OCCASIONAL PAPERS
Number 16

PN-ABD-627

MODERNIZING TRADITIONAL AGRICULTURE

Marc Nerlove

INTERNATIONAL CENTER FOR ECONOMIC GROWTH

The International Center for Economic Growth is a non-profit research institute founded in 1985 to stimulate international discussions on economic policy, economic growth, and human welfare. The Center sponsors research, publications, and conferences in cooperation with an international network of correspondent institutes, which distribute publications of both the Center and other network members to policy audiences around the world. The Center's research and publications program is organized around five series: Sector Studies; Country Studies; Studies in Human Development and Social Welfare; Occasional Papers; and a Reprint Series.

The Center is affiliated with the Institute for Contemporary Studies, and has headquarters in Panama and a home office in San Francisco, California.

Publication signifies that the Center believes a work to be a competent treatment worthy of public consideration. The findings, interpretations, and conclusions of a work are entirely those of the author and should not be attributed to ICEG, its affiliated organizations, its board of overseers, or organizations that support ICEG.

For further information, please contact the International Center for Economic Growth, 243 Kearny Street, San Francisco, California, 94108, USA Phone (415) 981-5353.

ICEG Board of Overseers

Y. Seyyid Abdulai
OPEC Fund for International Development, Austria

Abdalatif Al-Hamad
Arab Fund for Economic and Social Development, Kuwait

Roy Ash
Ash Capital Partnership, USA

Nicolás Ardito-Barletta, Chairman
Panama

Raymond Barre
France

Roberto Campos
National Senator, Brazil

Carlos Manuel Castillo
Costa Rica

A. Lawrence Chickering
International Center for Economic Growth, USA (ex-officio)

Gustavo Cisneros
Organizacion Diego Cisneros, Venezuela

Roberto Civita
Editora Abril, Brazil

A.W. Clausen
BankAmerica Corporation, USA

Edmund B. Fitzgerald
Northern Telecom, USA

Ivan Head
International Development Research Center (IDRC), Canada

Adalbert Krieger Vassena
Argentina

Pedro-Pablo Kuczynski
Peru & USA

Agustin Legorreta
Inverlat S.A., Mexico

Sol Linowitz
Coudert Bros., USA

Jorge Mejia Salazar
Colombia

Saburo Okita
Institute for Domestic and International Policies Studies, Japan

Tomas Pastoriza
Banco de Desarrollo Dominicano, S.A., Dominican Republic

John Petty
Marine Midland Bank, USA

Stephen Schmidheiny
Eternit A.G., Switzerland

Anthony M. Solomon
S.G. Warburg (USA), Inc., USA

J.J. Vallarino
InterAmerican Council of Commerce and Production, Panama

Paul. A. Volcker
USA

Modernizing Traditional Agriculture

By Marc Nerlove

International Center
for Economic Growth

Affiliated with the
Institute for Contemporary Studies

Copyright © 1988 by Marc Nerlove

Printed in the United States of America. All rights reserved. No part of this book may be used or reproduced in any manner without written permission except in the case of brief quotations in critical articles and reviews.

Inquiries, book orders, and catalog requests should be addressed to ICS Press, 243 Kearny Street, San Francisco, California 94108 (415) 981-5353.

ISBN 1-55815-033-1

PREFACE

We are pleased to publish this paper by Marc Nerlove, of the University of Pennsylvania, in our series of Occasional Papers. The series features broad reflections by senior scholars and policymakers on major "lessons" produced by recent advances of knowledge.

For many countries, economic development and the development of agriculture are virtually synonymous subjects. This paper considers the process followed in the modernization of agriculture, a subject of great importance to the later stages of agricultural development. The author then analyzes the factors amenable to policy guidance that can accelerate or hinder the process, concentrating on the role of technology and education.

Mr. Nerlove is a distinguished economic theorist and econometrician who has made ground-breaking contributions to economic science, including work that has advanced our understanding of the dynamics of agricultural production and markets. For these contributions, he has received some of the most important awards in the profession.

