuperscript{67} show for Tunisia, domestically developed new varieties will be received more favorably by farmers than unfamiliar imported varieties. A related hypothesis is that more exposure to appropriate information through various communication channels reduces subjective uncertainty. As before, the problem lies in measuring the extent of information to which the farmer is exposed.\textsuperscript{68} A common proxy variable is whether the farmer was visited by extension agents (e.g., Gerhart, Colmenares) or whether he attended demonstrations organized by the extension service or whoever supervises the introduction of new technology (as done by Demir\textsuperscript{69} and Perrin\textsuperscript{70}). Some studies used both variables as they represent different exposure sources. Other studies consider exposure to mass media (newspapers, radio, leaflets), literacy level of education, and period of time spent out of the village as appropriate measures. Results are mixed, and no general conclusions can be derived. The problem may lie simply in the fact that, in some instances, the proxy does not measure what it is supposed to approximate. For example, literacy may not have much to do with available information (see Vyas\textsuperscript{71}) if the extension service organizes an effective demonstration pilot program at the village level. Or, in cases where the extension service has failed in the past in solving a major farm problem (thus eroding farmers' confidence), the most dominant factor may be the information gained by observing the procedures and performance of neighbors, friends,
and relatives who have experimented with the innovation as the Indian study by Harriss indicates.

Demonstration and imitation effects that, in many areas of the world, were shown to be important factors may sometimes fail to exert influence as indicated in Ojo's study of the western region of Nigeria.

F. Human Capital

In dealing with U. S. agriculture, Welch draws a distinction between worker ability and allocative ability. Allocative ability is the ability to adjust to changes. Huffman uses these concepts to show that farmers with higher education possess higher allocative ability and adjust faster to reduction in nitrogen prices by adopting nitrogen-intensive technologies. He further noted that education is particularly important when extension activities are less intense.

These works were inspired by the work of Theodore Schultz in developing agriculture that showed the importance of human capital in dealing with the situation of disequilibrium which results from the introduction of new technology. Schultz later surveyed a number of studies which examined the ability to deal with disequilibrium. Many of these studies found that education plays a strong role in determining rates of adoption of new technology in developing agriculture.

Some indirect support for this assertion can be inferred from other studies surveyed in Lockheed et al. These studies find a
significant relation between education indicators and farm productivity. As the adoption of innovations increases productivity, the
importance of education (and extension) in affecting adoption behavior seems to be implied.

In Africa, however, a number of studies quoted in Helleiner tend to show that education is not an important factor. But,
because of extremely low levels of formal education, a new emphasis has developed in studies of African nonformal education and other aspects of learning. Potential alternative proxies of allocative ability include protein nutrition in infancy, incidence of disease and parasites, and exposure to various institutions of traditional or nonformal schooling. Some have also argued that the lack of importance of education in Africa is due to failure to consider other factors affecting farm-level acceptability in the original orientation of agricultural research. Helleiner has also argued that farmers' relationships with sources of information concerning new technology can play an important role in determining adoption rates.

6. *Sociological and Other Factors*

A number of sociological and other factors have also been shown to be important in some cases. For example, Helleiner hypothesized that, in an analogy to the inhibiting effect of communal landownership on innovation adoption, the extended family system in Nigeria and the obligations it entails may slow adoption processes. Sociological factors can be particularly important in determining the
flow of information concerning new innovations. For example, Takes suggests that residence for extended periods outside of the home area is important in explaining willingness to shift from food to cash production. Numerous studies reviewed by Rogers report the impact of various sociocultural factors; it is beyond the scope of this survey to list in detail the many variables and indicators included in these studies.

Problems may also be encountered in introducing new varieties of a subsistence crop. For example, Gafsi and Roe found significant resistance to new wheat varieties because of palatability problems. Another factor that must be considered is accessibility to the marketing network which is closely related to the status of transportation infrastructure. Farmers who are not connected by all-weather roads will refrain from adopting crops whose inputs cannot be assured because of inaccessibility in the rainy season. In the case of highly perishable outputs (e.g., dairy farming), a guaranteed access to marketing outlets is probably an essential condition.

External off-farm income sources are of relevance as well since they enable the farmer to undertake agricultural practices which may otherwise jeopardize his subsistence income. Also, off-farm income can help to overcome a working capital constraint or may even finance the purchase of a fixed-investment type of innovation. These effects have been verified empirically by Gerhart, Perrin, Gafsi, Demir, and Roching and Witt, among others, through the introduction of a measure (or a dummy variable) of such income.
Another important factor is the availability of complementary inputs. It is obvious that HYV seeds will not be adopted by most farmers unless (1) seeds are available and (2) some fertilizers are available, the reason being that the high-yield potential of the seed can, in most cases, be realized only if at least some fertilizers are applied. Thus, a sound study would try to assure that behavior is not supply constrained. But other inputs are also complementary at different degrees, e.g., water, storage facilities (for perishable crops), etc.

Related to the latter point is the issue of complementary innovations. That is, some innovations (which may or may not have been introduced simultaneously) are complementary to a certain degree. Thus, the HYV-fertilizer package is more profitable and less risky if an assured and regulated water supply is provided. The studies by Clay and by Duff, as well as the remark by Vyas, provide detailed descriptions of innovation complementarity and suggest the importance of jointly examining such adoption decisions empirically.

III. Evaluation of Previous Work and New Directions in Empirical Research

A. General

While the above sections reviewed the conclusions of a great number of empirical studies of adoption, it remains to discuss the validity of the conclusions obtained thus far. As discussed below, much of the empirical work has lacked a theoretical basis on which to
specify structural relationships and interdependencies. Thus, the functional forms which have been estimated may not correspond to any reasonable underlying decision behavior. More importantly, the models often fail to meet the statistical assumptions that are necessary to carry out hypothesis tests upon which the conclusions are based or the empirical work is so crude as to provide only qualitative rather than quantitative information about the adoption process. Finally, in many cases, endogenous variables have been used as explanatory variables without regard for the simultaneous equations bias which can result. This section deals with these issues and the approaches for adequate consideration of them.

