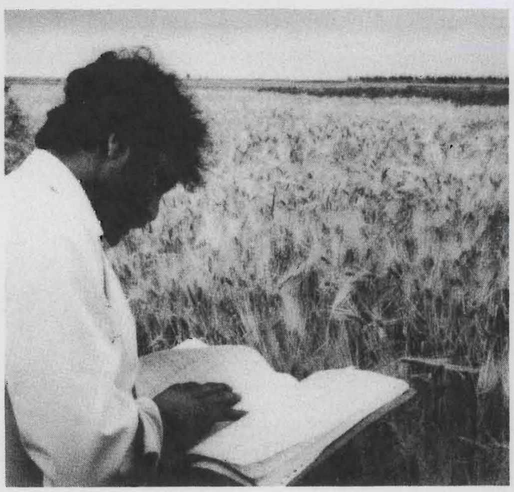
TECHNOLOGY, HUMAN CAPITAL, AND THE WORLD FOOD PROBLEM

Institute of Agriculture, Forestry and Home Economics
Department of Agricultural and Applied Economics
Agricultural Experiment Station



Miscellaneous Publication 37—1986
University of Minnesota

TECHNOLOGY, HUMAN CAPITAL, AND THE WORLD FOOD PROBLEM

Alexander von Humboldt Award
Colloquium
1984

G. Edward Schuh
Editor

TECHNOLOGY, HUMAN CAPITAL, AND THE WORLD FOOD PROBLEM

Alexander von Humboldt Award
Colloquium
1984

Institute of Agriculture, Forestry and Home Economics
Department of Agricultural and Applied Economics
Agricultural Experiment Station
Miscellaneous Publication 37 — 1986

TABLE OF CONTENTS

Alexander von Humboldt Foundation Award

This marks the tenth year that the Alexander von Humboldt Foundation Award has been given. It is awarded to the person(s) chosen by a select panel of judges as having made the most significant contribution to American agriculture during the previous five years. The Foundation itself is both a German and United States based organization funded by the Alfred Toepfer Company, a German trading firm. It is named for a famous German geographer of the 19th Century.

Recipients of the Alexander von Humboldt Award

1975

Dr. Theodor O. Diener

Plant Virology Laboratory Beltsville Agricultural
Research Center, ARS, USDA
Beltsville, Maryland

Dr. Joseph S. Semancik

Department of Plant Pathology, University of California,
Riverside, California

(Scholarship)

Patricia Ann Delwiche

University of Wisconsin, Madison, Wisconsin

1976

Dr. John D. Axtell

Department of Agronomy,
Purdue University, Lafayette, Indiana

(Scholarship)

Darrell G. Schulze

Texas A & M University
College Station, Texas

1977

Dr. Wendell L. Roelofs

Department of Entomology, Cornell University,
Ithaca, New York

Dr. Harry H. Shorey

Department of Entomology, University of California,
Riverside, California

(Scholarship)

Eileen Kladivko

Purdue University, Lafayette, Indiana

1978

Mr. Karl H. Norris

Instrumentation Research Laboratory
USDA, Beltsville, Maryland

(Scholarship)

Randall Gold

North Dakota State University, Fargo,
North Dakota

1979

Dr. Winston J. Brill

Department of Bacteriology,
University of Wisconsin, Madison, Wisconsin

(Scholarship)

Dale A. Jeschke

University of Illinois, Urbana, Illinois

1980

Dr. Perry L. Adkisson

Texas A & M University
Department of Entomology
College Station, Texas

(Scholarship)

E E Fung

University of Arizona
Tuscon, Arizona

1981

Dr. Warren E. Kronstad

Crop-Science-Department, Oregon State University,
Corvallis, Oregon

(Scholarship)

Scott P. Eisensmith

Michigan State University,
East Lansing, Michigan

1982

Dr. John McColl Bremner

Department of Agriculture, Iowa State University,
Ames, Iowa

1983

Howard L. Bachrach

USDA Plum Island Animal Disease Center,
Greenport, New York

Dr. George E. Seidel, Jr.

Department of Physiology and Biophysics,
Colorado State University
Ft. Collins, Colorado

1984

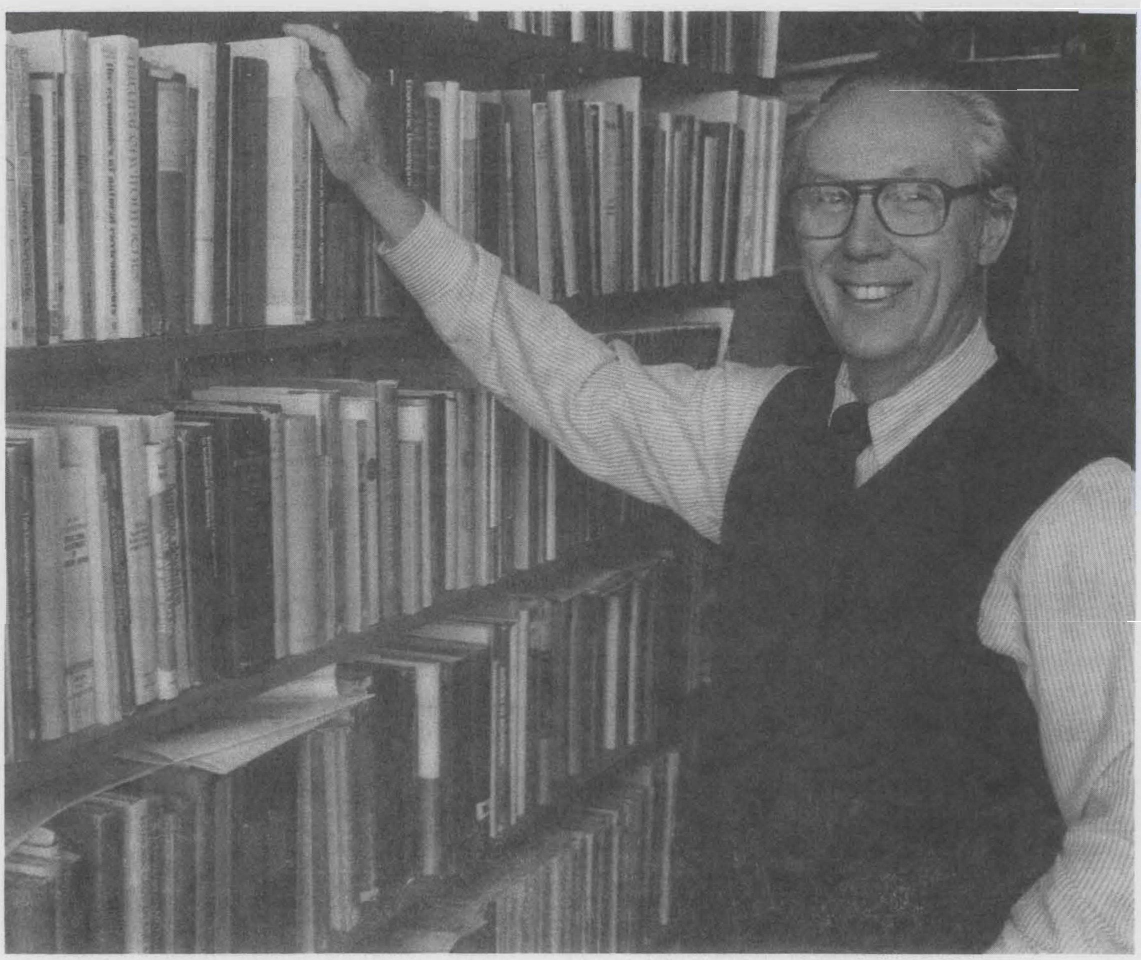
Dr. Vernon W. Ruttan

Department of Agricultural and Applied Economics
University of Minnesota, St. Paul, Minnesota

Vernon W. Ruttan
1984 Recipient

Professor Vernon Ruttan, a native of Michigan, received his B.A. from Yale University in 1948 and his Ph.D. from the University of Chicago in 1952. He was Head of the Department of Agricultural Economics at the University of Minnesota from 1965 to 1970 and President of the Agricultural Development Council from 1973 to 1977. He has also held positions with the Tennessee Valley Authority, Purdue University, the President's Council of Economic Advisers, and the International Rice Research Institute. He has been President of the American Agricultural Economics Association, was elected its youngest Fellow ever, and has received more research awards from that Association than any other person. He is also a Fellow of the prestigious American Academy of Arts and Sciences.

Vernon Ruttan is a creative and scholarly researcher, a prodigious writer, a surveyor of stimulating ideas, and a sought-after adviser to governments on science and technology policy. The Alexander von Humboldt Foundation recognizes him for outstanding research in the economics of technical change, the theory of agricultural development, and science and technology policy. Dr. Ruttan's research is notable because it shows how science and technology ease constraints to economic development, provide more abundant food, and improve living standards worldwide.



Appraisal of the Scientific Work of Vernon W. Ruttan

G. Edward Schuh*

Vernon Ruttan has been a very creative professional. He has been a prolific writer. His scholarship can only be described as massive. You will especially appreciate that statement if you ever attempt to trace the footnotes that document his scholarship, and thus realize how careful he is to relate his work to that of others in the field.

Ruttan has made contributions on a wide variety of fronts. Rather than pursue all of these, I want to focus instead on the theme which led to his receipt of the award we are here to celebrate tonight. Before doing that, however, I want to pay homage to his work on testing the Schultz urban-industrial impact model. His study of the "Impact of Urban Industrial Development in Agriculture in the Tennessee Valley and the Southeast"** not only advanced our understanding of the agricultural development process but influenced his later work in some very important ways. It helped make him more sensitive to interactions between the farm and nonfarm sectors, and especially to linkages through the factor markets.

Turning now to the more circumscribed field of the economics of technical change, Ruttan's work is an important example of how one idea progressively leads to another. His career exemplifies the importance of staying with a line of work for a significant period of time, and of persevering so as to develop in-depth perceptions. There are some important lessons for all of us from following his career.

I find it useful to divide Ruttan's contributions to science into four parts and four phases. The first phase was in the 1950s, and his contribution to science was in measuring the impact of technological change on agricultural productivity growth and output. He pioneered in this area, and one of his key contributions to the literature was an article in the Review of Economics and Statistics.*** This article received the published research award by the American Agricultural Economics Association in 1957 (one of his many awards). In that article he carefully measured the contribution of technical change to productivity growth and output in U.S. agriculture, and then projected the contributions that new production technology would make to the future expansion of agricultural output. This work became a classic in its field.

His next significant contribution came in the 1960s and early 1970s. Collaborating originally with Yujiro Hayami of Japan, and later with Hans Binswanger, he contributed to our understanding of the processes that generate technical change. This work led to the refinement and empirical testing of the induced innovation model, which is now so closely associated with his name.

The seminal idea behind the induced innovation hypothesis was that the direction of technological change is conditioned by the relative prices of inputs used in agricultural production. This idea carries with it the notion that there are alternative optimal or efficient growth paths for technical change for different economies. It puts technical change as the engine of agricultural growth and development, which role it plays by easing the constraints to output expansion imposed by inelastic input supplies. And it also gives a special role to institutional linkages whereby economic incentives and actions by political pressure groups contribute to keeping the focus of research and technical change on the efficient growth path.

---

*Head, Department of Agricultural and Applied Economics, University of Minnesota (until January 1985).

**Vernon W. Ruttan, "The Impact of Urban-Industrial Development on Agriculture in the Tennessee Valley and the Southeast," Journal of Farm Economics 37 (February 1955): pp. 38-56.

***Vernon W. Ruttan, "The Contribution of Technical Progress to Farm Output: 1950-1975," Review of Economics and Statistics 37 (February 1956), pp. 61-69.

These ideas were first published in their fullest amplitude in his book with Yujiro Hayami, Agricultural Development: An International Perspective.* This book had an enormous impact on agricultural development thought, in part because it provided the means of integrating a great deal of previous work by T.W. Schultz, Zvi Griliches, and other people who were trying to understand the process of agricultural development. This induced innovation model is now probably the most widely accepted model of agricultural development, and is the basis of agricultural development policy in a large part of the world. It has led to a great deal of empirical research, not only by Ruttan and his colleagues, but by others as well. The power of his model is illustrated by the fact that it can explain the growth paths of both Japan and the United States, two countries with very different resource endowments.

In the late 1970s and early 1980s, Ruttan turned his attention to agricultural research policy. His work in this area, which has been published in his book on Agricultural Research Policy,** is an application of his induced innovation model to the analysis of research policy. This application is an intellectual tour de force, however, in that it was necessary to integrate biological and other technical knowledge about agriculture with knowledge about institutions and how they work, and with knowledge about the economy as a whole. The very rich framework of analysis which this model provides has enabled Ruttan, as well as others, to understand the process of technical change in agriculture as well as a vast array of policy issues pertinent to science and technology policy.

Fortunately for those of us in the agricultural research and teaching establishment, Ruttan's work on science and technology policy came on stream just as the agricultural research establishment in this country was coming under fire from a number of different sectors. Armed with his conceptual framework and his vast empirical and institutional knowledge, Ruttan has provided the agricultural research community with an intellectual framework that has enabled it to respond to its critics and explain why many of their criticisms of the system have been misguided. The perspective outlined in this book offers insights into policy issues involving the proper rate at which agricultural research should be funded, whether the process of technological change should be focused on land-saving or labor-saving growth paths, on the interactons between basic and applied research, and on the character and nature of the institutional relations required for agricultural research to be an efficient source of growth.

In his more recent work Ruttan has studied the role and sources of institutional change. His nascent attempts to conceptualize the process of institutional innovation builds on his previous work on technical change. This new line of research potentially has enormous implications. The qualifier "potentially" is needed in this assertion because most of the payoff from that work is still to come. We are fortunate that Ruttan is still as productive as he is, and has the energy to take on these ever-expanding challenges.

To conclude these comments it is worth noting that Ruttan is one of those rare individuals whose professional contributions and professional career have really made a difference. They have made a difference because they have led to a great deal of additional work, both by him and by others. But his contributions also matter at a completely different level. Large numbers of people around the world are better fed and better off today because of his contributions. Moreover, in the future, there will be an even larger number of such people.

No better compliment could be paid to him. Nor could a better compliment be paid the sponsors of the Von Humboldt Award for honoring him as they are tonight.

---

*Yujiro Hayami and Vernon Ruttan, Agricultural Development: An International Perspective (Baltimore: The Johns Hopkins University Press, 1971).

**Vernon W. Ruttan, Agricultural Research Policy (Minneapolis: University of Minnesota Press, 1982).

Appraisal of the Contributions to Research and Graduate Education of Vernon W. Ruttan

Robert T. Holt*

The task is impossible: to comment briefly on the contributions of Vernon Ruttan to research and graduate education. To keep within the assigned time, I would just reflect on the innovative research that Ruttan has done with which I am most familiar. Less than a generation ago, economic models of growth treated technological innovation as an exogenous variable. It was as if the economists had an image of a mad inventor who is driven by some internal force completely removed from the economic realities around him. Inventions would pour from his fertile mind and those that happened to have some relevance would be picked up by entrepreneurs and developed into economically viable projects. Ruttan was one of a very small number of economists who challenged that notion.

His comparative work, with Yujiro Hayami, on the economic development of American and Japanese agriculture demonstrated clearly the way in which inventions were sensitive to the relatively scarcest of the factors of production. He showed how two cultures and economies as strikingly different as those in the United States and Japan in fact responded to the same kinds of economic pressures. The work is a classic and I use the term "classic" in its purest sense; it is a piece of research which does not have to be duplicated; it will stand for a very long time as the definitive work in the field.

Ruttan's more recent work on institutional innovation is equally as path-breaking. He has already demonstrated clearly the way in which new institutions have facilitated economic development in some countries and, even more important, the way in which the failure to invent institutions has significantly inhibited that development in other countries. I am sure that in the not too distant future, we will see another major work from the pen of Vernon Ruttan which will be a definitive treatment of induced institutional innovation.

Ruttan's contributions to graduate education reflect the ideal model of the scholar-teacher. His lectures and his seminars flow from his research endeavors; he does not assign the textbooks for students to ponder over; he is the text and the students learn from him not only knowledge about economic development. They also learn of the excitement of pursuing research on the cutting edge of a field and that excitement is transmitted to them more by example than by precept.

His contributions to graduate education, however, extend far beyond the confines of his own classroom. Students in a number of departments at this University, and others around the country and around the world, benefit from his works.

There is much discussion in the scientific community these days about developments in the science of cloning. Indeed, some suggest that in the not too distant future, it would be conceivable to clone human beings. If the state of technology ever advances that far, my candidate for a first human being to be cloned would be Professor Ruttan. But there is a sense in which that would not be nesessary. All of us have gained so much from reading his work and interacting with him personally that there is a little bit of Vern Ruttan in all of us who have had the opportunity to know him.

---

*Dean of the Graduate School, University of Minnesota.

Response to Award Presentation

Vernon W. Ruttan

It is indeed a signal honor to be the first social scientist to receive the distinguished Alexander von Humboldt Foundation Award. Von Humboldt's contributions to science were exceedingly broad. My colleagues in agronomy regard him as one of the founders of plant science. Geographers regard him as one of the seminal figures in their discipline. And the ecologists insist that he belongs to them.

The claims that those of us in economics can make are more tenuous. Let me quote from the Encyclopedia Britanica. "After futile studies in economics at the University of Frankfort (on der Oder) he spent a year at Berlin where he obtained some training in engineering and became passionately interested in botany. He then went on to Gottingen where his interest in science developed to include mineralogy and geology."