Nicolás Ardito-Barletta
General Director
International Center
for Economic Growth

Panama City, Panama
September 1988

ABOUT THE AUTHOR

Marc Nerlove is University Professor of Economics at the University of Pennsylvania and a Research Fellow at the International Food Policy Research Institute, Washington, D.C. He is a member of the U.S. Academy of Sciences and a Fellow of the Econometric Society and the American Statistical Association. Among his awards are the John Bates Clark Medal of the American Economic Association in 1969, the P.C. Mahalinobis Memorial Medal from the Indian Econometric Society in 1975, dissertation and article awards from the American Agricultural Economic Association in 1958, and the "enduring publication award" in 1979 for *Distributed Lags and Demand Analysis* (1958). His other books are: *The Dynamics of Supply: Estimation of Farmers' Response to Price* (1958), *Estimation and Identification of Cobb-Douglas Production Functions* (1965), *Analysis of Economic Time Series: A Synthesis* (1979, with D.M. Grether and J.L. Carvalho), and *Household and Economy: Welfare Economics of Endogenous Fertility* (1987, with A. Razin and E. Sadka).

MARC NERLOVE

Modernizing Traditional Agriculture

Recent research on economic development and growth in Third World countries has revealed the key role of agriculture in the process and reversed an earlier emphasis on industrialization. Although agriculture accounts for a smaller fraction of aggregate output as growth and development proceed, the agricultural sector represents more than a source of labor, capital, and foreign exchange for a growing industrial and service sector. It is a source of food, fibre, and oils to feed and clothe the growing urban population. It is also a market for the consumer goods and services produced in the nonagricultural sector and, increasingly, for inputs used in agricultural production. Advances in biotechnology and increased knowledge of plant and animal biology have led to major advances in agronomy and animal husbandry, which, in turn, have provided the foundation for increasingly modern agriculture sectors in many, but not all, parts of the Third World. Such modern agriculture, when it can be achieved,

This paper reports research supported by the International Food Policy Research Institute, 1776 Massachusetts Ave. N.W., Washington, D.C. 20036 U.S.A. I am indebted to John W. Mellor,
(continued on next page)

provides food, fibre, oils, and other products used in industrial processes at lower costs and permits scarce foreign exchange to be used for other development. In this paper I examine the process of agricultural modernization, focusing on the role of technology and the use of modern inputs. I begin with a typology.

A Typology of Agricultures

In *Transforming Traditional Agriculture*, T. W. Schultz (1964) argued that despite limitations in schooling, health, and experience in responding to new events that impinge on their farm enterprises, farmers in traditional agricultural settings do, in fact, allocate their limited resources in a highly efficient manner. But traditional agriculture is relatively stable; few adjustments tend to be required, and those that do occur tend to be small.

One can imagine an agricultural sector in which no changes in technology, infrastructure, markets and so forth have occurred for a very long time. Under such "stationary" conditions, farmers may be poor, uneducated, and slow to perceive or respond to change. They may, nonetheless, be in virtually perfect adjustment to their environment and attain a very efficient allocation of resources. In the case of a largely subsistence agriculture, there may be few price signals to which to respond. Efficient allocation of resources largely consists, then, of proper allocation of time, land, and whatever limited physical capital exists in various household activities. These include not only farming, but other types of household production and consumption, the rearing of children, and such limited gross investment in human

---

(continued from preceding page)

T.W. Schultz, and Stephen Vosti for helpful comments and to Theresa Bradley for research assistance. The empirical work which gives some substance to my conjectures and speculations would not have been possible without data collected during the period since 1976 by the Federal University of Vicosa, M.G., Brazil, under the direction of Sonia Coelho Alveringa and Evonir Batista de Oliveira, and with the help of Carlos A.M. Leite. Luiz J.M. Irias and Ruy Miller-Paiva, who led me on an extended "agricultural tour" of Brazil in 1985, have been a constant source of ideas and encouragement. Finally, Eliseu Abreu Alves, former President of Empresas Brasileiras de Pesquisa Agropecuaria, inspired this work and supported much of it earlier through IFPRI. I alone am responsible for errors and omissions.

The initial version of this paper was prepared for "Economics Day" at the University of Pennsylvania, April 8, 1988. Much of it reflects the further development of thought presented in the Kellogg Foundation Fiftieth Anniversary Lecture at the 1979 meeting of the American Agricultural Economic Association.

physical capital as may be necessary to maintain existing stocks. If farmers have limited needs for goods they themselves cannot produce and limited opportunities for off-farm employment, markets and the infrastructure of communications and transport may be poorly developed, or virtually nonexistent. In this case, one can learn very little about potential increases in output by observing past behavior. In particular, the influence of relative prices on farmers' decisions may appear to be slight simply because such prices are largely irrelevant to the allocation problems which these farm households resolve.