Before discussing each of these issues explicitly, it is worthwhile to consider exactly what the concept of adoption means in quantitative terms. In most cases, adoption cannot be categorized simply as "adoption" or "nonadoption" since adoption often takes place by degrees. For example, knowledge that a farmer is using HYVs may not provide much information about farmer behavior because he may be using 1 percent or 100 percent of his hectarage. Similarly, with respect to fertilizer adoption, a farmer may be using a small amount or a large amount per hectare on which it is applied. Indeed, on the basis of a comprehensive review of adoption studies, Schutjer and Van der Veen conclude that "the major technology issues relate to the extent and intensity of use at the individual farm level rather than to the initial decision to adopt a new practice." Thus, adoption apparently cannot be represented adequately by a dichotomous qualitative variable in most cases.
A more appropriate reflection of the rate of adoption is given by a continuous but limited variable. For example, the adoption of HYVs or of cultivation practices might be represented by a percentage or proportion-of-adoption variable (e.g., by land area or by farmer). Thus, the variable would be limited between, say, zero and one but could vary continuously between these two values. Adoption of fertilizer, on the other hand, may not have any definite upper limit on the quantity used but would be limited on the lower side by zero which may well be the observed choice prior to introduction of new technology. Finally, with other technologies such as tractors or oxen, adoption may seem appropriately reflected by discrete choices, i.e., number of tractors or oxen employed; but even in this case, continuous variables based on per-acre use may be more descriptive of the "extent and intensity" of adoption.

B. *Dichotomous and Continuous Adoption Variables*

Given this need for quantitative analysis, it is disturbing that many of the econometric studies of adoption thus far have focused only on whether or not a particular methodology is adopted rather than on how much. Furthermore, in this class of studies, there are also a number of studies which attempt to determine only the directional impacts of certain explanatory forces rather than their quantitative importance. In point of fact, several studies of adoption have been undertaken using chi-square contingency tables to perform nonparametric hypothesis tests of the importance of certain explanatory variables. For example, Clawson attempted to determine
whether landholdings influence the decision to use fertilizer in this framework, and Parthasarathy and Prasad used this approach to determine whether landholdings affected the decision to adopt HYVs. While the outcome of these tests may suggest a significant effect in statistical terms, there is no way of knowing from this type of analysis whether the economic importance of the effect is worth considering.

Another approach which also obtains only qualitative information regarding the effect of various explanatory factors is correlation analysis. For example, Rochin and Witt examine simple correlation coefficients statistically to determine the importance of farm size, tenure, family size, income, etc. on adoption of varieties of dwarf wheat. Rogers uses correlation analysis to relate modernization of agriculture in Brazil, India, and Kenya to literacy, age, education, social status, and other media-exposure variables. This analysis gives no information regarding the quantitative importance of various factors. Furthermore, the simple correlations between some variables may be highly influenced by other variables so that each correlation may include the spurious effects of the other variables.

Turning to those studies which have attempted to determine econometrically the quantitative importance of various explanatory variables, ordinary regression methods have been in most common use. However, many such studies have attempted to explain only the decision of adoption versus nonadoption rather than the extent or intensity of adoption. For example, a common practice has been to explain adoption empirically by an ordinary least-squares regression
of a 0-1 adoption variable (say, use of an HYV) and explanatory variables such as farm size, tenure, location, topography, etc. (e.g., Colmenares). However, normality of disturbances is obviously inappropriate for such regressions; and, thus, the estimated standard errors and t ratios produced by an ordinary least-squares regression are not appropriate for investigating hypotheses about the role and importance of various factors in the adoption process.

Second, ordinary linear-regression estimates obviously produce predictions other than zero or one for the dependent variable; if these predictions are considered as probabilities, then predictions less than zero or greater than one are nonsensical. At any rate, misspecification is obvious. Some studies, such as Cutie, recognize that normal hypothesis testing procedures are invalid in this approach but still claim unbiasedness of their estimated equations. These claims, however, are also not necessarily appropriate.

Turning to the econometric literature, one finds that appropriate estimation methodology has been developed for investigation of the effects of explanatory variables on dichotomous dependent variables (see, for example, the survey by McFadden). One of the most general models is the probit model in which the probability (of adoption, in this case) follows some distribution function. Perhaps the most popular form of the probit models is the logit model which corresponds to a logistic distribution function. Examining the empirical studies in the literature, however, reveals that very few have actually adopted those procedures that explicitly account for the qualitative nature of the dependent variable. Apparently, only
one probit study and one logit study have been performed. Gerhart used a probit analysis to explain adoption rates of hybrid maize in three different regions in Kenya (unfortunately, this study is subject to the other biases discussed below). Nerlove and Press used logit analysis in an interesting study of several types of adoption in Philippine agriculture (more will be said below regarding that study). The results of both of these studies are promising in terms of econometric possibilities for adoption studies.

With the backdrop of probit and logit models, it is also worthwhile to discuss another approach that has found its way into the adoption literature; discriminant analysis is a procedure for classifying observations in one category or another based on several explanatory variables. For example, Yapa and Mayfield used discriminant analysis to distinguish adopters of HYV maize on the basis of biological, communications, and input-access variables. The usefulness of discriminant analysis, however, is often confused with that of logit analysis. The relative odds of correct binary classification are given by the logit formula for this case, but the discriminant estimator is not generally a consistent estimator of the parameters of the logit model when selections are generated thereby. Furthermore, Press and Wilson have presented Monte Carlo evidence supporting the use of logit analysis in a wide range of problems that are commonly treated with discriminant analysis. Hence, the probit-logit methodology appears to be preferable for analyzing the adoption decision. As McFadden has further pointed out, the discriminant model is based on a statistical
structure that is incompatible with most choice theories, and the logit model is not.