It is not only from the perspective of the past that agriculture represents an appropriate focus for the von Humbodt award. We still have much to accomplish! In closing decades of the 20th century we are approaching the end of one of the most remarkable transitions in the history of agriculture.

Prior to the beginning of this century almost all increases in agricultural production occurred as a result of increases in area cultivated. The major exceptions were in Western Europe, where livestock based conservation systems of farming had developed, and in East Asia, where wet rice cultivation systems had developed.

But by the end of this century there will be few significant areas where agricultural production can be expanded by simply adding more land to production. Expansion of agricultural output will have to be obtained almost entirely from more intensive cultivation of the areas already being used for agricultural production. Increases in food and fiber production will depend, in large measure, on continuous advances in agricultural technology.

The task before us is clear. It is imperative, over the next several decades, that we complete the establishment of agricultural research capacity for each commodity of economic significance in each agroclimatic region of the world.

In completing the global agricultural research system, it will not be sufficient to focus only on the natural sciences and technology. The constraints on growth in agricultural production and productivity are both technical and institutional. Institutional innovations and improvements in institutional performance will also be necessary to generate the growth in production and income that rural people have a right to expect. This implies a very substantial growth in the demand for social science knowledge applied to agriculture.

CHAPTER ONE

The International Agricultural Research Centers: Evidence of Impact on National Research and Extension Programs

by
R.E. Evenson

THE INTERNATIONAL AGRICULTURAL RESEARCH CENTERS: EVIDENCE OF IMPACT ON NATIONAL RESEARCH AND EXTENSION PROGRAMS

R.E. Evenson*

The first International Agricultural Research Center (IARC), IRRI, is now 25 years old.[1] Several other IARC's have been in place for more than 15 years. A number of important changes have taken place, both in the development of the IARC's and in the building of national research and extension capabilities in the developing world over this period.[2] This paper reports the findings of a study that seeks to determine whether the development of the IARC system has produced a measurable impact on the size and character of national agricultural research and extension programs.

The first section of the paper provides a descriptive summary of national research and extension spending since 1959. It is intended both to provide general background and to motivate some aspects of the model developed in the second section. The third section reports econometric estimates of the determinants of investment in national research and extension programs. The final section draws inferences regarding IARC impact.

A Descriptive Summary of National and International Program Development

National investment in agricultural research and extension programs has grown at an impressive rate in the past 25 years.[3] Tables 1 and 2 (pages 14 and 15) summarize this investment. It may be seen that, in 1980 constant dollars, research spending in developing countries increased from 1959 to 1980 by a multiple of 5.8 in Latin America, 6.9 in Asia, and 3.6 in Africa. The comparable spending multiples for extension investment were 6.4 for Latin America, 3.5 for Asia, and 2.2 for Africa. Scientist man-year (SMY) multiples were lower than spending multiples (6.0 for Latin America, 4.1 for Asia, 4.2 for Africa) reflecting rising real costs per SMY. (For extension workers the multiples were 6.8 for Latin America, 1.8 for Asia, 2.9 for Africa.)

Table 3 (page 16) shows how research and extension "spending intensities," i.e. spending as a percent of the domestic value of agricultural product (G.D.P.), has changed from 1959 to 1980. These data show that in 1959 the low-income and middle-income developing countries were approximately twice as spending intensive for extension as for research.[4] The reverse was true for the industrialized countries. The rapid growth in spending intensities for research from 1959 to 1980 combined with little or no growth in extension intensities in the 1970's produced roughly equal spending intensities for research and extension in most developing countries.

Table 4 (page 17) provides comparable data for "manpower intensities" (i.e. ratios of manpower to G.D.P.). For research the same general pattern reflected in spending intensities is reflected in the manpower intensities. Because spending per SMY is lower in developing countries, they fare better by this measure. The difference between the low-income and industrialized countries is much reduced.

For extension, the picture is quite different. By 1959 low-income developing countries had attained very high extension manpower intensities, 5 to 7 times greater than those attained in industrialized countries. By 1980, with a slight decline in the intensities for industrialized countries, the difference was even greater. Middle-income and semi-industrialized countries also increased their extension intensities.

These manpower intensities should not be interpreted as though there were no differences in the quality of manpower between countries. There is little doubt that the general levels of training of both scientists and extension workers vary between countries and are lower in the developing countries. However, the differences are not as great as is generally supposed. There is also little indication that these differences have changed as research and extension spending has increased. These data do not include "extension type" spending associated with Rural Development Projects in developing countries. Were such data to be tabulated and included as extension

---

* Professor of Economics, Yale University.

spending, the magnitude of the differences in spending on extension relative to research in the developing countries would be even greater.

Table 5 (page 18) provides further insight into the motivation for the high extension manpower intensities in developing countries. It shows expenditure/manpower ratios for research and extension. These ratios include salaries of scientists and extension workers and related costs, including laboratory costs and the cost of technicians. The ratio of research costs to extension costs is as much as 20 to 1 for the low-income developing countries and only 3 to 1 or so for the industrialized countries. Some of this difference is a quality difference (extension workers have advanced training in most industrialized countries and may have little training in low-income countries), and some is due to real cost differences. Many low-income countries do not have the capacity to train agricultural scientists and must incur high costs to train researchers and to purchase scientific equipment.

Table 6 (page 19) offers some insight into the question of research quality. The Commonwealth Agricultural Bureau (CAB) provides abstracts of most of the world's agricultural literature. In 1983 it was publishing 21 abstracting journals. These journals were broadly classified as Basic Crop, Applied Crop, Basic Animal and Applied Animal research journals. (See notes to the Table.) Table 6 provides data on ratios of basic to applied publications abstracted in these journals by country for 3 periods. The data show that the 25 less-developed countries in the table actually have higher basic to applied ratios for both crops and animals than do developed countries.

These ratios are very rough proxies for the real degree of basicness of research. Many of the papers abstracted in the applied abstracting journals could be classified as basic and many papers in the journals classified as basic are applied. The main point of Table 6 is to show that the research in the 25 less-developed countries is not demonstrably more applied than research in developed countries.

Table 7 (page 20) reports data on spending by commodity in the form of spending intensities. Since these data will be utilized in the investment analysis to follow, a discussion of their origin is merited. With few exceptions, developing countries cannot provide a commodity breakdown for their research spending. They do well to provide data on total spending. It is possible, however, to obtain publications data from the CAB abstract system by commodity orientation. This was done for each country for two periods, 1972-75 and 1976-80. These data were then standardized into equal cost units utilizing Brazilian data. For Brazil, real spending by commodity and CAB publications data were available. It was thus possible to standardize publications into cost equivalent units. Standardized publications were then used to allocate actual expenditures to commodities.

The data show that spending intensities differ greatly by commodity in the 25-country sample (see Table 6 for the 25 countries--these 25 countries account for approximately 90 percent of total production in developing countries, excluding China). Spending intensities are low for coconuts, sweet potatoes and cassava, and high for cocoa, coffee and livestock. The table also shows that the IARCs account for relatively low shares of the total research on the commodities they work on. Since expenditures per SMY are very high in the IARCs (about 4-6 times the average for national spending), the IARCs are much less significant in terms of their share of scientific manpower devoted to these commodities.

Specifying the Determinants of Investment in Research and Extension

If IARC impacts on national research and extension spending are to be measured, a specification relating national spending to "determinants", including IARC investment, is required. Such a specification should be consistent with economic logic and political reality. Since IARC investments are commodity based, it is natural to develop the specification for spending by commodity.

The specification developed here is motivated by a project evaluation or planning perspective modified by political constraints. The specification includes variables that a rational planner would use to guide optimal investment. It also includes variables that reflect the political power of interest groups and political constraints.

Before discussion of the specification it will be useful to discuss the data to be utilized and to list the variables in the data. Two data sets have been constructed.

The first is a data set where the observations are for 2 periods, 1972-75 and 1976-80, for 24 countries.[5] For this data set it was possible to obtain aid variables, thus allowing a test of the role of aid in influencing national spending. The second data set is for the same countries, for a reduced set of variables measured annually for the 1962-82 period.

The observations in both data sets are on commodities (i.e., an observation is for a commodity, a country and a year) (or an average of 1972-5 or 1976-80 for the first data set). The commodities are rice, wheat, maize, sorghum, millet, cassava, field beans, potatoes, sweet potatoes, groundnuts, sugar and soybeans. However, actual measurements for a number of variables in the data set are not on a commodity basis.

Table 8 (page 21) provides a list of the variables for the two data sets with a short definition of each variable. Those variables marked with an asterisk are measured on a country rather than a commodity basis. That is, they are common to all commodities (accordingly their means are not comparable to the means of variables actually measured on a commodity basis).

The variables are classified as endogenous, (i.e., the choice variables being subject to analysis), partially endogenous, and exogenous. The exogenous variables are further classified as "economic" variables, "international transfer" variables, and "political-economic" variables.

The dependent variables in the analysis are the variables measuring national research spending and national extension spending.

RESEXP (measured in millions of 1980 dollars).
EXTEXD (measured in millions of 1980 dollars. This variable is not measured on a commodity basis).

The model by which this spending is determined is constructed in three stages. The first stage is motivated by supposing that a planner is attempting to maximize the economic surplus (i.e., both consumers' and producers' surplus), associated with the research or extension program. In the second stage the planner takes international transfer conditions into account. In the third, the planner takes political constraints into account. (This is the rationale for the classification of exogenous variables in Table 8.)

Before discussing these variables, it should be noted that several aid variables, AID, NDONORS, WBEXT, WBRES NHSTAFF, and INTCR are also included in the model. These cannot be considered to be exogenous determinants of national spending, however, since actions by the recipient countries as well as choices by donors responding to characteristics of recipient countries determine this spending. Thus these aid variables must be regarded to be simultaneously determined along with national spending. (See the following section for a discussion of the econometric treatment.)

Now consider the first stage of the planner's problem. A given research program can be expected to lower production costs per unit of production. The more units over which costs can be lowered, the higher the optimal level of research. Each commodity and each agro-climatic region presents different research problems to some degree. Hence units of production should be measured on a commodity-region basis. The two variables PROD (production) and DIVER (diversity), and the interaction of these two variables, are designed to pick up these effects.[6] National research spending is expected to rise as both production and diversity increase.

For some, perhaps most, research programs a "minimum critical mass" of research effort may be required for an effective program. If so there will be a threshold level of production below which a research program cannot be justified. Small diverse countries are more likely than larger countries to face these problems.

The variables EXPRAT and ARABLE are price variables reflecting prices of alternative sources of growth in supply. EXPRAT, the ratio of expenditures per SMY to expenditures per extension worker, is designed to reflect the relative costs of purchasing growth through extension investment. (Expressing it in ratio terms avoids the need to specify an exchange rate.) It is expected that when the price of research resources falls relative to extension resources more spending in research will take place. The ARABLE variable (the ratio of arable land currently to arable land six years previously) is designed to reflect the price of supply growth via land expansion. When the change in arable land is small, reflecting land exhaustion, more spending on research is expected.

Now turn to the second stage of the problem. The planner recognizes that technology may "spill-in" from other countries and from IARCs. He also recognizes, however, that the potential spill-in technology was designed for, or "targeted" to agro-climatic conditions in other countries. Other national programs will be targeting their research programs to their own agro-climatic conditions. The IARCs may target to a broader range of conditions that are extant in their host countries, but in practice they lack the resources to provide technology targeted to more than a limited range of environments. Thus, the planner will find that some technology available on the international market is directly suited to use (i.e., it is targeted to domestic conditions), but that much new technology (and related research findings) is "mismatched" (i.e., it is targeted to agro-climatic conditions differing from those of the country). The planner's response to closely matched technology from abroad will be to reduce domestic research investment since domestic research is a substitute for matched technology from abroad (extension spending may be inversed). The planner's response to mismatched technology from abroad will be to increase domestic research investment to modify and adapt the mismatched technology to domestic conditions. Of course, if the mismatch is too great it will not offer such opportunities.

We would then expect planners to exhibit a mixed response to technology from abroad. On the one hand, they will "free ride" on the research of IRACs and neighboring countries to the extent that they see these research units as producing closely matched technology with little scope for adaptation. On the other hand, they will respond with increased adaptive research to the extent that they see the units producing mismatched technology offering adaptation opportunities and to the extent that these units are producing "pre-technology" scientific discoveries that also enhance the productiveness of their own systems.

The variables CINTSP (cumulated spending in IARCs on the commodity), and RESNSR (SMY's working on the commodity in agro-climatic neighboring countries), are measures of the programs that a national planner will respond to. Whether the response will be a net negative free-riding response or a net positive adaptive-opportunity response depends on the nature of the technology. The variable TOTALAREA is a measure of the size of the country; the interaction of this variable with CINTSP is designed to identify whether the response to IARC investment differs for large and small countries.

Finally, the planner will respond to political constraints. The variables IMPORT and EXPORT measure the effects of international trade. Most countries implicitly place a higher value on international exchange than on domestic production. A unit of product that saves or earns foreign exchange is valued more highly than one that does not. A planner will respond to this by investing in more research on commodities that save or earn foreign exchange. Many countries intervene in agricultural markets. The UREARICE variable (the ratio of prices paid for urea fertilizer to prices raised for rice) is a measure of this intervention. A planner might attempt to "compensate" for some types of intervention by spending more or less on research.

The variables, ECONAG, URBANPOP and VIOLD, are crude proxies for political organization as well as for interest group power. A planner will respond to pressure from interest groups. He may, for example, respond to urban pressure groups by shifting resources from research to competing urban investments even though urban consumers are the major beneficiares of agricultural research.[7] High proportions of the labor force in agriculture are usually associated with weak political power of rural people. If so, this could reduce spending on research and extension.

These political variables, it should be noted, are proxies for many different combinations of interests and the ability to translate these interests into political action. In the absence of a political model little interpretation can be given to measured impacts. The justification for the inclusion of these variables in the model is simply that they may control for some differences in political conditions and reduce bias in the estimated parameters that can be given stronger interpretations.

ECONOMETRIC ESTIMATES

Table 8 provides a list of the variables discussed above. The actual specification requires a procedure for handling the partially endogenous variables, basically the Aid variables. In addition the functional form has to be specified.

The two period data set (set 1) does not have sufficient observations to estimate investment relationships for each commodity. It does contain aid variables and is suited to a general analysis of research investment based on pooled commodity observations. The second data set for the 1962-82 period does contain sufficient observations to enable an analysis of determinants of spending for each commodity and for extension spending as well. It does not contain aid variables.

Aid Determinants

The specification for the two period data set and for the aid analysis is considered first. This specification requires that national research spending and aid be treated as simultaneously determined. A Two Stage Least Squares procedure is appropriate. The endogenous variables are: AID, NDONORS, NHSTAFF, WBRES, WBEXT, INTCR, CONGRU, BASIC, EXTEXD, and RES.[8] The latter two variables are the most important from the perspective of this analysis. The model treats each of the first 8 variables as dependent on both EXTEXD and RES in addition to a number of exogenous variables. EXTEXD and RES are treated as dependent only on aid (AID or WBRES and WBEXT) and a different set of exogenous variables.

The econometric estimates based on this model are reported in Table 9 (page 23). Table 9 reports the results for the aid variables and for characteristics of national systems. Table 10 (page 24) summarizes the main results showing determinants of investment in field crop research, livestock and horticultural crop research, and extension.

The functional form used is linear except that several multiplicative or interaction variables are used. These are:

PROD2 = PROD x PROD
PRDIVER = PROD x DIVER
PRDXPORT = PROD x EXPORTS
PRDMPORT = PROD x IMPORTS
INTSPLOC = INTLOC x CINTSP
AREACINT = TOTALAREA x CINTSP

The Bool notation identifies the endogenous variables in each equation.

In Table 9, national research spending RES and extension spending EXTEXD are the endogenous variables treated in determining aid flows and characteristics of national research systems (these variables are predicted in Table 10). As the table shows, aid agencies do appear to respond to national investment in extension but not to investment in research. Higher extension spending appears to reduce both the aid level to agricultural research and the number of donors providing that aid. A measure of general aid to extension is not available but the results do show that World Bank aid to extension responds positively to national spending levels. (Of course, as Table 10 shows, national spending responds positively to World Bank support as well. The two stage least squares procedure is designed to identify the separate causal relationships.) Higher extension spending also appears to induce research programs with higher fractions of non-commodity oriented components.[9] It also induces more IARC aid in the form of non-host staffing.

The positive TOTALAREA and negative AREADIV coefficients in the AID, NDONORS, WBRES and WBEXT equations show that aid agencies respond negatively to diversity. They provide more aid to large countries with little diversity. Countries with small areas and high levels of diversity are in some sense discriminated against by aid donors. This is in contrast to a result in Table 10 showing that national governments do not respond negatively to diversity in their own funding decisions. Interestingly, the IARCs do respond positively to diversity in their non-host staffing decisions.

It appears that when governments pursue high fertilizer/rice price policies (interpreted here as general policies discriminating against farmers and in favor of consumers) aid agencies respond by offering less aid to research (and possibly more to extension). They do not compensate for anti-supply policies by investing more in research. National programs themselves also tend to respond to their own discriminating price policies by spending less on research extension. Their research programs are also more basic and more congruent. That is to say they are less commodity oriented and better matched to their commodity production patterns.

Aid donors generally tend to respond to land exhaustion (i.e., low levels of the ARABLE variables) by offering more aid to research. The World Bank does not. It appears to offer less aid to extension. Aid donors including the World Bank do appear to respond positively to the importance of the agricultural work force in the general labor force. This is in contrast to the tendency of national programs to spend less when the proportion of workers in agriculture is high. This is perhaps the one dimension where aid donors appear to be inducing more "qualitative optimal" programs.