Even when farmers sell a substantial fraction of their output of certain crops and buy other goods they need, fluctuations in market prices may induce little response simply because such changes are due to weather or other temporary factors that have little long-term significance for the allocative decisions being made.

Following Schultz, I will call this type of agriculture *traditional*. Traditional agriculture represents an equilibrium situation described well by Schultz (1964, pp. 831-32):

> Farm people who have lived for generations with essentially the same resources tend to approximate the economic equilibrium of the stationary state. When the productive arts remain virtually constant over many years, farm people know from long experience what their own effort can get out of the land and equipment. In allocating the resources at their disposal, in choosing a combination of crops, in deciding on how and when to cultivate, plant, water and harvest, and with what combination of tools to use with draft animals and simple field equipment — these choices will embody a fine regard for marginal costs and returns. These farm people also know from experience the value of their household production possibilities; in allocating their own time along with material goods within the domain of the household, they too are finely attuned to marginal costs and returns. Furthermore, children acquire the skills that are worthwhile from their parents and children have for generations under circumstances where formal schooling has little economic value.

Physical capital, as a factor of production, may have a high marginal product, but, in the stationary equilibrium of traditional

agriculture, there is little incentive to change the stock. Returns to new investment in physical capital must therefore be low relative to the rate of time preference. Human capital, to the extent that it has value primarily in disequilibrium situations, may have both a low marginal product and a low rate of return to investment in it. Compared to other types of agriculture, traditional agriculture is likely to be characterized by a low ratio of human to non-human capital.

Modern agriculture is not described in detail by Schultz. Presumably, it represents a state much like U.S. agriculture today. Agriculture is a relatively small sector of the U.S. economy and, in economic terms, much like any other industry. In organizational terms, the industry is characterized by a high degree of competitiveness; firms are small relative to the size of the market and more similar to firms in the service industries than to manufacturing firms. For historical reasons, much research and development is carried out in the public sector as well as by private sector firms supplying inputs to agriculture. Agriculture is highly commercialized, marketing virtually all output, purchasing most inputs, and valuing non-purchased inputs at opportunity cost. I would characterize this type of agriculture as one of *equilibrium growth*, that is, in *dynamic equilibrium*. The marginal product of human capital is high; rates of return to new investment in all forms of capital throughout the economy are also high, and more or less the same throughout the economy. Farmers, as all other economic agents in this economy, are highly responsive to price incentives.

In his work, Schultz focuses on how the economy moves from a state of traditional agriculture to a state of modern agriculture, what may be called the *agricultural transformation*. I call agriculture in the process of transformation *transitional agriculture*. "Agriculture" is in a state of *disequilibrium*. To set the stage for a closer look at transitional agriculture, let me describe briefly the two major changes we have experienced in U.S. agriculture since the 1930s. These changes reveal a great deal about the relationship between technological change and decisions about resource allocation. The first of these was the development and spread of hybrid corn, so well documented by Griliches (1957). While it may be true that the differential spread of hybrid corn in the U.S. can be explained in terms of differing costs and returns and farmers' perception of these differences, such a formulation is not particularly useful in understanding the complex forces

related to the supply of research and discovery which brought about the change and which governed its rate of spread.

On the other hand, the second major change—the remarkable fall in the cost of nitrogen fertilizer which took place in the 1950s and early 1960s and which resulted in a significant increase in the optimal amount of such fertilizer, applied to a variety of crops—was essentially a *price* phenomenon. Yet, as I think is shown by the studies of Wallace Huffman (1972, 1974, 1977), the changes that took place cannot be explained dynamically solely in terms of relative prices. There is virtually nothing in the production process for corn, for example, that would have prevented an almost instantaneous, complete adjustment; yet the adjustment did take time, and the speed with which it occurred varied substantially in different parts of the Corn Belt. Using country data for the period 1959-64, during which prices of nitrogen relative to corn fell about 25 percent, Huffman computes a partial adjustment coefficient showing actual changes during the five-year period as a fraction of the changes by country necessary to achieve an optimum, as determined from a production function for corn estimates from agronomic data. His major finding is that the speed of adjustment varies systematically across counties with respect to average levels of extension services provided, farmers' education, and farm size.