C. Continuous But Limited Adoption Variables

Next consider the possibilities for studying econometrically the degree or intensity of adoption as well as the decision of adoption versus nonadoption. Actually, many of the same empirical problems discussed above also carry over into problems where adoption is represented by continuous but limited variables. For example, many studies seek to explain the percentage of adoption on the basis of various explanatory variables. Thus, the dependent variable is continuous but limited to the interval $(0, 100)$; hence, this approach entails obvious specification bias when linearity is used and occasionally produces nonsensical predictions outside of the interval $(0, 100)$ (see, for example, the predictions reported by Anden-Lascôna and Barker). Other problems with limited dependent variables are provided by adoption of inputs, such as fertilizer, where there is an obvious lower limit of zero on the amount applied but no clearly defined upper limit. Here again, some studies, such as Cutie, have simply regressed fertilizer use linearly on various explanatory variables without considering the lower boundary. This approach is subject to the same criticism as above if some zero responses for fertilizer use are observed.

Other studies (e.g., David; David and Barker) avoid the problem of obtaining negative predictions for fertilizer use by using the logarithm of fertilizer use as the dependent variable;
thus, any finite explanatory variables lead to positive predictions for fertilizer use as long as finite coefficient estimates are obtained. While this approach is more acceptable, there may be many farms on which fertilizer is not used, and such predictions would not be possible in the logarithmic or semilogarithmic framework (given finiteness of variables and coefficients). Again, there would be an obvious problem of specification bias although perhaps not as serious as those above.

It therefore seems that, for most adoption problems, the necessity of valid hypothesis testing and of unbiased estimation of parameters of the adoption process requires explicit treatment of the limited nature of dependent variables reflecting adoption intensity. The probit-logit methodology is one possibility for doing so when the adoption process is dichotomous. But a strictly dichotomous variable often is not sufficient for examining the extent and intensity of adoption; in fact, most adoption variables fall in closed intervals or half lines. For some problems, like fertilizer use, sufficient modeling detail might be attained in a two-stage investigation where, first, the probability of fertilizer use is explained in a dichotomous choice model and then the quantity of use given adoption could be explained in a conditional model with the logarithm of fertilizer as a dependent variable. However, other adoption variables, such as the percentage or proportion of cropland used for HYVs, may require specific considerations of limited dependent variables. The general logistic specification is, again, a feasible functional form for reflection of variables in the
open-unit interval where ordinary estimation methods can suffice for a suitable transformation. Furthermore, for the more general limited dependent variable problem, significant progress in estimation has recently been made by Amemiya, Olsen, Fair, and Hartley.

D. Simultaneous Equations Considerations

Another critical issue which must be considered in econometric studies of factors affecting adoption is the possibility of simultaneous equations bias. Turning to econometric studies of adoption, one finds a number of cases where these considerations have not been made. For example, David and David and Barker attempt to explain the quantity of fertilizer used by an ordinary regression on the use of HYVs among other things. However, the decision to use more fertilizer and the decision to use HYVs are generally simultaneous decisions and, thus, probably subject to the same random disturbances, e.g., misrepresentation of the role of extension in learning about both practices. Hence, their results are apparently subject to bias and inconsistency. Sison, Prakongtanapan, and Hayami also used ordinary regression to determine the effect of the rice production technology choice (and other factors) on the amount of land used for rice production. Both of these variables are probably simultaneous choice variables, also, so that results are biased and inconsistent. Even in those studies that have correctly considered the qualitative nature of their dependent variables, most have been subject to this type of bias. For example, the probit analysis by
Gerhart using decision variables depicting use of drought crops and off-farm income (among others), explains adoption of high-yielding maize in Kenya. The discriminant analysis of Yapa and Mayfield explains maize adoption in terms of decisions on fertilizer use and well pumps. In each of these cases, because the decisions used as explanatory variables are probably determined simultaneously and subject to some of the same random forces, the results are questionable.

While simultaneous estimation of linear and even nonlinear systems of equations is a common econometric problem, the estimation problems offered by these cases, when considered in the context of the earlier part of this section, are somewhat more difficult. That is, each decision variable may require a qualitative representation in the study of adoption where limit values are often observed. Hence, a simultaneous probit, logit, or tobit model is needed. Again, these necessary developments have also been made in terms of econometric theory and procedure.

Nerlove and Press appear to have been among the first to discuss the logit model in a truly simultaneous equation framework. In the context of simultaneous estimation of several adoption decisions, it becomes possible to uncover interactions which can be extremely useful in attempts to manipulate the adoption process. For example, suppose several new technologies or practices are introduced in an attempt to modernize production, e.g., hybrid seed, chemical fertilizer, modern weeding practices, and modern land preparation practices. In this case, it may be that a farmer is
more likely to adopt fertilizer if hybrid seed is adopted but not necessarily vice versa. The results, if forthcoming, would suggest that extension work might concentrate more on hybrid seed adoption since fertilizer use is likely to follow. Nerlove and Press have, in fact, introduced a substantial technical framework for investigating these kinds of interactions in a simultaneous multinomial log-linear-probability model. Their framework includes interaction terms which can explain a tendency to adopt two or more new technologies at the same time. Furthermore, by appropriate inclusion of lagged adoption decisions as explanatory forces, their model possesses rich possibilities for explaining the dynamics of multitechnology adoption. Nerlove and Press have further applied the framework to simultaneous investigation of these four adoption decisions in Philippine agriculture. The analysis is quite brief and is provided only as an example but, nevertheless, the systematic framework provided for investigating these interactions offers great promise and begs for further application in the study of adoption.