Aid donors do not appear to respond to IARC locations in their programming. The IARCs, however, do favor IARC host countries in their placement of non-host staff, research contracts and collaborative agreements.

The qualitative dimensions of national programs appear to respond to political factors to some extent. A higher proportion of the labor force in agriculture appears to induce more commodity oriented and more congruent research programs. National programs also appear to respond to strong research programs by agro-climatic neighbors by undertaking a lower proportion of non-commodity research.

Research-Extension Determinants

Table 10 reports the most important results of this analysis. It shows the determinants of national research spending on field crops research, on livestock and horticultural crops research, and on extension spending. Two versions of each equation are reported. In the left-hand panel, general aid is treated as a determinant of spending. In the right-hand panel, World Bank aid to research (or extension) is treated as the determining variable. Cumulated IARC spending (CINTSP) on the commodity is treated as an exogenous variable[10] and serves to test whether IARC programs have stimulated or retarded national spending. This variable is also interacted with a variable measuring the size of the crop area in the country (AREACINT).[11] This is designed to measure whether the IARC impact is related to the size of the country.

Table 10 shows that IARC spending did not affect extension spending, but that it clearly had a positive impact on both field crop research spending and on livestock and horticultural crop research spending. Further, the impact is positively related to the size of the country being affected. For field crop research the approximately zero coefficient on CINTSP shows that for small countries there is little or no IARC impact. For large countries the positive impact is substantial. For livestock and horticultural crops it appears that a positive impact holds even for small countries. These results are not affected by the choice of aid variables.

The response of national research system spending to IARC spending is consistent with the estimated positive response to research undertaken by agro-climatic neighbors. The RESNSR variable measures the SMYs devoted to the commodity by other countries in the same broad agro-climatic zone. The positive response to this research and to IARC research shows that national systems see this research as opening up adaptive opportunities for their own research investment. The fact that countries do not respond to this research spending by spending more on extension is also consistent with a perception that the new technology being produced in these systems is not so well matched to their own production environments that they can simply facilitate its "spill-in" and adoption by investing in extension.

Thus the pattern of response in both research and extension spending to both IARC research and the research of agro-climatic neighbors is consistent with the fact that agricultural technology has a high degree of location specificity. The typical developing country appears to have recognized that new technology does not easily spill-in from abroad and that low cost extension investment is not sufficient to facilitate its transfer. On the whole, technology produced abroad is mismatched to conditions at home. The degree of the mismatch is not so great, however, that it does not present new opportunities for adaptive research at home. In addition to mismatched technology, research institutions abroad are also producing pre-technology science of relevance. It too, is of value at home only when a strong research capacity has been built.

This interpretation of the IARC impact has important policy implications (as described below). The statistical measures reported in Table 10 support this interpretation. However, it is also important that the more general investment estimates be judged against *a priori* logic or expectations to determine whether the specific IARC impacts are part of a generally consistent investment relationship.

To this end, consider the impacts of the economic variables on investment. For all research activities, the PROD and PROD2 impacts are significant and as expected. Holding agro-climatic diversity constant, an increase in the units produced of a commodity offers a type of scale economy to a research system. Thus spending per unit of production will decline as shown by the negative production squared term.

An increase in diversity itself does not have a strong impact on field crops research (although it is positive), but does appear to stimulate more spending on livestock and horticultural research when production is low. High levels of diversity reduce the production input on this research spending. The same situation holds for extension spending. Higher levels of diversity lower the impact of total area on extension spending. This appears to be a kind of diseconomy or discouragement effect.

The expected negative sign on the ARABLE variable is borne out only for the livestock and horticultural crops research (and possibly for extension). When the ratio of arable land currently to arable land six years previously is low it is indicating an exhaustion of arable land.

The EXPRAT variable measures the ratio of a "price" of research services to a price of extension services. Since the dependent variable is expressed in expenditure terms if this variable has a zero coefficient, the actual price elasticity is -1.[12] Since this ratio is probably measured with error, its coefficient will be biased toward zero. It is important, therefore, that the standard error be considered in interpreting this variable. To facilitate this a range of price elasticities (+/- 1 standard deviation) is reported in the following section. This range shows that prices do matter. Those countries that have lowered this ratio by developing a capacity for training scientists at home and reducing dependency on costly expatriate scientists have responded by buying more units of research.

The variables measuring political factors are important. They show very strong international trade effects. If a commodity is exported, more research per dollar of product is expended for all commodities. Export orientation also stimulates extension spending. This impact is higher for the horticultural crops and livestock, perhaps reflecting post-colonial effects in which research or export commodities traditionally had strong "mother country" support. It is interesting, however, that the impact of imports of the commodities has a stimulus effect of roughly the same magnitude for field crops and of larger magnitude for the livestock and horticultural crops. Imports do not effect extension spending.

This extra attention to trade commodities has several rational explanations. Most developing countries have pursued general economic policies that place a high value on foreign exchange. Demand elasticities for traded crops are high so supply can be increased without significant reduction in market prices. Increased imports of commodities may also provide political signals that something should be done about domestic supply. Of course, there may be a colonial legacy reflected in the data but the import effects suggest that a more general set of factors are operating to favor traded over nontraded commodities.

The variable proxying for agricultural price policies, UREARICE, does not have a significant effect on research although countries pursuing price policies that discriminate against farmers (as measured by a high fertilzer-rice price ratio) tend to spend less on livestock and horticultural crop research. They also spend less on extension, thus they do not attempt to compensate for negative price effects on supply by spending more on research and extension.

The variables measuring the characteristics of the agricultural labor force and the urbanization of the population reflect political processes that cannot be given very clear interpretations. An increase in the percent of the population living in urban centers of 100,000 or more tends to reduce spending on research and extension, particularly on field crops research. This presumably is measuring political power with an interest in directing government spending to nonagricultural interests. Countries with high proportions of their labor force in agriculture also spend less on research and extension, particularly field crop research. This variable is not measuring the same phenomena as the urbanization variable, but it is not inconsistent to suggest that farmer political power is actually weakest in the poorest economies with high proportions of workers in agriculture. Since this variable is also a proxy for the general wealth of a society it may be measuring a kind of wealth effect. If so it should be noted that there is a certain irrationality behind it since investment in research and extension is a production investment, not a form of public consumption.

The results reported in Tables 9 and 10 are based on the two period data set for which aid variables are available. The results with respect to the aid variables show that general aid for research (as measured by AID) does increase research spending for field crops research but not for livestock and horticultural crop research or for extension. The coefficients show two sorts of displacement of aid effects on research spending. First, research spending on field crops does not increase by the full amount of the aid. Second some reduction in livestock and horticultural crop research is induced by aid.

The results when World Bank aid is provided are similar for general aid to research although the apparent displacement is more severe. World Bank aid to extension, on the other hand, provides a strong stimulus to national extension investment.

The magnitude of the aid and other impacts on spending will be discussed further in the concluding policy section of the paper. Before turning to that discussion, results from the second data set will be reported (Table 11, page 25).

Annual Data Analysis

The annual data set, as noted earlier, does not have data or aid variables. It is, however, considerably richer in terms of observations by commodity. Accordingly, the results reported in Table 11 are by commodity and for pooled commodity groups: cereals (maize, sorghum, millet, rice, wheat), staples (beans, cassava, groundnuts, potatoes, sweet potatoes) and commercial crops (soybeans and sugar). (Dummy variables for commodities are included in all pooled regressions.) The specification differs from that in Table 10 in three ways. First, since aid variables are not available, the variable VIOLD (a predicting variable in the earlier analysis), is included in these regressions. Second, an effort is made to estimate both an area and production and hence yield impact on research spending. Third, international trade variables were not included in these regressions.

These results are generally consistent with those reported in Table 10 and show a high degree of consistency across commodities. The IARC spending impact which is of central concern to this study has a statistically significant coefficient in the regressions for maize, sorghum, rice, wheat, potatoes and sweet potatoes and in the pooled cereals and staples regression. Other studies have shown that the IARC contributions in terms of technology development and research contribution have been higher in these commodities than in beans, cassava and groundnuts. These latter commodities are generally regarded to present "difficult" challenges to researchers. To some extent this is due to the fact that they have received research attention for a shorter period of time than is the case for the cereal grains, where considerable research in developed countries has been undertaken over many years.

The response to the research by agro-climatic neighbors is positive in most commodities, and in the pooled regression, confirming the results reported in Table 10.

An increase in production while holding area constant, i.e., an increase in yield, stimulates research spending in the cereal grains and cassava, but yield is not generally highly correlated with research spending. An increase in general diversity does stimulate more research spending in almost all commodities, and the production impact on research spending is higher for all commodities, the higher the level of diversity.

These data show relatively weak land exhaustion effects. The relative price of research to extension services is a significant determinant of spending. It shows some bias in that a decline in the costs of doing research seems to stimulate the most research spending on wheat, rice and maize.

Land exhaustion effects are generally not significant. The political variables ECONAG and URBANPOP show effects similar to those reported for Table 10. Urbanization appears to be biased toward stimulating more research on wheat and less research on other commodities. When price policies discriminate against farmers, they also discriminate against research spending except for wheat and potatoes. Political violence is associated with reduced spending for most types of research.

On the whole, the results for specific field crop commodities reinforce the conclusions of the earlier analysis. They show a high level of consistency across commodities.

POLICY IMPLICATIONS

The results of the econometric exercise reported in Tables 9, 10 and 11 have substantial policy relevance. While they do show a considerable degree of consistency with rational planning on the part of national governments, it cannot be concluded that there is little reason for active policy interventions to change national government investment. Indeed another large body of evidence (see Evenson, Waggoner and Ruttan, 1981, and Ruttan, 1983) shows that research investments have produced extraordinarily high returns in terms of the increased agricultural output associated with research programs. The implication is that there is general underinvestment in research. Comparisons by region and by commodity show substantial variations implying underinvestment in at least some research programs.

With this in mind, then, it is useful to calculate the marginal impacts of alternative policy-related activities on national research and extension spending. Table 12 (page 26) reports a number of such calculations based on the regression estimates reported in Tables 10 and 11.

The table shows that the elasticities of both research and extension spending evaluated at the mean are in the .55 to .6 range. This means that at the mean of the sample a ten percent increase in production induces a 5.5 to 6 percent increase in spending. This could be due to fixed costs of undertaking research and extension programs and "real" scale economies due to size. The implied scale parameter is essentially the inverse of this elasticity (i.e., 1/.6 = 1.66). However, it may reflect an overestimate of real scale economies and a tendency on the part of governments to feel that once a substantial research program is in place, it need not be expanded with the importance of the crop. Conversely, it may reflect a tendency to build research programs for minor commodities.

The table also shows that when the commodity being produced is exported, research spending per unit of product is 1.39 as high for field crops and 1.54 times as high as for livestock and horticultural crops as it is for non-traded commodities. When the commodity is imported, spending per unit of product is 1.29 times as high for field crops and over 4 times as high for livestock and horticultural crops (where imports are generally very low). The policy implication for these calculations is not that traded commodities receive too much research attention but that non-traded commodities receive too little attention.

The positive response by countries to an added SMY on the commodity by a agro-climatic neighbor is quantitatively significant in field crops and appears to be biased towards all cereals except wheat and toward beans, cassava and groundnuts. The induced spending of $30,000 is large in view of the fact that the cost of the added SMY may be only a little more than that.

The calculations showing a reduction in price policy discrimination against farmers should probably be taken with skepticisim. Price policy and research and extension spending are interrelated in a complex fashion and it does not necessarily follow that a change in price policy will lead to a change in research spending.

Much more confidence can be placed in the computations for a ten percent decline in the research costs per SMY. Many countries have options to reduce these costs through improvement of their own capacity to train scientists and through better incentive structures to hold scientists in research positions. In Africa, an expansion in the indigenous scientists component and a reduction in administrative costs can easily allow a reduction in costs per scientist.

Table 12 reports four computations associated with a ten percent decrease in research costs per SMY. The upper two are the +/- one standard deviation range in expenditure change. The lower two are the +/- one standard deviation range in the elasticity of quantity with respect to the research (or extension) price. A decline in the research price by 10 percent will result in an increase in the quantity of SMYs purchased of 10.5 to 11.9 percent for field crop research and 4.74 to 6.52 percent for livestock and horticultural crop research. This will mean a small increase in spending on field crops research and a decrease in spending on horticultural crop and livestock research. A ten percent decline in extension costs, on the other hand, will increase the purchase of extension workers by 14.5 to 15.9 percent and will also increase total spending.

The final calculations regarding aid and IARC spending are of most interest. The form of the model measuring IARC impacts was that the stock (i.e., cumulated expenditures in 1980 dollars) of IARC investment impacted on the annual flow of national research spending. Thus, a million dollar increment to IARC spending 1978 would raise the value of the CINTSP variable in 1978, 1979, etc. If this IARC spending was in the field crops it would stimulate $229,000 added national research investment in the first year (1978). (This is calculated as the total of the spending impacts in the 24 countries in the sample. Presumably the scope of influence is wider than for these 24 countries, so this is an underestimate of the effect.) By 1988 a total of $2,290,000 added national research investment would have been stimulated by the 1 million dollar expenditure in 1978. With the data at hand it is not really possible to estimate the deterioration of this effect. It is conservative to suppose that it will last only ten years (about the average time period for IARC investment in the data set).

The results for individual field crops (based on Table 11 and the annual data) also show large investment impacts. Only cassava shows no impact. IARC investments of one million dollars in potatoes, sweet potatoes, wheat, sorghum and millet appear to stimulate an added million dollars in national spending within one or two years. Even for maize and rice the added national investment is significant.

This may be compared with the estimates for direct aid. They show that 1 million dollars in general aid increases field crop research by more than 1 million dollars but at the cost of reduced spending on livestock and field crop research. Thus taking this displacement into account, only $336,000 net incremental research spending takes place for the one million dollar aid grant or loan. The same calculation made for World Bank aid shows an even more severe displacement effect. A million dollars in World Bank aid results in only a net increment to spending of $222,000. In rather sharp contrast, it appears the World Bank extension aid has a large stimulus effect on extension spending.

The aid inputs, it must be noted, are difficult to estimate and this will lead some policy makers to discount them. Most aid donors, however, are predisposed to believe that their aid has sufficient "strings" that it will not be displaced. Yet, most of it, in fact, is displaced and generally displacement is probably efficient. When accompanied by strong policy advice and pressure as in the case of World Bank extension aid (the T. & V. system) aid can have a large effect.

It appears then that the IARC system has had a significant and positive impact on national research (and extension) programs in the developing world. It has stimulated more spending in national systems and this impact is sufficiently large that an aid donor interested in stimulating national research spending actually received more stimulus from a grant to the IARC system than from a direct grant to a national system. The IARC system probably had a significant impact on more qualitative aspects of national research systems as well.

A P P E N D I X   1

Table 1: Agricultural research expenditures and workers

Region/Subregion	Expenditures (000 Constant 1980 US$)			Workers (Scientist-Years)		
	1959	1970	1980	1959	1970	1980
Western Europe	274,984	918,634	1,489,588	6,251	12,547	19,540
Northern Europe	94,718	230,135	409,527	1,818	4,409	8,027
Central Europe	141,054	563,334	871,233	2,888	5,721	8,827
Southern Europe	39,212	125,165	208,828	1,545	2,417	2,686
Eastern Europe and USSR	568,284	1,282,212	1,492,783	17,701	43,709	51,614
Eastern Europe	195,896	436,094	553,400	5,701	16,009	20,220
USSR	372,388	846,118	939,383	12,000	27,700	31,394
North America and Oceania	760,466	1,485,043	1,722,390	8,449	11,688	13,607
North America	668,889	1,221,006	1,335,584	6,690	8,575	10,305
Oceania	91,577	264,037	386,806	1,759	3,113	3,302
Latin America	79,556	216,018	462,631	1,425	4,880	8,534
Temperate South America	31,088	57,119	80,247	364	1,022	1,527
Tropical South America	34,792	128,958	269,443	570	2,698	4,840
Caribbean and Central America	13,676	29,941	112,941	491	1,160	2,167
Africa	119,149	251,572	424,757	1,919	3,849	8,088
North Africa	20,789	49,703	62,037	590	1,122	2,340
West Africa	44,333	91,899	205,737	412	952	2,466
East Africa	12,740	49,218	75,156	221	684	1,632
Southern Africa	41,287	60,752	81,827	696	1,091	1,650
Asia	261,114	1,205,116	1,797,894	11,418	31,837	46,656
West Asia	24,427	70,676	125,465	457	1,606	2,329
South Asia	32,024	72,573	190,931	1,433	2,569	5,691
Southeast Asia	9,028	37,405	103,249	441	1,692	4,102
East Asia	141,469	521,971	734,694	7,837	13,720	17,262
China	54,166	502,491	643,555	1,250	12,250	17,272
WORLD TOTAL	2,063,553	5,358,595	7,390,043	47,163	108,510	148,039

Sources: Boyce, J. K. and R. E. Evenson, National and International Agricultural Research and Extension Programs. (New York: The Agricultural Development Council, 1975); and M. Ann Judd, James K. Boyce, and Robert E. Evenson, "Investing in Agricultural Supply" (Discussion Paper No. 442, Yale University Economic Growth Center, 1983).