Two additional points are worth making in this connection. First, the research process, especially in the U.S., has become institutionalized to such a degree that research itself and farmers' continuing responses to the wide range of new opportunities constantly opening up to them have become a central characteristic of modern agricultural growth. Second, developments in the industries supplying inputs to agriculture are not unrelated to other types of research, such as the continued development of new varieties of plants that use fertilizer and water more effectively or lend themselves more readily to mechanized cultivation and/or harvesting. The impact of the fall in fertilizer prices would have been far less without the hybrid varieties, and, conversely, the profitability of the new varieties would have been less with higher fertilizer prices. Let us take a closer look at transitional agriculture with the perspective of these changes in American agriculture over the last 50 years or so, which reveals the interaction between technology and resource allocation decisions.

Transitional Agriculture: Transformation and Disequilibrium

The following is a rather idealized description of the changes that occur in the process of agricultural transformation:

(a) As investments are made in better communications, transportation, and other types of infrastructure, opportunities increase for markets of all kinds to develop. Consequently, price signals are likely to become more important, not less, as farm people become less isolated. Moreover, the markets and prices that are important in understanding agricultural growth and resources allocation are not limited to product markets and prices. Clearly, inputs such as fertilizer, farm implements, herbicides and insecticides, better seeds, and so forth are increasingly purchased and used. But labor markets also develop more fully and farm people begin to respond to opportunities for off-farm employment, part-time, seasonal, and permanent. The impact of changes in the labor market on agricultural output and composition may be at least as great as the impact of changing product prices and the development of new technology.

(b) The process of technical change in agriculture accelerates and becomes increasingly institutionalized and indigenous. Improvements in varieties of plants and animals and in the other inputs that are necessary to make these varieties more productive become an increasing source of agricultural growth. The dynamics of the process can be understood only by understanding the determinants and manner of adoption of new agricultural technology and how it comes to be produced on a continuing basis. The so-called "green revolution" in India, i.e., the rapid adoption of new, highly productive wheat varieties by the small, financially poor, uneducated farmers of the Punjab is perhaps somewhat misleading in this connection. To be sure, this event and others like it the world over, and the development of international agricultural research centers, have had a major impact on supply. Continued change, however, is likely to rest more on the series of smaller, less dramatic developments. Perceiving these developments and how to put them to use is a key element in the process of modernization; it requires farm people to adapt to maintained disequilibria. For this reason, improvements in rural educational facilities, especially literacy and extension services, must play an important role. Development of other infrastructures, such as facilities for irrigation, drainage, and other forms of water control are

also essential. Many of these require major public investments, but the ability and willingness of farm people to take advantage of the increased availability of educational and extension services, or the public provision of certain types of infrastructure, can come only through changes in the nature of private investment, especially in human capital but also in on-farm physical capital.

(c) Demographic change accompanying agricultural transformation and economic development is a crucial element in agricultural modernization. To an important extent these changes are initiated by improvements in public health that result in sharply decreased mortality, particularly infant and child mortality, and in control and/or eradication of debilitating diseases, which make human labor less productive than it would otherwise be. However, many demographic changes have their roots in the individual decisions of farm people, as labor markets improve, and with growing awareness of opportunities outside of agriculture, to make greater investments in human capital. They do this by increased education and better nutrition for their children. As other forms of saving and provision for old age become available, they also have fewer children. Such demographic changes alter the nature of agricultural production, leading to increased use of nontraditional inputs and to a greater reliance on market. Thus they alter agricultural output and its composition, as well as the allocation of resources within agriculture.

(d) The role of government in this process is obviously important, and although there are many areas in which government intervention is both necessary and desirable, governments are nevertheless continually tempted to intervene when they should not. Such interventions may seriously impede agricultural development and distort the incentives and signals that prices provide in modern agriculture. Marketing boards, which supposedly regularize the flow of product from producer to market or stabilize extreme price fluctuations, frequently hold down the prices producers receive; and protection of domestic industry, such as fertilizer, serves to make the things that farm people buy more costly. Taken together, serious consequences may follow, as the infamous case of rice production in Thailand in the 1950s and 1960s serves to indicate.