IV. Theoretical Developments on Adoption Patterns

A. General

The critique of empirical adoption modeling efforts in the previous section points to the need for consideration of underlying theoretical relationships. Theoretical study of issues relating to adoption necessitates a clear definition of adoption variables and suggests a set of possible values that they can take on. Furthermore, theoretical analysis can lead to a better understanding of the
interdependence among adoption decisions and, thus, facilitate appropriate specification of the simultaneous adoption models. Finally, rigorous analysis helps to define in more precise terms the conditions under which certain arguments are valid.

For example, risk and risk aversion have been used to explain differences in input use and the relative rate of adoption of modern technologies by farms of different sizes. But different patterns of behavior are observed in different regions; and, thus, the impact of risk and risk aversion may not be the same in different areas because of the role of other factors. At present, a substantial body of literature exists on various micro- and macroeconomic aspects of innovations of the Green Revolution type. However, while many works provide detailed description of the experience of different regions and propose (heuristically) and sometimes verify empirically various arguments to explain observed patterns of behavior, there are relatively few formal models explaining adoption of new innovations and how various factors act upon one another in determining rates of adoption. Using traditional economic terminology, it would seem that the availability of a new production technology (in addition to the old one)—embodied in the use of hybrid seeds or new crops, fertilizers, pesticides, and proper timing of production activities—presents the farmer with a typical portfolio selection problem: the choice of an optimal mixture of risky activities differing in both riskiness and expected returns. But, unlike the simple portfolio problem, the farmer has some degree of control on both the level of risk and the mean return through the use of inputs such as fertilizers and pesticides.
In this section, several of the most recent formal theoretical approaches for comprehensively examining adoption decisions in an agricultural context are outlined and a number of forthcoming testable hypotheses are indicated. In the first part, theoretical models of a single farm are considered in the context of the *ex ante* decision of whether and how much to adopt of new practices. In the second part, industry models which depict the dynamic aspects of aggregate adoption are considered. Within these two frameworks, several interesting questions can be examined: How are factor use and output mix affected by attitudes toward risk? Are there differences between farms of different sizes? Are standard results of the theory of the firm still valid and under what conditions? What are the implications of credit constraints on factor use and output mix? How is landownership affected?

B. Models of the Single Farm

In theoretical models of the single farm that are used to investigate the role of uncertainty and farm size, the farmer is assumed to own a farm of a given size—say, \( L \) acres—which can be allocated between crops. For example, in a two-crop case, the first may be a low-yield crop which utilizes traditional techniques and, in particular, does not require chemical inputs. Another important characteristic of the traditional crop may be a relatively low level of uncertainty regarding yields. The second crop, which will be referred to as the "modern crop," can be an HYV or a cash crop utilizing modern inputs such as fertilizers, insecticides, and
improved seeds. On the other hand, it may be more vulnerable to
weather variations so that there is some degree of uncertainty
regarding the yield. Additional (and subjective) uncertainty
follows from the fact that the farmer is less familiar with the
modern crop. Considering this factor, the modern crop may be viewed
as more risky even if in reality it is no more susceptible to
extreme weather situations than is the traditional crop. Indeed, in
some cases, the modern crop may be more robust than traditional
varieties even though total uncertainty (from all sources) of the
modern crop is higher. Another factor which, in many cases,
increases modern crop uncertainty is higher vulnerability to local
pests.

These models are generally specified with production, $Q_i$, of
each crop and technology, $i$ (that is, the crop and technology com-
bination is indexed by $i$), depending on the land allocated to that
crop, $L_i$, and on the amount of other production factors, $X_i$,-
employed per hectare on that land as well as some random dis-
turbance, $\epsilon_i$,

$$Q_i = f_i(L_i, X_i, \epsilon_i).$$  \hspace{1cm} (1)

With output prices, $P_i$, and input price vector, $V$, short-run quasi-
rents are:

$$\pi = \sum_i P_i f_i(L_i, X_i, \epsilon_i) - \sum_i V'X_i L_i.$$  \hspace{1cm} (2)
If, in addition, switching to some new crops or technology requires a fixed setup cost, then an appropriate criterion for the farmer may be maximization of the expected utility of profits, \( \tilde{\pi} \), which are quasi rents, \( \pi \), minus set-up costs of \( k_i \) for each crop and technology combination used,

\[
\text{Max } E \left\{ \pi - \sum_{i} k_i \right\}. 
\]  

(3)

The farmers' objective function is then maximized subject to existing landholdings,

\[
\sum_{i} L_i = L, 
\]  

(4)

and possibly to an appropriate constraint representing credit availability

\[
\sum_{i} k_i + \sum_{i} V' \chi_i L_i \leq m, 
\]  

(5)

where \( \sum_{i} k_i \) represents long-run credit, \( \sum_{i} V' \chi_i L_i \) represents working capital requirements, and \( m \) represents total credit availability. Nonnegativity constraints must also be considered for \( L_i \) and \( \chi_i \).

Of course, the objective function in equation (3) represents an oversimplification of the dynamic considerations that could be made by a sophisticated planner. But intuition suggests that the myopic approach in (3) may be a reasonable representation of
decision-making by peasant farmers. Furthermore, such a simplification is important in facilitating analytical investigation.

To use this model analytically, it is usually necessary to make some explicit assumptions about the form of the production function in (1).\(^\text{116}\) Perhaps the most common specification, because of its analytical simplicity, corresponds to multiplicative risk:

\[
Q_i = f_i(L_i, X_i) \cdot \epsilon_i, \quad E(\epsilon_i) = 1.
\] (6)

With this specification, production variability increases linearly in the square of expected production. Considering the impact of fertilizers on the modern crop (assuming a fixed input of land and other factors), for example, it is well known that mean output increases with the input of fertilizers, although at a decreasing rate.