Table 2: Agricultural extension expenditures and workers

Region/Subregion	Expenditures (000 Constant 1980 US$)			Workers (Scientist-years)		
	1959	1970	1980	1959	1970	1980
Western Europe	234,016	457,675	514,305	15,988	24,388	27,881
Northern Europe	112,983	187,144	201,366	4,793	5,638	6,241
Central Europe	103,082	199,191	236,834	7,865	13,046	14,421
Southern Europe	17,950	71,340	76,105	3,330	5,704	7,219
Eastern Europe and USSR	367,329	562,935	750,301	29,000	43,000	55,000
Eastern Europe	126,624	191,460	278,149	9,340	15,749	21,546
USSR	240,705	371,475	472,152	19,660	27,251	33,454
North America and Oceania	383,358	601,950	760,155	13,580	15,113	14,966
North America	332,892	511,883	634,201	11,500	12,550	12,235
Oceania	50,466	90,067	125,954	2,080	2,563	2,731
Latin America	61,451	205,971	396,944	3,353	10,782	22,835
Temperate South America	5,741	44,242	44,379	205	1,056	1,292
Tropical South America	47,296	136,943	294,654	2,369	7,591	16,038
Caribbean and Central America	8,414	24,786	57,911	779	2,135	5,505
Africa	237,883	481,096	514,671	28,700	58,700	79,875
North Africa	84,634	176,498	172,910	7,500	14,750	22,453
West Africa	53,600	181,324	204,982	9,000	22,000	29,478
East Africa	39,496	86,096	106,030	9,000	18,750	24,211
Southern Africa	60,153	37,178	30,749	3,200	3,200	3,733
Asia	143,876	412,937	507,113	86,900	142,500	148,780
West Asia	28,211	97,315	119,780	7,000	18,800	16,535
South Asia	56,422	87,727	82,194	57,000	74,000	80,958
Southeast Asia	19,747	55,441	63,959	9,500	30,500	33,987
East Asia	39,496	172,454	241,180	13,400	19,200	17,300
China	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
WORLD TOTAL	1,427,913	2,722,564	3,443,489	177,521	294,483	349,337

Source: Boyce, J. K. and R. E. Evenson, National and International Agricultural Research and Extension Programs. (New York: The Agricultural Development Council, 1975); and M. Ann Judd, James K. Boyce, and Robert E. Evenson, "Investing in Agricultural Supply" (Discussion Paper No. 442, Yale University, Economic Growth Center, 1983).

Table 3: Research and extension expenditures as a percent of the value of agricultural product

Subregion	Public Sector Agricultural Research Expenditures			Public Sector Agricultural Extension Expenditures		
	1959	1970	1980	1959	1970	1980
Northern Europe	.55	1.05	1.60	.65	.85	.84
Central Europe	.39	1.20	1.54	.29	.42	.45
Southern Europe	.24	.61	.74	.11	.35	.28
Eastern Europe	.50	.81	.78	.32	.36	.40
USSR	.43	.73	.70	.28	.32	.35
Oceania	.99	2.24	2.83	.42	.76	.98
North America	.84	1.27	1.09	.42	.53	.56
Temperate South America	.39	.64	.70	.07	.50	.43
Tropical South America	.25	.67	.98	.34	.71	1.19
Caribbean and Central America	.15	.22	.63	.09	.18	.33
North Africa	.31	.62	.59	1.27	2.21	1.71
West Africa	.37	.61	1.19	.58	1.24	1.28
East Africa	.19	.53	.81	.67	.88	1.16
Southern Africa	1.13	1.10	1.23	1.64	.67	.46
West Asia	.18	.37	.47	.25	.57	.51
South Asia	.12	.19	.43	.20	.23	.20
Southeast Asia	.10	.28	.52	.24	.37	.36
East Asia	.69	2.01	2.44	.19	.67	.85
China	.09	.68	.56	n.a.	n.a.	n.a.
COUNTRY GROUP*						
Low-Income Developing	.15	.27	.50	.30	.43	.44
Middle-Income Developing	.29	.57	.81	.60	1.01	.92
Semi-industrilized	.29	.54	.73	.29	.51	.59
Industrialized	.68	1.37	1.50	.38	.57	.62
Planned	.33	.73	.66	---	---	---
Planned (excluding China)	.45	.75	.73	.29	.33	.36

*For definition of Country Groups see Note 2.

Sources: USDA, Indices of Agricultural Production, various issues.

Table 4: Research and extension workers relative to the value of agricultural product

Subregion	SY's Per 10 Million (Constant 1980) Dollars Agricultural Product			Extension Workers per 10 Million (Constant 1980) Dollars Agricultural Product		
	1959	1970	1980	1959	1970	1980
Northern Europe	1.05	2.01	3.14	2.76	2.56	2.61
Central Europe	.80	1.21	1.56	2.19	2.77	2.73
Southern Europe	.93	1.17	.96	2.00	2.76	2.69
Eastern Europe	1.44	2.97	2.84	2.36	2.88	3.13
USSR	1.38	2.37	2.34	2.26	2.33	2.50
Oceania	1.91	2.64	2.43	2.26	2.17	2.11
North America	.84	.89	.84	1.44	1.31	1.08
Temperate South America	.46	1.15	1.32	.26	1.19	1.26
Tropical South America	.41	1.41	1.77	1.71	3.95	6.46
Caribbean and Central America	.53	.86	1.20	.82	1.53	3.12
North Africa	.91	1.44	4.24	18.83	28.45	22.23
West Africa	.33	.61	1.42	7.61	14.01	18.08
East Africa	.32	.77	1.76	16.28	22.41	26.64
Southern Africa	1.90	1.96	2.47	8.73	5.94	5.62
West Asia	.33	.84	.88	4.39	7.25	6.54
South Asia	.50	.65	1.29	20.83	19.51	19.53
Southeast Asia	.47	1.28	2.07	9.81	13.07	19.72
East Asia	3.80	5.29	5.72	6.57	7.05	6.13
China	.22	1.66	1.49	n.a.	n.a.	n.a.
COUNTRY GROUP*						
Low-Income Developing	.43	.67	1.40	18.14	18.61	20.43
Middle-Income Developing	.69	1.31	2.40	8.89	14.68	15.98
Semi-industrilized	.70	1.21	1.36	2.80	4.95	5.21
Industrialized	1.24	1.71	1.85	2.37	2.31	2.12
Planned	1.02	2.27	2.13	--	--	--
Planned (excluding China)	1.40	2.54	2.50	2.29	2.49	2.63

Sources: See Tables 1, 2 and 3.

Table 5: Expenditures per scientist year/extension worker

Region/Subregion	Research Expenditures per SY (000 Constant 1980 US$)			Extension Expenditures per Extension Worker (000 Constant 1980 US$)		
	1959	1970	1980	1959	1970	1980
Western Europe	44	73	76	15	19	18
Northern Europe	52	52	51	24	33	32
Central Europe	49	98	99	13	15	16
Southern Europe	25	52	78	5	13	11
Eastern Europe and USSR	32	29	29	13	13	14
Eastern Europe	34	27	27	14	12	13
USSR	31	31	30	12	14	14
North America and Oceania	90	127	127	28	40	51
North America	100	142	130	29	41	52
Oceania	52	85	117	24	35	46
Latin America	56	44	54	18	19	18
Temperate South America	85	56	53	28	42	34
Tropical South America	61	48	56	20	18	18
Caribbean and Central America	28	26	52	11	12	11
Africa	62	65	53	8	8	6
North Africa	35	44	27	11	12	8
West Africa	108	97	83	6	8	7
East Africa	58	72	46	4	5	4
Southern Africa	59	56	50	19	12	8
Asia	23	38	39	2	3	3
West Asia	53	44	54	4	5	7
South Asia	22	28	34	1	1	1
Southeast Asia	20	22	25	2	2	2
East Asia	18	38	43	3	9	14
China	43	41	37	n.a.	n.a.	n.a.
COUNTRY GROUP*						
Low-Income Developing	34	40	47	2	2	2
Middle-Income Developing	42	44	47	7	7	6
Semi-industrilized	41	45	46	10	10	11
Industrialized	55	80	93	16	25	29
Planned	33	32	31	–	–	–
Planned (excluding China)	31	25	30	13	13	14

Sources: See Tables 1 and 2.

Table 6: Ratios of basic to applied research

	Crop Research			Animal Research		
	1972-75	1976-79	1980-83	1972-75	1976-79	1980-83
Argentina	.13	.16	.08	.33	.59	.90
Brazil	.18	.19	.17	.66	.97	.91
Chile	.13	.13	.14	.38	.47	.59
Colombia	.15	.17	.22	.34	.61	.90
Mexico	.16	.10	.07	.32	.61	.90
Peru	.25	.49	.26	.23	.15	.44
Venezuela	.18	.14	.12	.51	.95	1.40
Ghana	.12	.07	.12	.25	.48	.53
Kenya	.15	.16	.18	.23	.71	.96
Nigeria	.14	.22	.19	.32	.59	.64
Sudan	.12	.04	.13	.58	.53	.60
Tanzania	.04	.07	.13	.93	1.11	1.11
Tunisia	.09	.05	.07	.57	1.18	2.10
Uganda	.10	.06	.23	.29	.97	1.79
Egypt	.14	.16	.16	.30	.41	.50
Sri Lanka	.08	.09	.09	.33	.36	.26
India	.21	.27	.26	.29	.43	.38
Indonesia	.05	.10	.08	.64	.92	.43
South Korea	.14	.15	.19	.58	.43	.61
Malaysia	.22	.21	.17	1.07	.61	.51
Pakistan	.10	.08	.09	.36	.43	.43
Philippines	.19	.16	.15	.51	.37	.30
Taiwan	.17	.29	.27	.76	.42	.30
Thailand	.17	.16	.18	1.37	1.97	2.68
Turkey	.41	.40	.28	.47	.73	.50
25 Developing Countries	.18	.22	.21	.37	.52	.54
All Developed Countries	.16	.15	.16	.23	.34	.30

Note: Ratios are based on counts of abstracted publications by class of journal defined as follows:

Basic Crop Journal: Helminthological Abstracts (B); Rev. Plant Pathology

Applied Crop Journals: Field Crops Abstracts, Herbage Abstracts, Horticultural Abstracts, Review of Applied Entomology, Soils and Fertilizers, Wood Abstracts.

Basic Animal Journal: Helminthological Abstracts, Protozoologist Abstracts, Review of Med. & Vet. Mycology

Applied Animal Journals: Animal Breeding Abstracts, Dairy Science Abstracts, Nutrition Abstracts (land and feeding), Rev. Applied Entomology (A), Vet. Bulletin and Index Vet.

Table 7: Research as a percent of the value of product, by commodity, average 1972-79 period, 25 countries

Commodity	REGION: Africa	Asia	Latin America	All Countries	Spending by International Centers	Ratio IARC Spending to Total
Wheat	1.30	.32	1.04	.51	.02	.04
Rice	1.05	.21	.41	.25	.02	.07
Maize	.44	.21	.18	.23	.03	.11
Cotton	.23	.17	.23	.21	--	--
Sugar	1.06	.13	.48	.27	--	--
Soybeans	23.59*	2.33	.68	1.06	--	--
Cassava	.09	.06	.19	.11	.02	.15
Field Beans	1.65	.08	.60	.32	.04	.11
Citrus	.88	.51	.57	.52	--	--
Cocoa	2.75	14.17*	1.57	1.69	--	--
Potatoes	.21	.19	.43	.29	.08	.21
Sweet Potatoes	.06	.08	.19	.07	--	--
Vegetables	1.56	.41	1.13	.73	--	--
Bananas	.27	.20	.64	.27	--	--
Coffee	3.12	1.25	.92	1.18	--	--
Groundnut	.57	.12	.60	.25	.005	.02
Coconut	.07	.03	.10	.04	--	--
Beef	1.82	.65	.67	1.36	.02	.02
Pork	2.56	.39	.60	1.25	.02	.02
Poultry	1.99	.32	1.12	1.64	--	--
Other Livestock	1.81	.89	.42	.71	--	--

Sources: M. Ann Judd, James K. Boyce, and Robert E. Evenson, "Investing in Agricultural Supply" (Discussion Paper No. 442, Yale University, Economic Growth Center, 1983); and USDA, Indices of Agricultural Production, various issues.

(*) Ratios are high because production is very low.

Table 8: Variables dictionary: research and extension investment analysis

	1972-75, 1976-80 Data		1962-82 Data	
	Mean	Std. Dev.	Mean	Std. Dev.
Endogenous (Choice) Variables:				
RES: Annual Spending (millions of 1980 dollars) by Commodity on Research	.9819	2.24	0.69	1.70
EXTEXD: Annual Spending (millions of 1980 dollars) on Extension (all commodities)	30.68	41.95	26.50	39.60
AID: Value of Aid from all Sources (millions of 1980 dollars)	25.00	17.67	n.a.	
NDONORS: The Number of Donors Providing Aid to Research	4.92	2.93	n.a.	
WBRES: World Bank Supported Research Programs (including national commodity)	10260	93445		
WBEXT: World Bank Supported Extension Programs (including national components)	10383	67300		
NHSTAFF: Number of IARC Scientists in Countries other than IARC Host Countires	3.88	3.52		
INTCR: Number of Joint IARC-Joint IARC-National Research Collaborative Research Agreements	.27	1.44		
BASIC: Ratio of Non-commodity Oriented Research to Commodity Research (See Table 7)	24.97	6.84		
CONGRU: A measure of Congruence Between Research Spending and Commodity Value $CONGRU = a - \sum (V_i - C_i)^2$ where V_i is research share, C_i is commodity share	.85	.13		
Exogenous Variables:				
Economic				
PROD: Value of Commodity Production (millions of 1980 dollars)	223.34	653.63	2113.62	8452.20
DIVER: Inverse of the Sum of Squared shares of Production in Commodity Agro-Climatic Combinations	0.4118	0.21	0.39	0.20
EXPRAT: Ratio of Expenditures per SMY to Expenditures per Extension Worker	10.14	9.99	9.44	9.10

(continued)

Table 8 (continued)

ARABLE: Ratio of Arable Land in the Current Period to Arable Land Six Year Earlier	1.09	.11	1.05	0.10
CINTSP: Cumulated Research expenditures on the Commodity in IARCs (millions of 1980 dollars)	6.17	13.78	4580.59	10148.80
International Transfer				
RESNSR: Research Scientist-years on the commodity by Neighboring Countries in similar Geo-climate regions (millions of 1980 dollars)	8.67	12.61	5.14	7.60
INTLOC: A Dummy Variable - 1 if the country is hosting the IARC undertaking research on the commodity	.019	.14	n.a.	
TOTALAREA: Total in crops in the country (000 ha)	10715.19	20902.44	10740.77	21558.60
Political - Economic				
IMPORTS: Value of Imports of the Commodity (millions of 1980 dollars)	16.39	71.68	n.a.	
EXPORTS: Value of Exports of the Commodity (millions of 1980 dollars)	24.46	100.75	n.a.	
UREARICE: Ratio of Prices Paid by Farmers for Urea Fertilizer to Prices received for rice	2.74	1.61	2.76	1.79
ECONAG: Percent of Economically Active Population Working in Agriculture	54.45	19.77	56.62	20.20
URBANPOP: Percent of the Total Population Living in Urban Areas of 100,000 population or more	34.53	21.58	32.05	21.10
VIOLD: Percent of Population Killed in Domestic Political Violence in Past Decade	.12(-10)	.12(-9)	0.00	0.00
Other				
T1: A Dummy Variable - 1 if time period is 1972-75	0.05	0.5	n.a.	
R1: A Dummy Variable = 1 if Country is Located in Asia	0.4	0.49	n.a.	
R2: A Dummy Variable = 1 if Country is Located in Africa	0.32	0.47	n.a.	

Table 9
Estimated Coefficient and Statistics of Two-Stage
Least Squares Equations for Determinants of Aid*

Independent Variable	DEPENDENT VARIABLE							
	AID	NDONORS	WBRES	WBEXT	NHSTAFF	INTCR	BASIC	CONGRU
Intercept	21.541	6.93	-44.15	-39.45	4.70	2.22	13.38	.264
	(2.02)	(4.49)	(2.55)	(1.46)	(2.36)	(1.76)	(3.38)	(4.17)
B001.RES*	.830	.022	1.31	.305	.112	-.010	.191	.0009
	(1.27)	(.23)	(1.24)	(.18)	(.92)	(.13)	(.78)	(.24)
B001.EXTEXP*	-.298	-.018	-.063	.316	.050	-.011	.087	-.0001
	(5.49)	(2.30)	(.71)	(2.29)	(4.91)	(1.71)	(4.35)	(.30)
TOTLAREA	.003	.0002	.003	.004	-.0003	.00005	-.0008	$1x10^{-6}$
	(10.46)	(5.49)	(6.72)	(5.53)	(6.10)	(1.49)	(6.84)	(.54)
AREADIV	-.010	-.0008	-.010	-.014	.001	-.0002	.0025	$1x10^{-6}$
	(9.65)	(5.63)	(6.18)	(5.44)	(6.72)	(1.43)	(6.89)	(.24)
URBARICE	-3.070	-.328	-4.82	1.96	.115	.057	2.48	.008
	(4.88)	(3.61)	(4.73)	(1.23)	(.98)	(.76)	(10.67)	(2.26)
ARABLE	-12.972	5.83	5.94	46.52	-.097	.618	10.35	.035
	(1.88)	(5.86)	(.53)	(2.66)	(.08)	(.76)	(4.06)	(.87)
ECONAG	.595	-.048	.946	.099	-.024	-.029	-.180	.005
	(4.50)	(2.49)	(4.41)	(.028	(.96)	(1.83)	(3.66)	(6.88)
URBANPOP	.119	-.131	.423	-.195	-.047	-.019	-.016	.007
	(1.12)	(8.49)	(2.45)	(.72)	(2.39)	(1.55)	(.41)	(11.40)
VIOLD	5547.1	2637.9	24723	68422	5399.7	-1200.7	22495	90.88
	(.66)	(2.22)	(1.85)	(3.27)	(3.51)	(1.23)	(7.38)	(1.86)
INTLOC	5.766	.510	-2.94	15.24	1.54	3.09	-5.29	-.048
	(1.40)	(.86)	(.44)	(1.46)	(2.01)	(6.35)	(3.47)	(1.98)
CINTSP	-.005	.0015	-.035	.066	-.005	.003	.050	.000
	(.11)	(.23)	(.46)	(.56)	(.62)	(.51)	(2.44)	(1.48)
AREACINT	$-4x10^{-7}$	$-4x10^{-8}$	$-8x10^{-7}$	$8x10^{-6}$	$-1x10^{-7}$	$1x10^{-6}$	$-3x10^{-8}$	$-4x10^{-9}$
	(.23)	(.13)	(.24)	(1.55)	(.33)	(5.49)	(.04)	(.32)
EXPRAT	-.675	-.010	-.563	-.322	.003	-.031	.151	-.000
	(4.35)	(.48)	(2.24)	(.82)	(.10)	(1.71)	(2.62)	(.88)
RESNSR	-	-	-	-	-	-	-.116	-.001
							(3.16)	(1.89)
F	23.55	29.53	24.03	37.68	10.42	9.33	15.64	22.24
R^2	.384	.438	.388	.4989	.216	.198	.308	.388

*Absolute values of asymptatic t-ratios in parentheses
The B001 rotation indicates that these variables are treated as endogenous variables (See Table 10).