Thus, the important areas of change are: (1) the demand for and supply of new technology and new inputs; (2) the development of marketing and transportation infrastructure, permitting increased

commercialization; (3) an increase in the rate of return to human capital and an increased stock of such capital relative to other forms of capital; (4) better functioning labor markets; (5) demographic change, falling rates of mortality, morbidity, and fertility; and (6) increased government intervention to regulate markets, to promote domestic industry, to produce and disseminate new technology and inputs, to supply various forms of infrastructure, such as irrigation, electrification and transport, and to provide increased education and skills to both rural and urban population.

Technology clearly plays a major role in agricultural modernization, but the process cannot be understood solely in terms of technology. It must be considered in terms of the interaction of technology with a number of social and economic factors. With this in mind, I now turn to a closer look at the demand for new technology and new inputs in transitional agriculture. Put another way, I consider the rate at which, and the extent to which, technological innovations and concomitant use of modern inputs, obtained from the nonagricultural sector, will spread in response to their availability.

The Demand for New Technology and Modern Inputs in Transitional Agriculture

There is now a large and growing international research establishment devoted to basic agricultural science and to the development and adaptation of new technology for agriculture and animal husbandry throughout the world and in many existing diverse agroclimatic situations. How this establishment came to be and how it has grown is a fascinating story but not the one I wish to tell here. Rather I focus on the use of new technology and inputs obtained largely from the nonagricultural sector as a major factor affecting the growth and modernization of transitional agriculture. The adoption and diffusion process is one particularly adapted to study if one is lucky enough or has sufficient foresight to conduct them at the right place and time. Here I offer some thoughts and conjectures about this aspect of the problem of supply dynamics in transitional agriculture with particular reference to data collected by the Federal University of Vicosa in the Zona da Mata, a small region in the Southeast corner in the state of Minas Gerais in Brazil (see Note on page 5).

In a world of uncertainty and competitive markets, in which firms are price takers and all of them have access to the same information about technologies available to produce goods or services, differences among firms in their fixed resources and the prices they face explain differences in the choice of technology and inputs used. If fixed resources and prices are the same, then all firms will use the same most efficient technique. The presence of uncertainty and risk aversion is one of the factors that affects this standard result because the ability of firms to take risks will vary according to their wealth or their size and their preferences.

In agriculture, the presence of uncertainty deserves special attention because it affects both production and demand. The variability of the prices of different crops depends on whether a particular crop or livestock product is sold in local, domestic, or international markets, and on whether prices are regulated by a public agency. The distributions of yields are characterized by different parameters because some crops are more sensitive than others to adverse weather and to pests. In addition, the distribution of a particular crop's yield depends on the type and amounts of other inputs used. The usual assumption in the agricultural economics literature is that modern inputs involve not only higher mean returns but also higher risk than traditional inputs. Although it is not necessarily true that modern inputs increase risk (some are risk reducing, such as pesticides), farmers may perceive them as being riskier, either because of a lack of information, or because they may involve other changes that increase risk.

There are several actions farmers can take to deal with risks involved in agricultural production. Newbery and Stiglitz (1981) distinguish between actions to share risk or to transfer it to others and actions to reduce the total amount of risk. Land tenure contracts and crop insurance belong to the first category. Product diversification, choice of technique, acquisition of better information, and crop storage are means of reducing total risk. Other risk-reducing actions are diversifying the household's income sources and producing for family consumption rather than for the market when crop yield and price are highly and positively correlated.

Just and Zilberman (1983) discuss the effects of production and price uncertainty on choice of technology. Their analysis assumes a single crop that can be produced either in a traditional manner using

traditional inputs or in a modern manner using modern inputs. Both the new and the old technology are assumed to be risky, but the new is assumed to be riskier and the amount of risk to vary with the quantity of the modern input per unit area and the proportion of the area of the farm devoted to traditional and modern crops.

Farmers are assumed to maximize the expected utility of income, which is the sum of the revenues obtained from the production of a single modern crop (or a crop produced with modern inputs) and of a single traditional crop (a crop produced with traditional inputs). Land is fixed, and farmers have to decide on how much of it to cultivate with each technology, as well as what level of inputs to use. Essentially, the problem of adoption is treated as a problem in portfolio choice.