However, empirical evidence suggests that the degree of yield variability (i.e., the degree of uncertainty) increases at a slower rate with the level of fertilizers than is implied by (6).\(^\text{117}\) Furthermore, when other new technologies—such as pesticides and machinery—are considered, the effects of increased use may be to reduce yield variability absolutely. For example, pesticides are generally thought to reduce vulnerability to random insect and disease infestations, whereas overcapitalization may permit quick and timely operations and, thus, reduce vulnerability to adverse weather conditions.
A general formulation that can depict such phenomena but yet permit tractable rigorous analysis is provided by the production function,

\[ Q_i = f_i(L_i, X_i) + g_i(L_i, X_i) \, \epsilon_i, \, \, E(\epsilon_i) = 0 \]  \hspace{1cm} (7)

(see Just and Pope\textsuperscript{118}). The variability-increasing effect of fertilizer is represented by \( \frac{\partial q_i}{\partial X_{ij}} > 0 \), while the variability-reducing effect of pesticides or machinery is represented by \( \frac{\partial q_i}{\partial X_{ik}} < 0 \). Of course, an increase in scale (an increase in area cultivated) should generally increase variability of output, \( \frac{\partial q_i}{\partial L_i} > 0 \).

In addition to these stochastic specifications, further analytical possibilities are obtained by employing more specific assumptions with respect to \( f_i \) and \( g_i \). For example, adopting the assumption of constant returns-to-scale in the mean output function and assuming, in addition, that the risk component per acre (H/L) is a function of the fertilizer/land ratio only (treating pesticide input as given), the production function becomes

\[ Q_i = L_i \, f_i(X_i) + L_i \, g_i(X_i) \, \epsilon_i, \, \, E(\epsilon_i) = 0. \]  \hspace{1cm} (8)

Using models of the above types, a number of comparative static results relating to adoption and forces affecting adoption have been found. For example, Hiebert uses the general production function in (1), the objective function in (3), and the land constraint in (4) to examine the effects of uncertainty and imperfect
information on adoption (and level of use) of fertilizer where only variable costs are incurred in adoption \((k_i = 0)\). Imperfect information on yield response is represented by a subjectively random effect of fertilizer in the production function.

The results indicate that risk aversion (as compared to risk neutrality) is associated with use of less land and less fertilizer in production of the modern crop. Nevertheless, the probability that a randomly chosen farm will adopt increases as the stock of information pertaining to modern production increases, say, through extension efforts. If different producers have different abilities to decipher and analyze extension information, the likelihood of adoption also depends (positively) on producer skills.

As Hiebert indicates, these theoretical results regarding the effects of extension are consistent with arguments advanced by Nelson and Phelps\(^{119}\) and by Welch. In addition, the likelihood of adoption increases as the physical environment of the farm is better. A more favorable environment (better soil, water availability) increases the expected utility of income from modern production and, hence, increases the probability that a farm will adopt the new technology. This result is consistent with the empirical findings of Griliches.\(^{120,121}\)

In another study, Feder\(^{122}\) assumed that uncertainty is associated only with the new crop which, unlike the traditional crop, requires fertilization. He uses a constant returns-to-scale version of the formulation in (8) to model the stochastic production function of the new crop with the objective function in (3) and the land
constraint in (4). He also assumed that adoption of the new crop does not require any fixed initial cost \( (k \equiv 0) \). Using this framework he found that the level of fertilizer use per acre (for the new crop) is independent of the degree of risk aversion, uncertainty, and farm size when farmers are not restricted by credit constraints. Under these circumstances, risk affects only the land allocation decision (between the old and new crops) in a manner consistent with Hiebert's findings. Considering the effect of farm size on relative land allocation, Hiebert showed that the share of the modern crop depends on the relationship between relative risk aversion \( \left[-\left(\frac{U''}{U'}\right) \cdot \pi\right] \) and income. Although there is no definite theory regarding the latter relationship, when utility is defined over income in excess of a subsistence level, the share of area allocated to the modern crop increases with farm size.

Just and Zilberman later extended these considerations to all inputs using the production function in (8) and showed that whether modern inputs are used more or less intensively depends on whether the modern inputs are risk reducing or risk increasing. Their results also demonstrate that correlation of outputs under alternative technologies plays an important role in determining adoption rates. Using the mean-variance approach, they showed that, if the correlation of outputs under old and new technologies is positive, then larger farms will devote more land in absolute terms but less land in proportionate terms to the new technology than will smaller farms. This result is, thus, consistent with the empirical observations presented above.
Another factor which may explain a positive relationship between farm size and the share of the modern crop is related to fixed transaction costs and information acquisition costs associated with the new technology as shown in Feder and O'Mara and Just, Zilberman, and Rausser. They demonstrate also that, at a given point in time, there may be a lower limit on the size of adopting farms such that farms smaller than the critical level will not adopt the new technology. The critical size increases with higher fixed information costs. But these results would not hold in the absence of uncertainty, given that the new technology is more profitable and that it is neutral to scale.

While the above results were derived within an expected utility optimization model, it has been demonstrated by Roumasset using a "safety-first" type of model that refusal to adopt new HYVs may be the result of higher "disaster level" yield probabilities associated with HYVs in rainfed crops.

Using a similar safety-first model, Bell shows that, in a simple case where only the modern production technology is considered, smaller farms will apply less fertilizer per acre. This is because their subsistence requirements per acre are higher than those of larger farms, forcing them to refrain from spending too much cash on fertilizers which may not necessarily increase yield, especially if the crop is poor.