Table 10

Estimated Determinants of Two Major Groups of Research and Extension Spending*

Independent Variables	Dependent Variable: Field Crop Research Spending (1)	(2)	Horticultural Crop & Livestock Research Spending (3)	(4)	National Extension Spending (5)	(6)
Intercept	2.69 (2.48)	2.36 (2.27)	3.08 (1.94)	3.37 (2.16)	43.01 (1.56)	75.72 (3.18)
PROD	.001 (2.98)	.001 (3.91	.005 (5.92)	.005 (5.65)	– –	– –
PROD2	$-1-2x10^{-7}$ (3.98)	$-1.2x10^{-7}$ (4.16)	$-1x10^{-6}$ (5.58)	$-1x10^{-6}$ (5.58)	– –	–
TOTLAREA	– –	– –	– –	– –	.005 (4.79)	.003 (4.21)
DIVER	1.09 (1.54)	.055 (.14)	.287 (.27)	1.17 (2.08)	9.15 (.28)	8.89 (1.11)
PRDIVER	.001 (1.17)	.0005 (.63)	−.005 (3.03)	−.004 (2.61)	– –	– –
AREADIV	– –	– –	– –	– –	−.014 (3.88)	−.007 (2.93)
UREARICE	.044 (.81)	.033 (.06)	−.125 (1.62)	−.088 (1.29)	−5.82 (2.16)	−5.16 (5.51)
ARABLE	.574 (1.03)	.493 (.91)	−1.20 (1.48)	−1.11 (1.38)	−2.51 (.17)	−19.88 (1.57)
ECONAG	−.060 (3.35)	−.039 (3.27)	−.015 (.58)	−.034 (1.91)	.223 (.23)	−.297 (1.09)
URBANPOP	−.035 (2.91)	−.023 (2.40)	−.013 (.75)	−.022 (1.50)	−.113 (.24)	−.309 (1.45)
EXPRAT	−.008 (1.05)	−.011 (1.45)	.054 (5.17)	.053 (4.83)	−1.87 (7.31)	−1.67 (7.85)
INTLOC	−.285 (.57)	−.095 (.19)	1.27 (.99)	.975 (.79)	– –	– –
INTSPLOC	.211 (1.12)	.185 (1.00)	.378 (.70)	.342 (.63)	– –	– –
PRDXPORT	$2x10^{-6}$ (5.71)	$2x10^{-6}$ (5.50)	$1x10^{-5}$ (10.85)	$1x10^{-5}$ (10.86	$3x10^{-5}$ (3.59)	$2.5x10^{-5}$ (3.35)
PRDMPORT	$1.7x10^{-6}$ (9.43)	$1.6x10^{-6}$ (9.53)	$7x10^{-5}$ (5.01)	$7x10^{-5}$ (5.04)	$-3x10^{-6}$ (.90)	$-3x10^{-6}$ (1.00)
RESNSR	.031 (3.35)	.024 (2.95)	.019 (2.38)	.023 (3.17)	−.179 (.58)	−.277 (1.66)
T1	.126 (1.03)	.048 (.42)	.239 (1.29)	.283 (1.57)	−9.19 (2.75)	2.87 (.66)
R1	−.451 (1.59)	−.156 (.55)	−.786 (1.88)	−.951 (2.32)	−3.42 (.38)	−4.23 (.76)
R2	.409 (1.26)	.204 (.70)	−.111 (.24)	.123 (.29)	25.02 (2.05)	34.59 (5.65)
CINTSP	−.002 (.42)	$2x10^{-5}$ (.00)	.026 (3.00)	.025 (2.90)	.018 (.14)	.086 (.93)
BOO1.AID	.027 (2.04)	– –	−.020 (1.02)	– –	.012 .01	– –
BOO1.WBRES	–	.006 (1.38)	– –	−.001 (.20)	– –	– –
BOO1.WBEXT	– –	– –	– –	– –	– –	.367 (3.30)
AREACINT	$1x10^{-6}$ (4.29)	$1x10^{-6}$ (4.07)	$1.6x10^{-6}$ (6.15)	$1.6x10^{-6}$ (6.05)	$3.7x10^{-6}$ (1.04)	$2.5x10^{-7}$ (.08)
R^2F	43.17	45.03	32.16	32.36	35.31	47.25
R^2	.64	.65	.59	.60	.55	.62

*Absolute values of asymptotic t-ratios in parentheses.

Table 11: Estimated determinants of commodity-specific national agricultural research and extension spending annual data 1963-80 - 25 countries

Dependent Variable: Spending in 1980 Dollars

Independent Variables	Maize	Sorghum	Millet	Rice	Wheat	Cereals	Beans	Cassava
PRODUCTION	0.000024*	0.00013**	0.00074**	0.00041**	0.00047**	0.00023**	-0.00168**	0.000024**
AREA	0.000045*	-0.000013	-0.00033**	-0.00056**	-0.00031**	-0.00019**	0.00135**	-0.00008**
IARCSPENDING	0.000009**	0.000022*	0.000040	0.0000067*	0.000069**	0.000016**	0.0000065	-9.517E-07
UREARICEPRICE	-0.0302	-0.0503**	-0.0387*	-0.0259	0.2594**	-0.0971**	-0.0188	-0.0452**
RESNEIGHBORS	0.0217**	0.0307**	0.0355**	0.0121**	-0.0556**	0.0129**	0.0434**	0.0672**
PROPAGRWKRS	-0.0132**	-0.0124**	-0.0177**	-0.0599**	-0.0079	-0.0286**	-0.0059*	-0.0035**
URBANIZATION	-0.0049	-0.0064*	-0.0078*	-0.0539**	0.0241**	-0.0266**	-0.00049	-0.00092
RESEXTPRICE	0.0076*	-0.0109**	-0.0094*	0.0361**	0.0702**	0.0173**	-0.0236**	0.0016
LAND EXHAUSTION	-0.3481	-0.0993	-0.2721	0.0174	0.5191	-0.1608	-0.3485	-0.7014**
DIVERSITY	0.6024**	0.4825**	0.7590**	1.0257**	-0.2170	0.3572	0.4242**	-0.0632
PROD X DIVERSITY	0.000015**	0.000019**	0.000022**	0.000038**	0.000054**	0.000017**	0.000016**	-0.0000013*
POLVIOLENCE	-696.59**	-555.88**	-616.31**	-2016.22*	-3383.09**	-649.20**	-548.93**	-113.82
R^2	0.5554	0.5904	0.6905	0.7575	0.8179	0.6859	0.7526	0.2946
F	48.94	56.46	61.12	122.32	175.95	173.45	119.15	16.36

Independent Variables	Groundnuts	Potatoes	Sweet Potatoes	Staples	Soybeans	Sugar	Commercial Crops
PRODUCTION	0.00014**	-0.00007**	0.0000012	-0.000028**	0.000082	0.000043**	-0.000014**
AREA	-0.000031	0.0033**	0.00011	0.00023**	0.0011**	-0.0018**	0.0014**
IARCSPENDING	0.000026	0.0000042**	0.000019**	0.000006**	n.a.	n.a.	n.a.
UREARICEPRICE	-0.0144	0.0238**	-0.0426**	-0.0240**	-0.0206	0.0556**	0.0231*
RESNEIGHBORS	0.0358**	-0.0069	-0.0637**	0.0399**	0.0218**	0.0118*	0.0182**
PROPAGRWKRS	-0.0052**	-0.0122**	-0.0030*	-0.0048**	-0.0107**	-0.0250**	-0.0185**
URBANIZATION	-0.0021	-0.0054**	-0.0052**	-0.0015	-0.0081*	-0.0047	-0.0060**
RESEXTPRICE	0.0052*	-0.0060**	0.0019	-0.0066**	-0.0179**	0.0023	-0.0088**
LAND EXHAUSTION	0.0086	0.2074	-0.1212	-0.0386	0.6474	0.0393	0.3016
DIVERSITY	0.4257**	-0.3061**	0.0131	0.0855	0.4924**	1.0267**	0.7411**
PROD X DIVERSITY	0.0000057**	-0.000004**	2.967E-07	0.0000059**	0.000021**	0.000023**	0.000021**
POLVIOLENCE	-181.44*	72.86	-39.83	-250.59**	-1378.33**	-547.79**	-969.57**
R^2	0.4169	0.6297	0.1432	0.3297	0.8886	0.7037	0.8203
F	28.00	66.61	6.55	98.45	341.67	101.67	396.02

*T ratio between 1.5 and 2.0

**T ratio greater than 2.0

Table 12: Calculated impacts on national research and extension investment (millions of 1980 dollars)

Policy Variable	Annual Research Spending Million Dollars (from Table 10)		
	Field Crops	Livestock and Horticulture Crops	Extension Spending
1 million $ added to commodity production (elasticity)	.00164(.551)	.00396(.584)	.00624(.592)
1 million $ added to commodity exports	.000634	.002277	.00695
1 million $ added to commodity imports	.000472	.01253	-.000937
1 added SY by agro-climatic neighbor	.0305	.01901	-.1792
Ten percent decline in research costs per SY or ten percent spending rise in extension costs per EW (± one s.d.)	.00005 to -.00017	-.00064 to -.00042	.00188 to .00145
Quantity Elasticity (± one s.d.)	-1.051 to -1.191	-.474 to -.652	1.456 to -1.591
1 million dollars added to IARC research stock			
a) first year	.229	1.084	.105
b) after 10 years	2.290	10.840	1.050
1 million dollars general aid research	1.194	-.858	+.047
World Bank aid (to research or extension)	.285	-.063	1.468

	Research Spending by Commodity (from Table 11)									
	Maize	Sorghum	Millet	Rice	Wheat	Beans	Cassava	Ground nuts	Potatoes	Sweet Potatoes
1 added SY by agro-climatic neighbor	.0217	.0307	.0355	.0121	-.0506	.0434	.0672	.0358	-.0069	-.0637
Ten percent decline in urea-rice price	.030	.050	.039	.026	-.0259	.019	.045	.015	-.024	.043
1 million dollars added to IARC investment										
a) first year	.225	.550	1.000	.168	1.725	.162	-.000	.650	1.050	.475
b) after 10 years	2.250	5.500	10.00	1.680	17.250	1.620	-.000	6.500	10.500	4.750

NOTES

1. See Oram and Blindish, 1981 for a detailed discussion of expenditures in the international system.

2. The development of national research and extension systems is documented in Judd, Boyce and Evenson, 1984, and Kislev and Evenson, 1975.

3. Judd, Boyce and Evenson, 1984, provide details. The Appendix to this paper provides country tables summarizing changes in national system development.

4. The definition of country groups is that used by The World Bank in its World Development Report, 1984.

5. See Table 6 for a list of countries. Taiwan is excluded from this list.

6. Diversity is measured at the country level. It is defined as $DIVER = \sum_{i=1}^{n} S_i^2$ where S_i is the share in total agricultural product of the ith crop agro-climatic combination.

7. Many studies show that while consumers are the major gainers from agricultural research, they are not strong supporters of research (see Evenson, 1980, and Rose-Ackerman and Evenson, 1983).

8. The variable BASIC does not necessarily measure "basic" research. Noncommodity oriented research can include farming systems and economic research.

9. The CINTSP variable is a naturally exogenous variable since IARC spending is undertaken in a specific location and thus cannot respond to country specific conditions. It can, of course, respond to commodity conditions.

10. Note that this is not the area of the crop on which the research observation is made, but the area of all crops.

11. Note that

$$dC(PQ) = dP(0) + dQ(P)$$

$$\frac{d(PQ)}{dP} = Q + \frac{dQ}{dP}(P)$$

$$\frac{dPQ}{\alpha P} \cdot \frac{P}{PQ} = \frac{PQ}{PQ} + \frac{dQ}{\alpha P} \cdot \frac{P}{Q} = 1 + \eta$$

12. The World Bank is a relative late-comer to the research and extension support field. It provided very little support prior to 1974. Its lending since then for research and extension has been:

	Research	Extension
1974-6	227.5 $million	314.4 $million
1977-80	271.9 $million	1033.0 $million
1981-4	890.0 $million	740.5 $million

As can be seen, the World Bank became a major factor in extension support after 1977 and a major factor in research after 1980.

REFERENCES

Boyce, James K. and Robert E. Evenson. "National and International Agricultural Research and Extension Programs," Agricultural Development Council, 1975.

Evenson, Robert E. "Observations on Brazilian Agricultural Research and Productivity," Revista De Economia Rural Vol. 20, No. 3, July/Sept. 1982.

Evenson, Robert E., P. Waggoner, and V.W. Ruttan. "Economic Benefits from Research: An Example from Agriculture," Science 205, Sept. 1979.

Guttman, Joel. "Interest Groups and the Demand for Agricultural Research," Journal of Political Economy 86, June 1978.

Jamison, D.T. and L.J. Lau. Farmer Education and Farm Efficiency. Baltimore, Johns Hopkins University Press, 1982.

Judd, M. Ann, James K. Boyce, and Robert E. Evenson. "Investing in Agricultural Supply," Economic Development and Cultural Change forthcoming, E.G.C. Discussion Paper 442, Yale University, Economic Growth Center, 1983.

Kislev, Yoav and Robert Evenson. "Investment in Agricultural Research and Extension, An International Survey," Economic Development and Cultural Change 23, April 1975.

Oram, Peter and Vishva Bindlish. "Resource Allocations to Agricultural Research: Trends in the 1970's (A Review of Third World Systems)," Washington, D.C., International Food Policy Research Institute, 1981.

Otsuka, Keijiro. "Public Research and Price Distortion: Rice Sector in Japan," Ph.D. Dissertation, University of Chicago, 1979.

Rose-Ackerman, Susan and Robert E. Evenson. "Public Support for Agricultural Research and Extension: A Political-Economic Analysis," Economic Growth Center, Yale University, 1982.

Ruttan, Vernon W. Agricultural Research Policy. Minneapolis, University of Minnesota Press, 1984.

World Bank. "World Development Report," Washington, D.C. 1983.

CHAPTER TWO

The Evolution of Farming Systems and Agricultural Technology in Sub-Saharan Africa

by

Hans P. Binswanger and Prabhu L. Pingali

THE EVOLUTION OF FARMING SYSTEMS AND AGRICULTURAL TECHNOLOGY IN SUB-SAHARAN AFRICA*

Hans P. Binswanger** and Prabhu L. Pingali***

Today we honor Vernon Ruttan for one specific and two more general achievements. The specific achievement is his book on Agricultural Research Policy. Following the lead established by T.W. Schultz and Zvi Griliches, this book not only discusses the contribution which scientific agricultural research can make to development, but provides detailed guidance on how to institutionalize and manage agricultural research and how to focus it on high payoff activities which capitalize on a country's or region's abundant resources while conserving its scarce ones.

The first more general achievement (shared with collaborators such as Hayami, Binswanger and others) is the resurrection of the theory of induced technical change from the obscurity into which an intellectual misconception of W.E.G. Salter had placed it, and to show empirically its relevance for explaining success and failure in agricultural development. The second general achievement is Ruttan's theory of induced institutional change, by which the same economic forces shape the evolution of institutions which influence the rate and direction of technical change: final demand, constraints and opportunities implied by factor endowments, as well as a number of other material forces. Most, but not all, of the empirical work of Ruttan and his collaborators, concentrates on technical changes arising from science-based research and the mechanical and chemical agroindustries, and on the institutional changes observed in "modern" agriculture.

Vernon Ruttan was not alone in emphasizing the endogeneity of technical and institutional change in agriculture. Ester Boserup, whose work was badly neglected by agricultural economists, dealt with the same two topics, but in the context of what T.W. Schultz called "traditional" agriculture. She focused on farmer-generated changes in farming systems, technologies and land rights, which over the course of history have been independently developed in numerous locations across the world along systematic lines. Her work is particularly relevant today for understanding the pattern of agricultural development in sparsely settled areas of Sub-Saharan Africa. But even elsewhere the relevance of Boserup's work lies in the continued complementarity of farmer-generated innovations with science- and industry-generated innovations.