In reality, of course, more than one crop or livestock product is produced, and more than one type of modern input is used. Just and Zilberman assume that modern inputs are riskier than traditional inputs. As noted, however, while it is true that modern varieties and their yields are more sensitive to moisture when the crop is fertilized, other types of modern inputs, such as herbicides, reduce risk. Use of vaccines and feed supplements in livestock production also reduces risk. Thus, as the use of some modern inputs increases, risk may increase, while for others it may decrease. The existing theory of the effects of risk on adoption of modern technology is incorrectly based on the assumption that modern technology is riskier than traditional.

The importance of the Just-Zilberman contribution, which is affected by the above limitation, lies in the suggestion that one may *indirectly* determine how attitudes towards risk affect adoption decisions by the implications of such attitudes for the observed behavior of farmers. In crop production, for example, as the size of the farm increases, both the optimal allocation of land and the use of modern input per hectare will change. These changes are influenced by attitudes to risk (that is, the extent of absolute risk aversion and whether relative risk aversion is increasing, decreasing, or constant) and by the covariance of yields or returns between the two technologies. The impact of changes in farm size on the optimal allocation of land and level of use of modern inputs is obtained by standard methods of economic analysis.

Unfortunately, the analysis of adoption of modern technology and inputs as a portfolio problem does not appear to generalize easily

to more than two technologies and more than two modern inputs. If we could unambiguously measure the marginal increase (or decrease) in the risk premium associated with the level of production of each crop and livestock product, then we could obviously equate the marginal return to the marginal increase in the risk premium for all unpriced inputs, such as land, and to the marginal return to purchased inputs. The risk premium can be declining for only one activity for an interior solution. The problem is that the risk premium associated with each activity is a complicated function of the correlations of returns as well as their variances and expected values. The mix of crop and livestock production will change with wealth or the size of the enterprise. Moreover, this mix depends on many factors other than wealth, such as the specific agroclimatic conditions that each farmer or tenant encounters. In addition, the presence of fixed costs of adoption will affect both the mix of products and the extent to which modern inputs and techniques are used in each activity. Nonetheless, key variables in any empirical analysis are (a) farm size in relation to both the particular mix of crop and livestock products produced, and (b) the extent to which modern inputs, such as chemical fertilizers, pesticides, vaccines, and feed supplements, are used.

Risk and farmers' attitudes towards it are not the whole story. Roumasset (1979), for example, argues that other dimensions of uncertainty, such as information acquisition, may be more important than risk attitudes. And other factors, such as the quality of land and market imperfections, may be more important in explaining the behavior of farmers. If risk preferences are a decisive factor, then risk-specific measures to influence adoption are appropriate. Some countries are funding research aimed to reduce yield variability, or are providing crop insurance. If uncertainty is related to price variability, then the provision of storage facilities or guaranteed prices is appropriate. If the cause of non-adoption is related to fixed costs, then the answer is policies aimed at reducing them.

If other factors are more important, such as market imperfections, lack of marketing infrastructure, or tenure arrangements, appropriate policies may be quite different. With respect to such alternative explanations of adoption behavior, I offer the following conjectures again based on the data collected during 1978-84 on transitional agriculture in the Zona da Mata:

Conjecture 1: Information and education facilitate moderniza-

tion. The use of modern inputs requires that farmers be aware of their existence and know their properties in order to compare the distribution of returns under each technology. The accuracy or quality of a farmer's knowledge depends on his source of information (other farmers, extension agents, radio, or newspaper) and on his level of education. Education improves farmers' ability to collect and use information and to adjust to changes (reducing learning time). We find a positive relationship between quality of information and adoption of new technology, and an inverse relation vs. the age of the operator.

Conjecture 2: Market imperfections impede modernization. The presence of market imperfections reduces incentives to adopt new technology. There are several potential sources of market imperfections. In input markets, prices charged to farmers may vary according to farm size or location, or there may be non-price supply constraints. Use of modern inputs may require complementary inputs, such as labor or use of machinery in land preparation, which constitute an indivisible input. If rental markets for agricultural machinery exist, both large and small farmers will be able to adopt, but these markets often do not exist. In output markets, prices paid for food by farmers may be higher than prices received, leading farmers to grow food crops that may be much less responsive to modern inputs than cash crops. Farmers may obtain different prices from their crops depending on where they sell them. Farmers who sell only in local markets may get lower prices, reducing the profitability of modern inputs. We found evidence that market imperfections impede the adoption of new technology and the process of agricultural modernization.