However, it should be pointed out that a number of studies have argued (although not in the context of technology adoption) that variable input use may theoretically be higher on smaller farms even
when uncertainty prevails (e.g., Srinivasan).\textsuperscript{128} Empirical evidence shows contradictory patterns, and it is obvious that results depend on other components in the model such as land quality (irrigated or not) and land-credit relationships. Thus, assuming that a binding credit constraint prevails and that credit availability is proportional to the size of the farm, Feder\textsuperscript{129} showed that increases in uncertainty levels (e.g., areas with rainfed agriculture versus irrigated areas) are likely to cause lower shares of modern cropland but higher fertilizer/land ratios. Both land allocation and fertilizer/land ratio decisions depend crucially on the relationship between relative risk aversion and income. However, if relative risk aversion is approximately constant, it can be shown in the Feder model that (i) both the fertilizer/land ratio and the land allocated to the modern crop increase with farm size if credit increases more than proportionately with farm size; (ii) if the utility is defined over income in excess of a subsistence level, the fertilizer/land ratio is independent of farm size, but land allocation to the modern crop increases with farm size.

Whereas the general theory of production under uncertainty develops plausible hypotheses regarding the relationship between input use and prices, not all results are applicable in the present case. Thus, it was shown, in the context of the adoption model discussed by Feder, that subsidies on fertilizers do not necessarily increase the amount of land allocated to the modern crop (although fertilizer/land ratios will be increased). On the other hand, subsidies on the price of the modern crop (which would have no effect
on input ratios under full certainty) will induce higher fertilizer/land ratios if the elasticity of mean yield with respect to fertilizer is higher than the elasticity of the risk effect [the latter is the elasticity of the $g_1$ function in equation (7) with respect to fertilizer]. A similar condition applies for increases in land allocated to the modern crop as well as for an increase in total output of the modern crop in response to crop price subsidies. This emphasizes the importance in empirical work of proper estimation procedures for stochastic production functions (as was demonstrated by Just and Pope).\(^{130}\)

Considering the use of pesticides under uncertainty, the model presented in Feder\(^{131}\) implies that lower values of the maximum potential yield are associated with lower pesticide use. Furthermore, there exists a lower bound such that, if the maximum potential yield does not exceed the bound, pesticide use will not be adopted at all.

As mentioned earlier, the relationship between tenurial arrangements and the adoption of new technologies is also the subject of considerable controversy. In his article Bahduri\(^{132}\) develops a model which shows that a landlord's double role, as both a provider of credit and a landowner (which is quite common in India, the country on which Bahduri focuses), creates a situation such that the landlord may not permit adoption of yield-increasing innovations; as this will reduce the tenants' indebtedness to the landlord, the income from lending will decline more than the output share will increase. In a similar vein, although using a more complicated model
(incorporating uncertainty and a mean standard deviation utility function),\textsuperscript{133} Scandizzo\textsuperscript{134} concludes that landlords will be reluctant to adopt land-augmenting innovations if interest earnings and price margins are high (due to the fact that landlords market their tenants' output). The response to labor-augmenting innovations may be similar although the likelihood of resistance is smaller. Considering the tenants, Scandizzo demonstrates that low interest rates will make land-augmenting innovations less attractive but will induce acceptance of them.

Bahduri's analysis was criticized by a number of authors. Newbery,\textsuperscript{135} for example, argues that "if the landlord has sufficient monopoly power to exploit the peasant and withhold the innovation then he should have sufficient power to extract the extra profit generated by the innovation." Similarly, Ghose and Saith\textsuperscript{136} raise objections to the overly simplified assumptions characterizing Bahduri's model and present an alternative formulation concluding that under most circumstances landlords will favor adoption of yield-increasing technologies. Recently, Srinivasan\textsuperscript{137} has refuted Bahduri's calculations; in fact, empirical evidence from India\textsuperscript{138} does not support the assumptions underlying his model. In his comments on Scandizzo's model, de Janvry\textsuperscript{139} raises a number of factual and methodological objections. In particular, the assumption of fixed cropsharing parameters is criticized for essentially the same reason as that mentioned by Newbery. Rather than being a means for extracting profits, usurious interest rates serve to tie the tenant to the land
and weaken his bargaining position. Thus, under semifeudal conditions, landlords would not be reluctant to adopt yield-increasing innovation subject to the usual profitability and risk considerations.

Although the landlord-moneylender link does not seem to provide sound hypotheses on the relationship between the land tenure system and innovations, Newbery constructs a model which implies that sharecropping could hinder adoption of innovations. The essential assumptions are that both production and labor markets are subject to uncertainties and that the new technology (unlike the traditional one) is such that tenants' inputs (in particular, labor) cannot be supervised. This implies that the innovation increases the moral hazard and is, thus, unacceptable to the landlord unless he can increase fixed charges and reduce the share he receives of the crop; but such changes are likely to be rejected by tenants. It is claimed that, under such circumstances, the landlord may prefer to evict his tenants and resort to the use of hired labor with the new technology; however, if supervision costs are high, such an outcome is doubtful.

The tenurial contract may change as a result of technological change as demonstrated by Bell in his detailed analysis of the choice of lease arrangements. Tenants' attitudes toward adoption are shown to depend not on the form of the existing lease but on the profitability and riskiness of the new technology. Whenever the innovation is attractive to the tenant, it will also be attractive to the less risk-averse landlord. The latter will also be inclined to share in the variable costs if he was not doing so already.
Further hypotheses regarding tenure systems and the impact of technological change are formulated by Bardhan.\textsuperscript{142} He constructs a model with endogenous wage determination as well as allocation of land between sharecropping and self-cultivation. The analysis yields a number of results including the following: (a) the percentage of area under tenancy will increase if a land-augmenting technological change is introduced; (b) a larger degree of imperfection in the market for inputs which are complementary with HYV cultivation technology leads to a lower percentage of area under tenancy; and (c) a higher labor intensity of the crop induces a higher incidence of tenancy.\textsuperscript{143}

C. Aggregate Models and Dynamic Patterns

Relatively few formal models of adoption processes over time have been developed in the context of innovations in agriculture. However, some inferences are possible from the substantial literature on dynamic adoption patterns of general innovations.