Boserup's work was badly neglected, perhaps because she focused solely on population density as the main driving force of agricultural intensification. In this paper we briefly discuss other important determinants of agricultural intensification such as: transport infrastructure, external final demand, and the endogenous distribution of population across different agroclimatic zones. We treat the overall rate of population growth of a country as exogenous for its enquiry. Nevertheless and in accordance with Boserup, we recognize that the rate of population growth has important endogenous components. These endogenous components are not, however, relevant for the topic at hand, as the rate of growth itself is exogenous to the farmer. We then discuss the consequences of agricultural intensification.

In Boserup's (1965) analysis, intensification has eight principal effects: (1) it reduces fallow period; (2) it increases investment in land; (3) it encourages the shift from hand hoe cultivation to animal traction; (4) it encourages soil fertility maintenance via manuring; (5) it reduces the average cost of infrastructure; (6) it permits more specialization in production activities; (7) it induces a change from general to specific land rights; (8) it reduces the per capita availability of common property resources (forest, bush and/or grass fallows, communal pastures). To these effects we add agroclimatic and soils considerations which were almost totally neglected by her, but were emphasized in the seminal work of Hans Ruthenberg on Farming Systems in the Tropics. Our own

---

*Craig Lissner and Hans Jansen assisted in data assembly and analysis. Their contribution is gratefully acknowledged.

**Hans P. Binswanger is Senior Economist and Unit Chief in the Agricultural and Rural Development Department, Research Unit, The World Bank.

***Prabhu L. Pingali is a Consultant with the Agricultural and Rural Development Department, Research Unit, The World Bank.

particular addition is a discussion of the systematic changes in land-use patterns and soil quality preferences associated with intensification.

The discussion in this paper is illustrated by two-way frequency charts using data from 56 villages in 10 countries of Sub-Saharan Africa and India. This data was collected in 1983-84 using the group interview technique as part of a larger research effort on agricultural mechanization and the evolution of farming systems in Sub-Saharan Africa. Although not substitutable for rigorous empirical testing these frequency tables provide preliminary support for the proposition presented in the paper.

DETERMINANTS OF THE INTENSITY OF LAND-USE

Population Density

The existence of a positive correlation between the intensity of land-use and population density has been shown by Boserup (1965, 1980). She argues from the premise that during the neolithic period forests covered a much larger part of the land surface than today. The replacement of forests by bush and grassland was caused by (among other things) a reduction in fallow periods due to increasing population densities.

> "The invasion of forest and bush by grass is more likely to happen when an increasing population of long fallow cultivators cultivate the land with more and more frequent intervals." (Boserup, 1965, p. 20)

Table 1 (page 48) presents the relationship between population density and the intensity of the agricultural system. At very sparse population densities, up to perhaps four persons per square kilometer, the prevailing form of farming is the forest fallow system. A plot of forest land is cleared and cultivated for one or two years and then allowed to lie fallow for 20 to 25 years. This period of fallow is sufficient to allow forest regrowth. An increase in population density will result in a reduction in the period of fallow and eventually the forest land degenerates to bush savannah. Bush fallow is characterized by cultivation of a plot of land for two to six years followed by six to ten years of fallow. The period of fallow is too short to allow forest regrowth. Increasing population densities are associated with longer periods of continuous cultivation and shorter fallow periods. Eventually the fallow period becomes too short for anything but grass growth. The transition to grass fallow occurs at population densities of around 16-64 persons per square kilometer. Further increases in population result in the movement to annual and multicropping, the most intensive systems of cultivation. All along the course of this transition farmers make investments in land. Initially, they are confined to land clearing and destumping. Drainage investments, leveling, erosion control investments and eventually irrigation investments follow. The capacity to double or triple crop usually requires very large investments.

Since the turn of this century we have observed a substantial increase in the natural rate of population growth across the world, mainly due to a sharp decline in the death rates caused by rapid advances in public health services. At the worldwide level, and at the level of a specific country, the decline in arable land per capita must be attributed primarily to this general increase in population. Within a country and within regions, however, population concentrations vary by soil fertility, altitude and market accessibility. These intra-country variations are briefly discussed below using examples primarily from Sub-Saharan Africa. Table 2 (page 49) provides the major causes and consequences of population concentrations.

Soil Fertility

The marginal productivity of labor is relatively higher on more fertile soils and hence one would expect immigration from less endowed areas leading to reductions in cultivable areas per capita. Ada district, Ethiopia, Nyanza Province, Kenya and the southern province of Zambia are a few examples of fertile areas that are relatively densely populated and intensively cultivated. High altitude areas are similarly densely populated due to immigration from the lowlands because of lower disease incidence (notably malaria and sleeping sickness). Population concentrations on the Ethiopian and Kenyan Highlands are popular examples of this phenomenon.

Given suitable soil conditions, areas with better access to markets, either through transport networks or those in the proximity of urban centers, will be more intensively cultivated. Intensification occurs due to two reasons:

a. Higher prices and elastic demand for exportables implies that marginal utility of effort increases, hence farmers in the region will begin cultivating larger areas; and

b. Higher returns to labor encourage immigration into the area from neighboring regions with higher transport costs.

Intensive groundnut production in Senegal, maize production in Kenya and Zambia, and cotton production in Uganda have all followed the installation of the railway and have been mainly concentrated in areas close to the railway line. Similarly, agricultural production around Kano, Lagos, Nairobi, Kampala and other urban centers is extremely intensive compared to other parts of these countries. It should be noted that agricultural intensification in response to improved market access could occur even under low population densities due to individual farmers expanding their area under marketed crops. The consequences of intensification in these circumstances do not differ from those in areas with high population densities.

Soil fertility and transport infrastructure interact in two ways. First, a large region of high quality land provides incentives for the construction of infrastructure to exploit that potential. Second, where roads or railway lines are built for non-agricultural purposes such as to the copper mines of Zambia, they will cross both fertile and infertile areas. The impetus for intensification, however, is felt only in the fertile areas, as the infertile areas are unable to compete in output markets due to their higher costs of production.

Other Causes

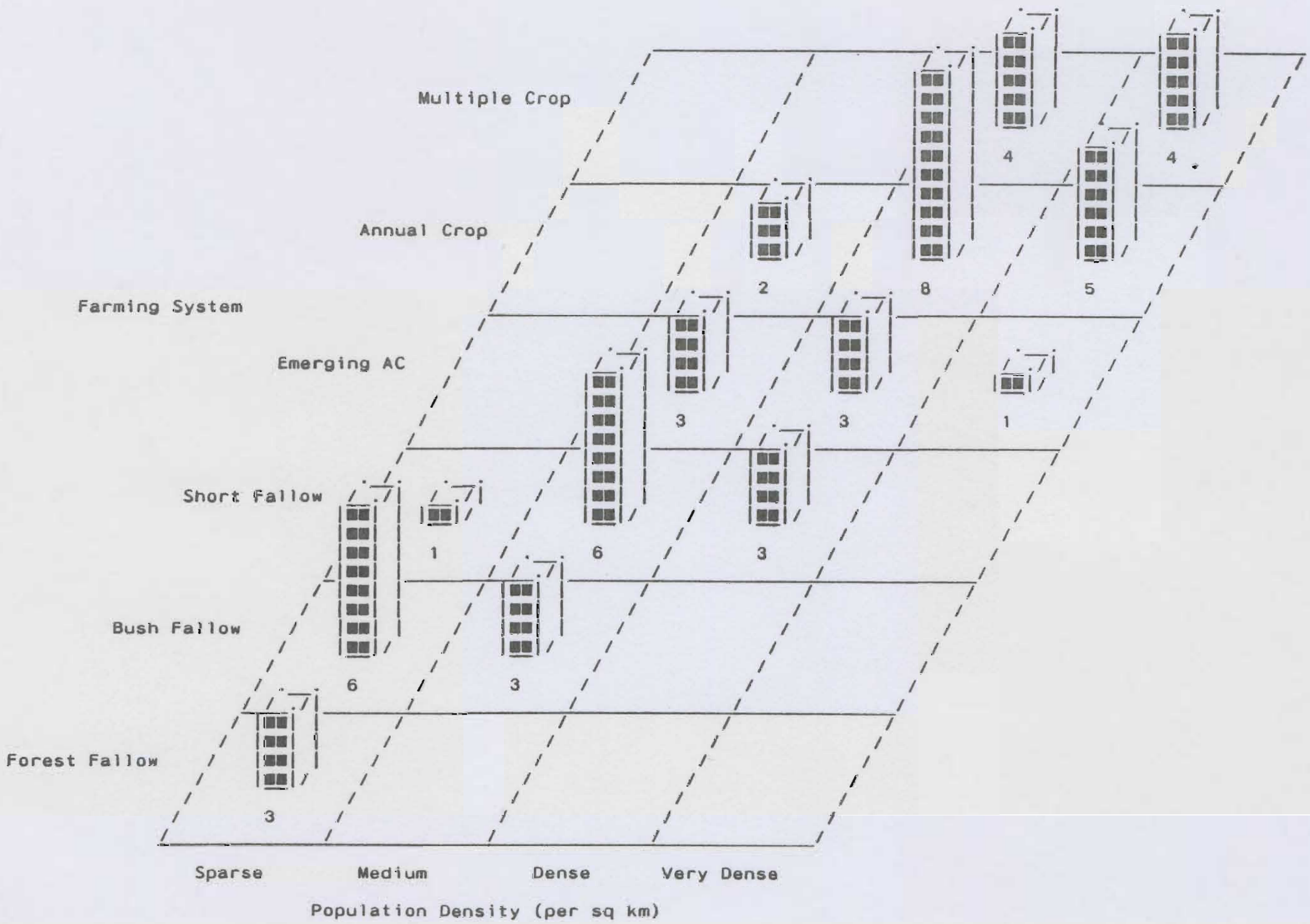
Finally, it should be noted that inter- and intra-country variations in population densities, especially in Sub-Saharan Africa, have historically been caused by tribal warfare and slave trade resulting in population concentrations in relatively inaccessible highlands. Population concentration on the high plateau of Rwanda and Burundi was in response to the incursion of slave traders and for health reasons. Similar migrations from the lowlands to the Mandara Mountains in Cameroon, the Jos Plateau in Nigeria and the Rift Valley in Kenya and Tanzania have been based on the desire for personal security. Subsequent natural population growth has made many of these areas the most densely populated parts of Africa.

The above discussion leads to the broad generalization that for given agroclimatic conditions, increases in population density and/or improvements in market access will gradually move the agricultural system from forest fallow to annual cultivation and eventually to multi-cropping. Empirical support for these two determinants of agricultural intensification is provided by means of two-way frequency charts using our data set from Sub-Saharan Africa.

Graph 1 presents the positive relationship between population density and farming intensity. Forest and bush fallow systems are predominant under sparse population densities (less than 15 persons/km^2), 9 of the 10 sparsely populated areas in our sample practice these systems of farming, the remaining case is under short fallow. In the medium density group (16-50 persons/km^2) one begins to observe the transition to more intensive systems of farming. Here the majority of the cases (9 of 14) fall in the short fallow and emerging annual cultivation categories, there are no forest fallow cases at this density level and bush fallow tapers off to 3 out of 14 cases. In the dense population groups (51-100 persons/km^2) annual and multi-crop cultivation are well established with 12 of 18 cases in these systems and three cases emerging towards annual cultivation. There are three remaining short fallow cases presumably at the lower end of the population density group. Nine of the ten cases in the very dense population group (greater than 100 persons/km^2) practice annual or multi-crop cultivation, with the remaining case emerging towards annual cultivation.

The classification of our cases shows a very definite trend towards agricultural intensification as population densities increase. Neither in our field visits nor during our literature survey have we come across any cases of sparsely populated areas under annual cultivation or cases of very densely populated areas under forest or bush fallow systems. Presumably, the former could occur under sparse population densities if market access is excellent, while the latter could not occur even under poor market access conditions.

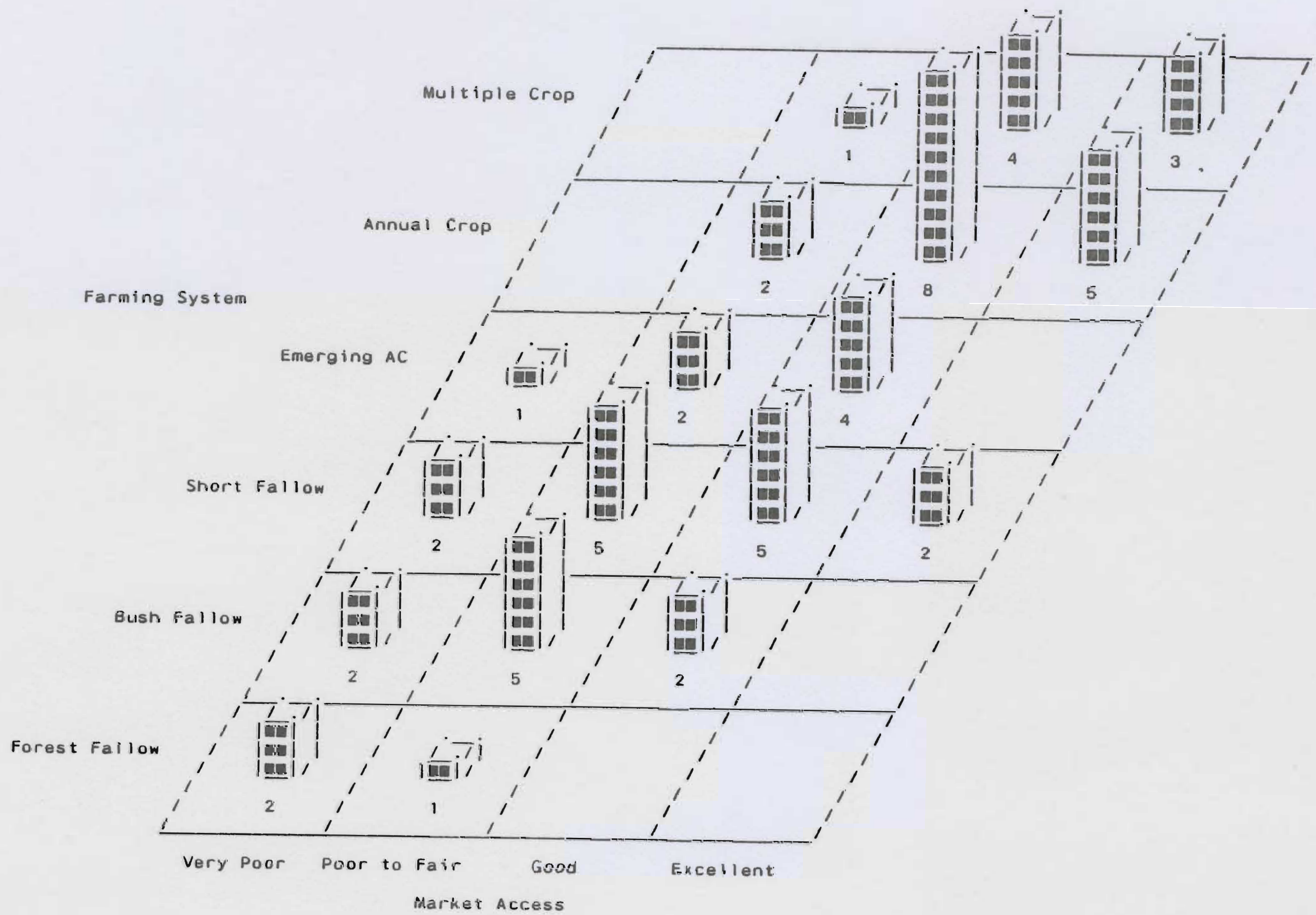
Graph 1: Population Density and the Intensification of Farming Systems



The positive relationship between the ease of market access and farming intensity is shown in Graph 2. For a given population density an improvement in market access results in further intensification of the farming system. Under very poor market access mainly extensive forms of farming such as forest and bush fallow are practiced. Under fair market access we observe 9 of the 16 cases with intensities of short fallow and above. Among the cases where market access is good, 22 of the 24 cases are at intensities of short fallow and above. Where market access is excellent, 9 of the 10 cases are under annual or multi-crop cultivation and the remaining case is approaching permanent cultivation.

Graph 3 presents the agroclimatic constraints on the process of intensification. At an annual average rainfall of less than 750 mm, which includes the low rainfall semi-arid and the arid zones, one does not see forest and bush fallow cultivation. This is due to: (a) the slow rate of vegetative regrowth under arid conditions which does not permit forest regeneration even at low densities, and (b) cultivation being concentrated mainly on the lower slopes and depressions which are relatively more responsive to intensification investments. Under high rainfall conditions such as the humid tropics (rainfall greater than 1,200 mm) one tends to observe a predominance of forest and bush fallow cultivation. Permanent cultivation of field crops under humid conditions is hard to sustain due to high levels of leeching and soil acidification problems. The exceptions in the graph are from the highlands of Kenya and Ethiopia which, of course, do not suffer from the same problems as the humid lowlands and therefore can be cultivated permanently. Sustained permanent cultivation

Graph 2: Market Access and the Intensification of Farming Systems



of field crops is most feasible in the medium rainfall zones (751-1,200 mm), which is consistent with our empirical evidence.