Conjecture 3: Farm tenure diversely affects the modernization process. It has been argued that sharecropping can be an impediment to the adoption of modern technology if modernization increases the sharecropper's independence of the landowner (Bhaduri, 1973; Scandizzo, 1979) or it increases moral hazard (Newbery, 1975). The interlinkage of markets (landowners may provide credit to sharecroppers and market the product) may affect the choice of technology, and the direction depends on the impact of borrowing on the effort supplied by the sharecropper (Braverman and Stiglitz, 1986). The theoretical discussion of the role of tenure arrangements is far from complete, but it is clear that the specific terms of the contract are important. It is plausible that if the sharecropper has to bear all the costs of inputs and give the landowner a share of the output, the

expected return required to trigger adoption by sharecroppers will be higher than for owners, everything else equal. Whether the landowner has other sources of income should also matter in determining his optimal decision in relation to the choice of inputs and to the choice of contract. In the Zona da Mata, we found tenants are less prone to modernize than owners are, but this is not clearly the case in other parts of Brazil or of the world.

Conjecture 4: The natural environment shapes the extent and direction of modernization. Yields obtained with each technology may differ across farms because the quality of land varies from one farm to the next. One may be next to a river or stream; another may have a small proportion of flat land. Past decisions (which crops were grown, and which inputs and tillage practices were used) may affect the properties of the soil. These factors will lead to variations in the distribution of yields across farms and thus affect adoption decisions in various ways. The quality of the capital invested in livestock may affect decisions in the short term. Both short- and long-term decisions will be affected by the nature of pasture land and the suitability of land and climate for growing feed crops. To the extent we could measure these effects, we found they were important in the Zona da Mata.

Conjecture 5: Cash constraints limit farmers' ability to use modern inputs. Using modern inputs often involves switching from on-farm produced inputs to market-supplied (factory-produced) inputs. Farmers need greater cash resources to use modern rather than traditional inputs. Where output and capital markets are not well developed, farmers face a cash constraint that prevents them from having access to new technologies. The availability of cash depends on how much of his production a farmer sells, what he produces, how much credit can be obtained, and whether other sources of income are available (farmers may rent land out, have a job off the farm, etc.). These variables turned out to be the most important ones in explaining farmers' decisions in the Zona da Mata.

Conjecture 6: The product mix changes in the course of modernization and plays a role in it. Although the mixture of crop and livestock products is an endogenous variable affected differentially by a number of factors mentioned above, it is exceptionally important in determining the diffusion of new technology and new inputs. Particularly in developing countries, few agricultural sectors and few individual agricultural establishments are monocultural. Most farmers

the world over produce a variety of crop and livestock products. Because new technology affects different products in profoundly different ways, the mix of crop and livestock products is a major factor in the determination of how new technology and inputs will spread and is, in turn, itself changed greatly by the use of modern techniques and inputs. Considerable heterogeneity of product mix and production practices characterizes agriculture in the Zona da Mata.

Conjecture 7: Infrastructure and the availability of complementary inputs are essential in the process of modernization. As suggested earlier, the availability of marketing and transportation infrastructure may play a key role in agricultural modernization because such infrastructure permits the commercialization of agriculture. Another way of saying this is that the transition from a subsistence-oriented to a market-oriented agriculture generates cash flow, which is, in turn, essential to the use of modern agricultural technology, to purchase modern inputs from the nonagricultural sector, and to enable farmers to use the extensive credit programs that are characteristic of public support of agricultural development. Beyond this, however, the availability of certain kinds of complementary inputs similar to infrastructure, such as irrigation and water control and rural electrification, may greatly influence the profitability of using new technology and modern inputs. Although a major program of irrigation and land reclamation has been undertaken in the Zona da Mata region, we do not find significant effects among farms of the availability of these complementary inputs. Most farms are not electrified, and, although infrastructure varies across farms, we have not been able to ascertain the effects of access to electricity on farmers' behavior. Other research underway is expected to support this conjecture.