One of the better known works is that of Kislev and Shchori-Bachrach.\textsuperscript{144} Their model describes an "innovation cycle" where a new product or a new production technology becomes available to a competitive industry. The more skilled producers are assumed to have a higher opportunity cost for their resources and are also more efficient in their acquisition of technical knowledge. Knowledge is also affected by communal learning by doing which is represented through the cumulative aggregate output of the industry. The level of knowledge affects the production function of
each firm; and it is shown that, initially, the higher skilled producers will adopt the new technology while the lower skilled producers will wait until sufficient experience has developed at the industry level. While industry's output expands, with the joining of lesser skilled producers the price drops (demand is stationary); and it is quite possible that the higher skilled producers will switch to alternative activities since the opportunity cost for their resources is high. This process is shown to conform to a case study of vegetable production technologies in Israel.

The work of Day and Singh constructs another dynamic model of adoption where farmers' behavior is characterized as "cautious optimization." With the passage of time, farmers' self-imposed constraints which are due to risk aversion are gradually removed (learning-by-doing effects) and financial constraints are relaxed (effects of buildup of surplus cash generated by profitable adoption in previous years). Therefore, adoption increases over time until an upper ceiling is reached.

The particular relationship between farm size and the process of adoption over time is the focus of the paper by Feder and O'Mara. Assuming a fixed adoption set-up cost and uncertainty regarding the yield associated with the modern technology, their model introduces dynamic elements through reduction of uncertainty over time due to both learning by doing in the Kislev-Shchori manner and exogenous effects. It is shown that, initially, larger farms will start with experimentation by applying the new technology on part of the land and using the traditional techniques of cultivation on the rest of
the land. Farms below a critical size will not use the new
technology. With the passage of time, those who have already
adopted the innovation on part of their land expand their use of it
or switch completely to the innovation while new adopters join from
the ranks of smaller farms as the critical landholding size declines
over time. It is shown that those who join late (the smallest
farms) may not need to experiment since the level of uncertainty
will be quite low for laggards. The aggregate rate of adoption,
measured by the ratio of land cultivated using the new technology
relative to total cultivated land, demonstrates an "S-shaped"
pattern over time as observed in reality for many innovation
diffusion processes.146

The notion of changing information over time is also emphasized
by Hiebert. While he does not formulate a complete dynamic model,
he indicates that changes in the perceived distributions due to
learning will increase the probability of adoption. Similarly,
O'Mara employs a Bayesian model whereby producers improve their
prior benefits on the basis of observed performance and, thus, are
inclined to increase the share of the modern technique over time.

The enormous literature on general processes of diffusion
stresses the role of communication147,148 and imitation.149 A
number of works show that diffusion processes can be described quite
accurately by compact mathematical formulae such as a logistic curve
or other specific sigmoids.150,151,152,153 The parameters as-
sociated with these functions are determined by factors char-
acterizing the distribution of certain properties (e.g., risk
aversions, wealth) over the population of decision-makers as well as economic factors pertaining to the innovation and the environment in which it is being introduced (adoption costs, input prices, cost of alternatives, product prices, etc.). As emphasized by Hernes, it is important not to assume that a specific mathematical formulation governs the adoption of technology. By introducing heterogeneity in the population both statically and dynamically, Hernes shows that the cumulative distribution of adoption may be skewed either rightward or leftward when either external influences follow the usual exponential function or internal influences follow the usual logistic function. From these results, he concludes that the shape of the growth curve in itself provides little information about which underlying process is applicable.

V. Conclusions and Implications for Further Adoption Research

The adoption research reviewed herein seems to support the following major conclusions. First, most adoption research thus far has viewed the adoption decision in dichotomous terms (adoption/nonadoption). But for many types of innovations, the interesting questions may be related to the intensity of use (e.g., how much fertilizer is used per hectare or how much land is planted to HYV). Future studies can rectify this problem by properly accounting for a more varied range of responses and by employing statistical techniques suitable for the type of variables considered.

Second, empirical research of adoption behavior should recognize that, in many cases, several innovations which have various degrees
of complementarity are introduced simultaneously. It follows that adoption decisions for various innovations are interrelated. Consideration of these interrelationships should be reflected in the econometric procedures. Doing otherwise may introduce biases and detract from the validity of the conclusions reached.

Third, the conflicting conclusions which are sometimes indicated by studies from different regions or countries may, in many cases, be the result of differing social, cultural, and institutional environments (aside from "pure" economic factors). It is thus essential to provide detailed information on the interactions among the various factors which generate the observed behavioral patterns.

Furthermore, in consideration of the dynamic aspects of adoption, descriptive studies suggest that a given farmer may follow a sequential process of adoption of production practices. For example, a farmer may adopt initially, on a limited basis, the use of HYV and fertilizer. With time, he may extend the acreage of the new crop and then realize that the scale of his operation with the new technology justifies the purchase of pesticide applicators and the use of pesticides. Assuming that the adoption of these new techniques results in a sufficient increase in the farmer's wealth, he may later purchase an ox or even a tractor for soil preparation activities. As this example indicates, adoption of new technologies is not done in a "one-shot" manner but, rather, in stages. Further work is needed to understand any order and regularity in such a chain process.
Finally, differential adoption rates of Green Revolution technology by different socioeconomic groups (classified, for example, by tenure status or holding size) are often found to disappear once the process is sufficiently advanced (e.g., Ruttan). But even if this is the case, the early adopters (usually the larger and wealthier farms) can accumulate more wealth and use the differential in the subjective value of land to acquire more land from the laggards. Thus, special attention to changes in landholding patterns (as well as tenancy arrangements) is warranted.