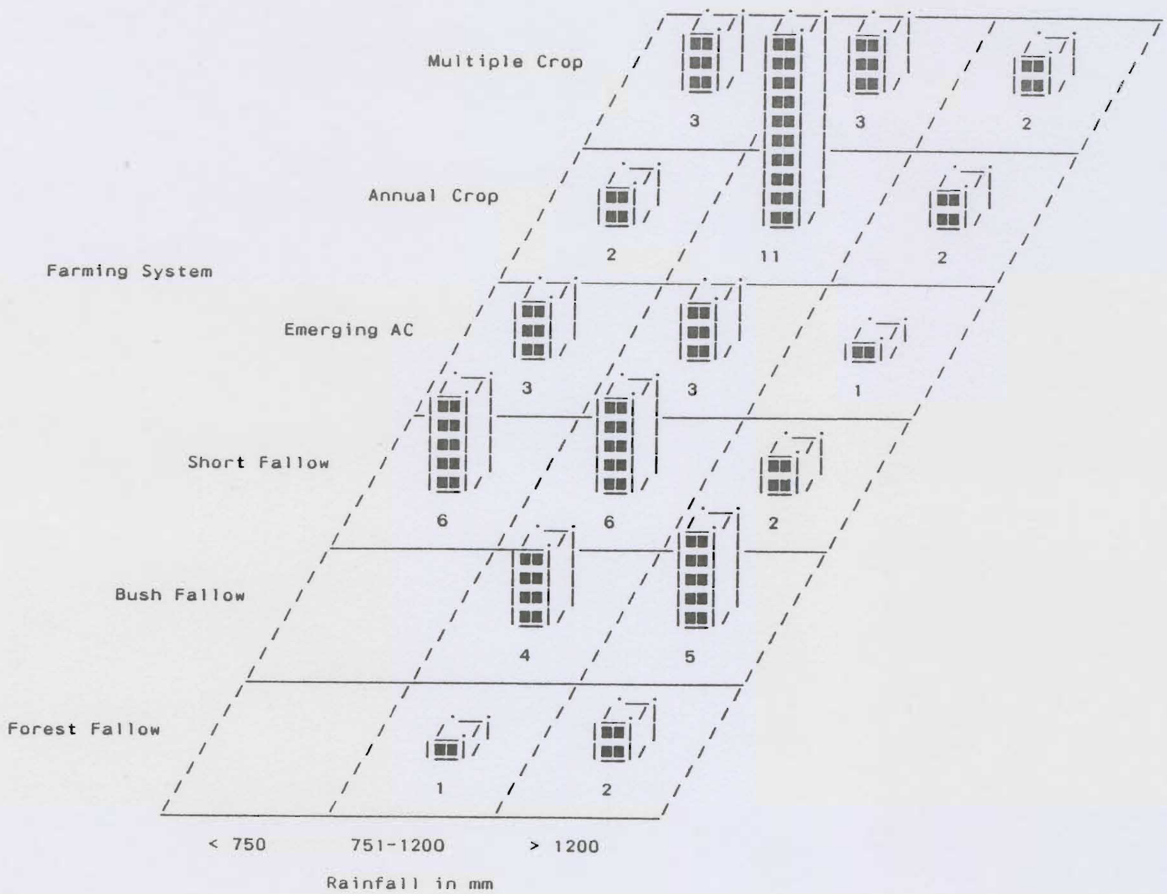
THE CONSEQUENCES OF AGRICULTURAL INTENSIFICATION

Agricultural Intensification and Soil Preferences

The intensification of agricultural systems is constrained by climatic and soil factors. Table 1 illustrates the impact of climatic factors on the intensification of the agricultural system. For given agroclimatic conditions the extent of intensification is conditional on the relative responsiveness of the soils to inputs associated with intensive production such as land improvements, manure and fertilizers. The responsiveness of intensification is generally higher on soils with higher water and nutrient holding capacity. This is primarily because higher water holding capacity reduces drought risk. Water holding capacity is higher the deeper the soils and the higher their clay content. It is low on shallow sandy soils.

Figure 1 (page 6) presents a stylized picture of the differences in soil types across a toposequence for given agroclimatic conditions. Soils on the upper slopes are relatively light and easy

Graph 3: Agroclimatic Zones and the Intensification of Farming Systems

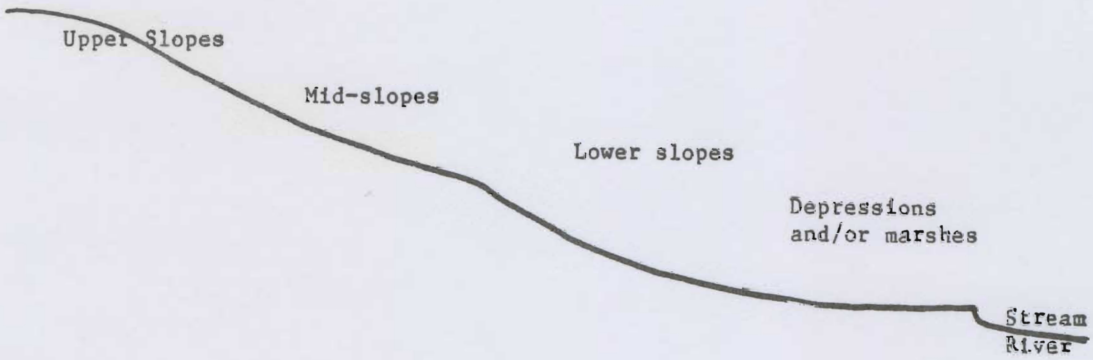


to work by hand, and tillage requirements are minimal. The clay content and hence the heaviness of the soils increases as one goes down the toposequence, consequently power requirements for land preparation increase. Movement down the slope also reduces yield risks due to increased water retention capacity of the soils. The soils are heaviest in the depressions and marshes at the bottom of the toposequence. These bottom lands or bas fonds are often extremely hard to prepare by hand and are often impossible to cultivate in the absence of investments in water control and drainage. The extremely high labor requirements for capital investments and land preparation make the bottom lands the least preferred for cultivation under low population densities, and they are often found to be under fallow. As population densities increase, however, the bottom lands become intensively cultivated due to the relatively higher returns offered to labor and land investments, especially in rice cultivation. Also, as population densities increase, labor supply increases, making it possible to undertake the labor intensive investments in irrigation, drainage, etc.

Soil type differences across a toposequence that are characterized here could be micro-variations limited to a few hundred meters or a few kilometers, or they could be macro-variations where entire regions are part of one toposequence level. For example, large parts of northeastern Thailand can be characterized as upper slopes, although there are, of course, depressions in northeast Thailand within micro toposequences. The central plains of Thailand are largely flood plains and have the characteristics of bottomlands and marshes.

Figure 1

Toposequence and Soil Type



Relatively Light Relatively Risky	Intermediate in case of cultivation and risk	Heavy low risk	Must be prepared and sometimes requires investment in water control & drainage. Ideal for wetland rice

Power requirements for land preparation	Low → High
Response to intensification investments and inputs	Low → High
Erodability	High → Low

Preferences for cultivating different points of the toposequence is also dependent on the agro-climatic conditions. Table 3 (page 49) presents soil preferences by farming intensity and agroclimatic zones. Under arid conditions lower slopes and depressions are the only land which can be cultivated because only here is water retention capacity sufficient to sustain a crop at very low rainfall levels. This is the reason for the intensive cultivation systems of an oasis type which one observes in arid areas even under low population densities. Pockets of arid farming in primarily pastoral areas of Botswana are a good example of this phenomenon.

Under semi-arid conditions the midslopes are the first to be cultivated. As population densities increase, cultivation replaces grazing on the lower slopes and eventually in the depressions. Power sources for tillage are first used in the bottom lands, generally around the time when population pressure makes these lands valuable for cultivation. The reversal of land preferences is quite dramatic. In the semi-arid zones of Africa, where population density is low, the lower slopes and depressions are left for grazing and contribute only minimally to food supply. In the semi-arid zones of India, on the other hand, the depressions are intensively cultivated usually with rice, using elaborate irrigation systems and animal traction.

Yield risks due to low water availability are not a major problem in the sub-humid and humid tropics, hence one finds cultivation starting at the upper slopes and gradually moving downwards as population pressure increases. At high population densities the swamps and depressions become the most important land sources for food production, often associated with extremely intensive rice production. One observes such labor intensive rice production in South and Southeast Asia and could expect the same for Africa as population densities increase.

Population pressure leads to a sharp reversal in preference (price) of different types of land in all but the arid zones. As population densities increase one observes the cultivation of land which requires substantially higher labor input but which at the same time is also more responsive to the extra inputs.

Cultivation Techniques and Labor-Use

As discussed by Boserup and Ruthenberg, the total labor input per hectare on a given crop is positively correlated with the intensity of farming, holding technology constant. Table 5 (page 51) presents examples of labor-use with farming intensity in rice cultivation. In West Africa, the movement from forest fallow to annual cultivation using the hoe results in an increase in total labor input per hectare from 770 hours in Liberia to 3,300 hours in Cameroon. The increase in labor input occurs due to an increase in intensity with which certain tasks have to be performed (for example, land preparation and weeding) and due to an increase in the number of operations performed (e.g., manuring, irrigation, etc.). A discussion of labor-use across intensities of farming is provided below. Table 4 (page 50) presents the increase in operation performed with the intensification of the farming system.

In the forest and bush fallow systems of cultivation, land clearing, planting and harvesting are the major tasks performed. Fire is the most prevalent technique for land clearance. This form of land clearance in addition to regenerating the soil also reduces weed growth. Land clearance by fire requires very low levels of labor input: 300 to 400 hours per hectare for forest fallow systems in Liberia and Ivory Coast. The ground, being under tree cover, is soft and hence no further land preparation is required prior to sowing with a digging stick or a hand hoe. Such systems of cultivation require almost no weeding or cultivation and the period between planting and harvesting is virtually task free.

As the fallow period becomes shorter and the land under fallow becomes grassy, fire can no longer be used for land clearance. Fire cannot destroy grass roots, hence grasses persist through the growing season. The intensive use of a hoe for land preparation becomes essential to clear the grass roots. Land preparation and sowing take up almost 40% of the total labor input for the annual cultivation of rice in Cameroon. Under short fallow systems of cultivation the need for early season weeding and plant protection become pronounced. Also manure use is required to complement fallow periods for maintaining soil fertility.

Permanent cultivation of land requires labor investments for irrigation, drainage, and leveling or terracing. It also requires the development of more evolved manuring techniques to restore soil fertility. Land preparation and intercropping and weeding become much more important tasks.

Intensification therefore leads to both an increase in agricultural employment and an increase in yields per hectare. However, intensification of farming, in the absence of a change in tools used, would probably lead to a decline in yield per man-hour. This can be deduced from the observation that the greater proportion of the additional labor input is used for maintaining soil fertility, weeding and plant protection. In other words, labor input per hectare may increase at a faster rate than yield per hectare in the movement to more intensive systems of farming. Pingali and Binswanger (1984) found a significant positive increase in labor-use with farming intensity using data from 52 specific locations in Africa, Asia and Latin America. We also show a significant downward shift in labor-use when hand hoes are replaced by animal drawn plows and a further shift when animal draft is replaced by tractors.

The Evolution of Tool Systems

The transition from digging sticks and hand hoes to the plow is closely correlated with the evolution of the farming system and cannot be understood by using choice of techniques analysis familiar to economists. The emergence of mechanical tillage is generally observed at late bush fallow and early grass fallow stages and not before. The switch from one set of tools to the next would occur when the resulting labor-saving benefits exceed the costs of switching to new tools.

The simplest form of agricultural tool, the digging stick, is most useful in the extensive forest and bush fallow systems where no land preparation is required. As the bush cover begins to recede, the ground needs to be loosened before sowing and at this stage hand hoes replace digging sticks. Hand hoes are used for land preparation and weeding in the latter stages of bush fallow, grass fallow and even some instances of annual cultivation. Land preparation using the hoe becomes extremely labor intensive and tedious by the grass fallow stage because of the persistence of grass weeds. The use of a plow for land preparation becomes almost indispensible. A switch to the plow during grass fallow results in a substantial reduction in the amount of labor input required for land preparation. The net benefits of switching from the hoe to the plow are conditional on soil types and topography. The benefits are lower for sandy soils and for hilly terrain.

The above discussion on the evolution from hand hoes to animal drawn plows is formalized in Figure 2. This graph compares the labor costs under hand and animal powered cultivation systems and shows the point where animal traction is the dominant technology.

The overhead labor costs in the transition from hand to animal power are the cost of training animals, the cost of destumping and leveling the fields, and the cost of feeding and maintaining the animals on a year-round basis. The cost of training the animals is independent of the intensity of farming. The cost of destumping is extremely high under forest and early bush fallow system. As the length of fallow decreases, the costs of destumping decline because of reduced tree and root density. Destumping requirements are minimal by the grass fallow stage. The costs of feeding and caretaking of draft animals is also very high during forest and early bush fallow, primarily due to the lack of grazing land and due to the prevalence of diseases such as trypanasomiasis. As the fallow becomes grassy, grazing land becomes prevalent and so does animal ownership; hence the costs of maintaining draft animals decline. By the annual cultivation stage, however, grazing land becomes a limiting factor, necessitating the production of fodder crops which in turn lead to an increase in the cost of feeding and maintaining draft animals.

The total cost of using draft animals for land preparation, early season weeding and manuring is given by the curve T_p. The curve T_h shows how total labor cost using hand hoes increases for land preparation and weeding, while T_h' adds in the cost of maintaining soil fertility. The shape of the T_h' curve depends on: (a) the ease of producing compost; (b) the rate of decay of organic matter; and (c) the cost of chemical fertilizer. In humid and sub-humid areas it is easier to produce compost and manure relative to semi-arid and arid areas due to an abundance of natural vegetation, hence the labor costs involved in the production of manure are lower and the T_h' curve is flatter. In hot tropical areas, high temperatures cause the organic matter to decay at a faster rate relative to the more temperate highlands, and hence require additional compost and manure inputs making the T_h' curve steeper. The T_h' curve becomes flatter the cheaper chemical fertilizers are, due to the substitution of fertilizers for labor intensive manure production.

Animal drawn plows become the dominant technology at the point where the costs of hand cultivation exceed the costs of transition to animal power. This switch point is shown in the figure. Before this point is reached the overall cost of production is lower for the hand hoe, and cultivators consistently reject the plow. This discussion illustrates the following conclusions:

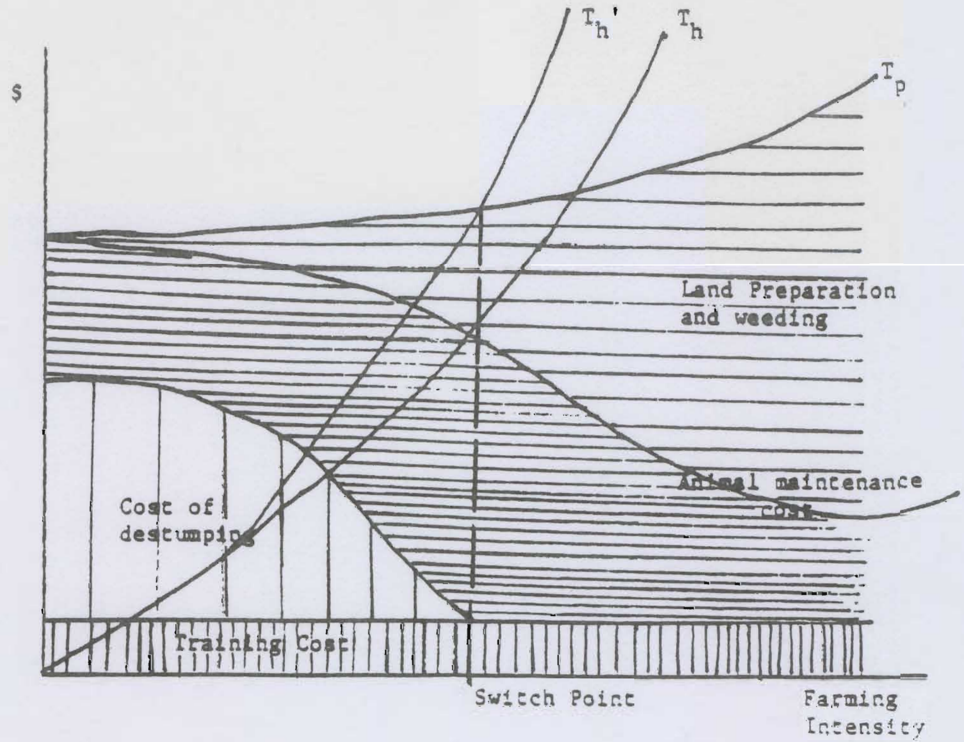
a. The transition to animal-drawn plows would not be cost effective in forest and bush fallow systems due to the very high overhead labor required for destumping and animal maintenance.

b. There is a distinct point in the evolution of agricultural systems where animal draft power becomes the economically dominant mode of land preparation.

c. This dominance point is conditional on soil types and soil fertility: the transition would occur sooner for hard to work soils (clays) and for soils which require higher labor input for maintaining soil fertility.