Our sample is biased towards the inclusion of small farms. Given this timetable, size of farm as a measure of overall wealth does not appear to affect product mix or relative input levels in the Zona da Mata. I conclude that farmers' risk aversion is a minor factor in the adoption of new technology, at least in this region.

In this essay, I have focused on the role of new technology and modern inputs in the modernization of traditional agriculture. Understanding this role entails both an analysis of the way in which new technology and modern inputs are produced and an analysis of how and when farmers put these developments into practice. Both are

important. My own research focuses on the process of adoption. Drawing on this research, I argue that risk and risk avoidance currently emphasized in the agricultural economics literature is less significant than other factors such as information and education, market imperfections, tenure status, cash constraints, product mix, natural environment, and infrastructure and the availability of complementary inputs.

REFERENCES

Bhaduri, A., 1973, "Agricultural Backwardness under Semi-Feudalism," *Economic Journal*, 83: 120-37.

Braverman, A., and J.E. Stiglitz, 1986, "Landlords, Tenants and Technological Innovations," *Journal of Development Economics*, 23: 313-32.

Griliches, Z., 1957, "Hybrid Corn: An Exploration in the Economics of Technical Change," *Econometrica*, 25: 501-22.

Huffman, W.E., 1977, "Allocative Efficiency: The Role of Human Capital," *Quarterly Journal of Economics*, 91: 59-80.

_____, 1974, "Decision Making: The Role of Education," *American Journal of Agricultural Economics*, 56: 85-97.

_____, 1972, "Contributions of Education and Extension to Differential Rates of Change." Unpublished Ph.D. dissertation, University of Chicago.

Just, R.E., and D. Zilberman, 1983, "Stochastic Structure, Farm Size and Technology Adoption in Developing Agriculture," *Oxford Economic Papers*, 35: 307-28.

Newbery, D.M.G., 1975, "Tenurial Obstacles to Innovation," *Journal of Development Studies*, 2: 63-277.

Newbery, D.M.G., and J.E. Stiglitz, 1981, *The Theory of Commodity Price Stabilization: A Study in the Economics of Risk*. Oxford: Clarendon Press.

Roumasset, J.A., 1979, "Unimportance of Risk for Technology Design and Agricultural Development Policy," in A. Valdes, G.M. Scobie, and J.L. Dillon (eds.), *Economics and the Design of Small Farmer Technology*. Ames: Iowa State University Press.

Scandizzo, P.L., 1979, "Implications of Sharecropping for Technology Design in Northeast Brazil," pp. 122-39 in A. Valdes, G.M. Scobie, and J.L. Dillon (eds.), *Economics and the Design of Small Farmer Technology*. Ames: Iowa State University Press

Schultz, T.W., 1964, *Transforming Traditional Agriculture*. New Haven, Ct: Yale University Press.

ICEG Academic Advisory Board

Michael J. Boskin
Stanford University, USA

Rudiger Dornbusch
Massachusetts Institute of Technology, USA

Ernesto Fontaine
Universidad Catolica de Chile, Chile

Francisco Gil Diaz
Banco de Mexico, Mexico

Malcolm Gillis
Duke University, USA

Arnold C. Harberger
University of Chicago, USA

Helen Hughes
Australian National University, Australia

Glenn Jenkins
Harvard Institute for International Development, USA

D. Gale Johnson
University of Chicago, USA

Roberto Junguito
Economic Consultant, Colombia

Anne O. Krueger
Duke University, USA

Deepak Lal
University College London, England

Ronald I. McKinnon
Stanford University, USA

Charles E. McLure, Jr.
Hoover Institution, USA

Gerald M. Meier
Stanford University, USA

Seiji Naya
Resource Systems Institute East/West Center

Juan Carlos de Pablo
Cronista Comercial, Argentina

Affonso Pastore
University of São Paulo, Brazil

Gustav Ranis
Yale University, USA

Michael Roemer
Harvard Institute for International Development, USA

Leopoldo Solis
Committee of Economic Advisors to the President, Mexico

David Wall
University of Sussex, England

Richard Webb
Universidad Catolica, Peru

James Worley
Vanderbilt University, USA

21