Existing dynamic models of adoption assume that landownership does not change during the period of the analysis. In many cases, however, the introduction of a new process and its adoption pattern result in changes in income distribution and landownership patterns; and these changes, in turn, will affect the rate of adoption of this new technology or of any other technology. Thus, it is important to develop a dynamic framework that can analyze sequential adoption of chains of technologies, taking into account the effect of adoption on landownership patterns and wealth distribution and the feedback effect of these changes on the adoption processes themselves.
Footnotes

1 This paper does not attempt to survey the voluminous literature which provides descriptive detail of various cases of technology adoption along with sundry heuristic explanations of observed phenomena.

2 Ruttan lists two other generalizations which relate to the effects of new technology on wages, income, and prices. These generalizations are not included here because the focus of this paper is on explaining the adoption process itself rather than its effects. (W. Ruttan, "The Green Revolution: Seven Generalizations," *International Development Review* 19 no. 4 [December 1977]:16-23.)


21 Michael Lipton, "Inter Farm, Inter-Regional and Farm Non-Farm Income Distribution: The Impact of New Serial Varieties," World Development 3 no. 6 (March 1978):321 (hereafter cited as "Inter Farm").


23 Parthasarathy and Prasad (n. 15 above).

24 Burke, p. 148.

25 Perrin and Winkelmann, p. 893.


27 Singh, pp. 53 and 54.


For example, preferential access to limited supplies of fertilizers may be of importance only during the initial years before distribution channels are properly organized.


43 Alviar (n. 8 above).


46 Lipton (n. 21 above).


49 Max Lowdermilk, "Diffusion of Dwarf Wheat Production Technology in Pakistan's Punjab" (Ph.D. diss., Cornell University, 1972).


51 Hodgdon (n. 11 above).


54 Schutjer and Van der Veen, p. 18.

55 John Von Pischke, "When is Smallholder Credit Necessary?" Development Digest 26 no. 3 (July 1978):6-14.

56 Grant Scobie and David Franklin, "The Impact of Supervised Credit Programmers on Technological Change in Developing Agriculture," Australian Journal of Agricultural Economics 21 no. 1 (April 1977):1-12.

57 Edward J. Clay (n. 9 above).


60. Lipton (n. 21 above).


62. Colmenares (n. 35 above).


67. Gafsi and Roe (n. 12 above).

69 Nazmi Demir, Adoption of New Bread Wheat Technology in Selected Regions of Turkey (Mexico City: Centro Internacional de Mejoramiento de Maiz y Trigo, 1976).

70 Richard Perrin, New Maize Technology and Its Adoption in Vera Cruz, Mexico (Mexico City: Centro Internacional de Mejoramiento y Trigo, 1976).

71 Vyas, p. 29.


81 Thomas E. Haller, "Education and Rural Development in Columbia" (Ph.D. diss., Purdue University, 1972).


83 Robert Evenson, "The Green Revolution in Recent Development Experience" (paper presented at the University of Chicago Economics Workshop, 1974).


The study by Takes in Nigeria is an exception. (Charles A. P. Takes, "Socio-Economic Factors Affecting the Productivity of Agriculture in Okigwi Division [Eastern Region]") mimeographed preliminary report [______: Nigerian Institute of Social and Economic Research, 1963].)

Helleiner (n. 41 above).


Takes (reference cited in n. 86 above), pp. 89-91.


Everett Rogers, "Modernization".


Robert V. Burke, pp. 135-154.

96 Vyas, p. 29.

97 Schutjer and Van der Veen, p. 28.

98 Rogers, "Modernization," Chapter 5.


103 Daniel McFadden, Ibid.


105 Daniel McFadden, "Quantal Choice."

107 Cristina C. David, "Factors Affecting Fertilizer Consumption," in Interpretive Analysis of Selected Papers from Changes in Rice Farming in Selected Areas of Asia (Los Banos, Philippines: International Rice Research Institute, 1978), pp. 67-82.


Nerlove and Press (n. 100 above).

The work by Hiebert provides a notable exception. (Dean Hiebert, "Risk, Learning and the Adoption of Fertilizer Responsive Seed Varieties," American Journal of Agricultural Economics 56 no. 4 [November 1974]:764-768.)


121 Hiebert did not investigate the impact of farm size on adoption.


128 Srinivasan (n. 29 above).
129 Gershon Feder (n. 122 above, "Farm Size").
130 Just and Pope (n. 117).


133 It may be noted, however, that a mean standard deviation expected utility function does not correspond to any underlying utility function. This may be shown simply by means of a contradiction using a two-point profit distribution and a three-point profit distribution where the third point is the mean of the two-point distribution. Nevertheless, the mean standard deviation criterion has validity on the basis of the safety fixed approach proposed by Kataoka. (S. Kataoka, "A Stochastic Programming Model," *Econometrica* 33 no. 1/2 [March 1963:181-396.)


140 de Janvry, p. 137.

141 David Newbery, pp. 272-275.


143 While the first of the above hypotheses is in contradiction to the conclusions obtained by Newbery, Bardhan's model does not consider the presence of uncertainty and risk aversion. Furthermore, the specification of the landlord's decision problem ignores the fact that, although the landlord cannot supervise the tenant's labor input, he takes into account the tenant's reaction function which is affected by the amount of land allocated to him.


146 Zvi Griliches (n. 120 above).

147 Everett Rogers, "Diffusion."

148 Everett Rogers, "Modernization."


150 Zvi Griliches (n. 120 above).


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