Figure 2

A Comparison of Labor Costs under Hand and Animal Powered Cultivation



T_p = Labor costs for land preparation, early season weeding and manuring using animal traction

T_h = Labor costs for land preparation and early season weeding using land hoes

T_h' = T_h plus labor costs for maintaining soil fertility without manure from draft animals

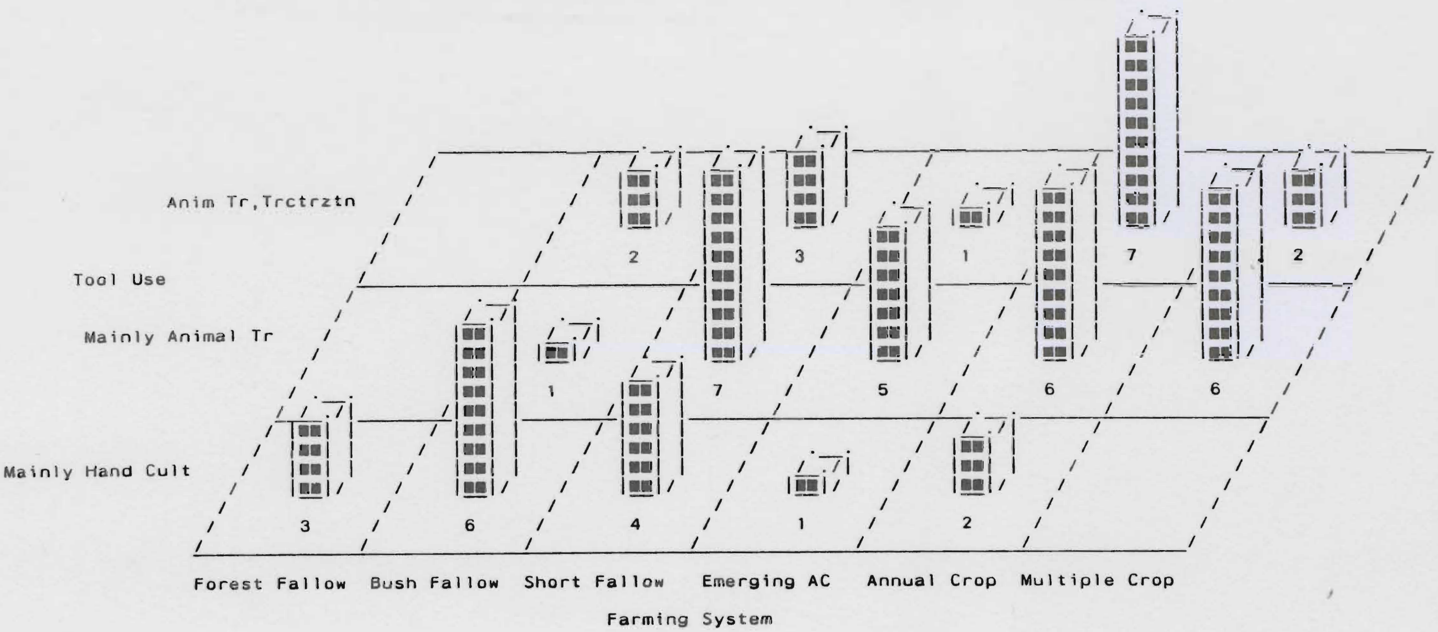
Switch Point = Farming intensity at which animal traction is the dominant technology.

Tractor drawn plows have not successfully been introduced into any systems prior to the grass fallow stage. Indeed, as we show in Pingali, Bigot and Binswanger, it is almost impossible to bypass the animal traction stage and move directly to tractors. This is because the quality and hence the cost of destumping is much higher for tractor operations than for animal drawn plows. Moreover, the societies concerned are usually characterized by extreme capital scarcity and cannot usually afford the substantially higher capital costs associated with tractors.

Once the stage of animal cultivation has been reached, however, tractors and animals become almost perfect substitutes for plowing. The choice of techniques analysis now finally becomes relevant. The factors involved are the relative costs of land, labor and capital, the seasonality of agricultural production and the cost of tractors.

Using the data set from Sub-Saharan Africa we provide a frequency chart of tool use with the evolution in farming systems in Graph 4. As discussed above, hand cultivation is predominant in the

Graph 4: Evolution of Farming Systems and Tools Used



forest and bush fallow systems--none of the forest fallow cases use any other form of tillage, while six of the nine bush fallow cases use hand tools. The majority of cases under short fallow use animal draft power (7 out of 14 cases), three locations use a combination of animal and tractor power, while the remaining four continue to use hand hoes. The dominance of mechanical tillage (both animal draft and tractors) becomes more prominent as short fallow is replaced by permanent cultivation. Of the 30 cases under emerging or established permanent cultivation, 27 reported using animal draft or a combination of animal draft and tractors for tillage. The exceptions where hand tillage persists are the hill slopes of Sukumaland, agricultural areas surrounding Kano city, and the Yatenga region of Burkina Faso. In the first two cases the light sandy soils are easy to work by hand and in the last case, Yatenga, there is a severe plowing-sowing trade-off due to an extremely short growing season.

Development of Fertilizer Use

Under forest and bush fallow cultivation long-term soil fertility is maintained by periodic fallowing of land. Renewed vegetative growth on fallowed land helps to return fresh organic matter to the top soil and therefore re-charges it with nutrient supplies. Also, when fire is used for clearing vegetation prior to cultivation, the burnt ashes return to the top soil the nutrients taken up by tree and bush cover. This closed cycle of nutrient supply is disrupted when long fallow periods are replaced by grass fallows.

The nutrient supply to the soil under grass fallow declines since grass cover cannot return the same amount of nutrients to the soil as tree and bush cover. Accordingly, at this stage the farmer starts complimenting fallow periods with additional organic waste and dung from cattle and livestock. At first these fertilization techniques are fairly rudimentary, often involving no more than a periodic transport of household refuse to the cultivated plots.

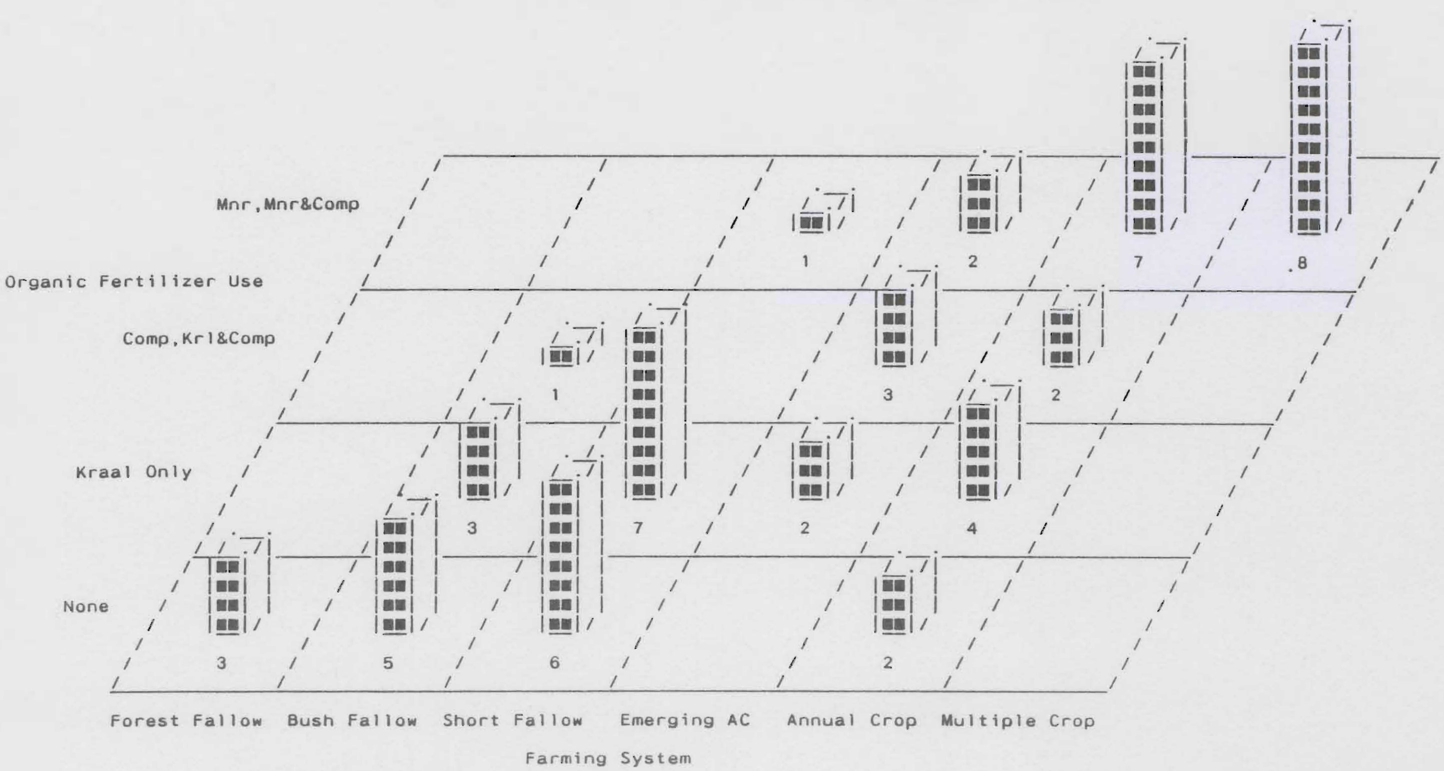
As farming intensities increase, more labor intensive fertilizing techniques such as composting and then manuring evolve. The use of animal manure is common in most of the densely settled, intensively cultivated pockets of Sub-Saharan Africa. The inhabitants of Ukara Island in Lake Victoria, for instance, laboriously collect three tons of manure per year from each adult head of cattle and transport it by head load to the fields.

The final stage in the evolution of organic fertilizer use is the incorporation of legumes in a crop rotation cycle as green manuring. Green manuring along with other fertility restoring measures is a common practice in several parts of India and China. The use of cowpeas in the rotation cycle is becoming increasingly common among the permanently cultivated areas of Africa.

At the multi-cropping stage one tends to observe increased use of chemical fertilizers as a substitute for the labor intensive manuring techniques. Such general use of chemical fertilizers is still very rare in Sub-Saharan Africa, although the use of fertilizers for select crops, such as cotton and groundnuts, which are produced for the market is becoming common.

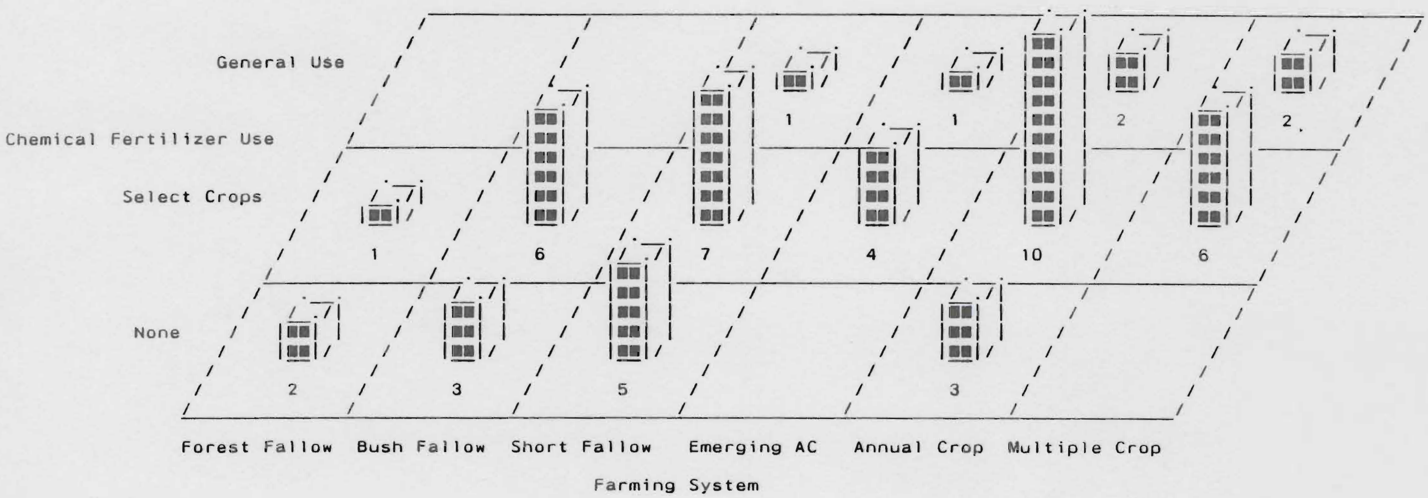
Graph 5 shows the evolution in organic fertilizer use with an intensification of the farming system. Under the forest fallow system we observe no organic fertilizer use and under bush fallow there is a move towards the use of kraal dust and one case of compost use, although the majority of cases still do not use any organic fertilizer. By the grass fallow stage, however, there is a marked switch with the majority of cases (8 out of 14) using kraal dust or other more intensive techniques. Most of the cases under annual and multi-cropping use some form of organic soil fertility restoring techniques, with the majority using animal manure. The two exceptions are from the Arusha region of Tanzania where the very fertile volcanic soils do not yet require fertility restoration.

Graph 5: The Development of Organic Fertilizer Use



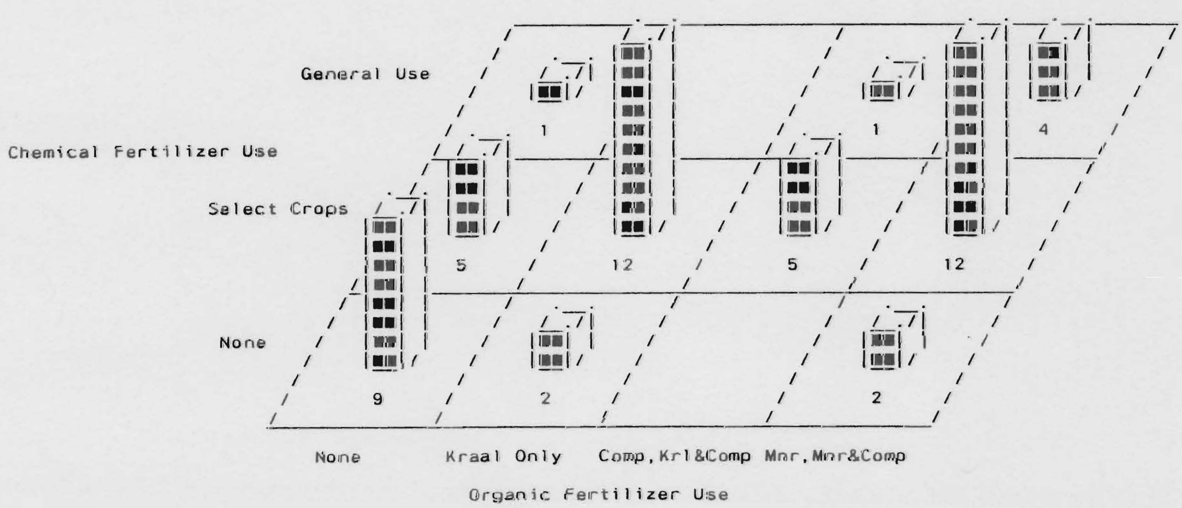
The patterns of chemical fertilizer use are presented in Graph 6. The categories of chemical fertilizer use are: no use; use on select crops; and general use for all crops. The general use of chemical fertilizers is still not common, and only 7 of the 56 cases report such use; of these, five are under permanent cultivation systems. The use of chemical fertilizers for marketed crops is more generally prevalent, and 34 of the 56 cases reported such use. It is interesting to note that there is no general relationship between farming intensity and chemical fertilizer use for select crops. This is perhaps because even under low intensities of farming, some market crops are grown on small permanent plots of land. The cases where no chemical fertilizer is used follow farming intensities more closely; 10 of the 13 cases of no fertilizer use practice forest, bush or short fallow cultivation. Of the three annual cultivation cases not using chemical fertilizers, two are from the volcanic soil locations of Arusha region, Tanzania, and one is an exclusively subsistence crop production case in South Nyanza, Kenya.

Graph 6: Farming Intensities and Chemical Fertilizer Use



Graph 7 highlights the complimentarity between organic and chemical fertilizer use. The striking feature here is the selective use of chemical fertilizers occurring in association with the general use of organic fertilizers. We have no cases of general chemical fertilizer use in the absence of organic fertilizers, although we have two cases of exclusive organic fertilizer use.

Graph 7: Complimentarity Between Organic and Chemical Fertilizer Use



Changes in Land Rights

It is well known that the most prevalent organization of land rights under low population density is "communal property" where members of particular lineage groups have general cultivation rights, i.e., they are assured the right to cultivate a plot, but when they abandon it again to fallow, the cultivation right to that plot reverts to the lineage. On the other hand, intensive high population density areas typically have "private property" rights, i.e., cultivators have a large array of rights to specific plots. The distinction between communal and private property, however, is a rather harmful oversimplification, as it focuses on a simplistic legal codification of land rights rather than on the process "induced institutional innovation" by which societies move from general land rights to specific land rights by the gradual addition of one specific right after another. While there are enormous variations in how this process proceeds and while political powers have often interfered with it or speeded it up, there are general tendencies as described below.

With general land rights, cultivators typically own only the right to cultivate in a particular region. A lineage head assigns the right to use a specific plot to cultivators who retain this right as long as they actually cultivate the plot; when the current cultivator departs--usually to leave the plot fallow--the use right to the plot reverts to the lineage. In very land abundant environments outsiders are often welcome and general cultivation rights may thus be available to lineage groups which are broadly defined to include almost everyone. When population densities increase, the groups or lineages become more narrowly defined and more people are regarded as outsiders who are excluded from the general cultivation right.

With the development of specific land rights, the cultivator can begin to assert certain rights in specific plots, starting with the right to resume cultivation of the specific plot after a period of fallow. At a later stage he asserts, and will receive, the right to assign the plot to a heir or temporarily to another member of the same lineage; the use right in the plot does not revert to the lineage head anymore. Such changes often occur at different times in different regions or subregions of a country. Often a system is still described as a "communal property rights system" when all land already is passed from generation to generation within individual families. With increasing population density, the rights assignable by the individual cultivator become more extensive and may include the right to rent out the land to other lineage members, or even to outsiders. Rights to graze cattle on fallow plots or stubble shift from all members of the community to the individual. Eventually individuals acquire the right to sell land to other lineage members and even to outsiders.

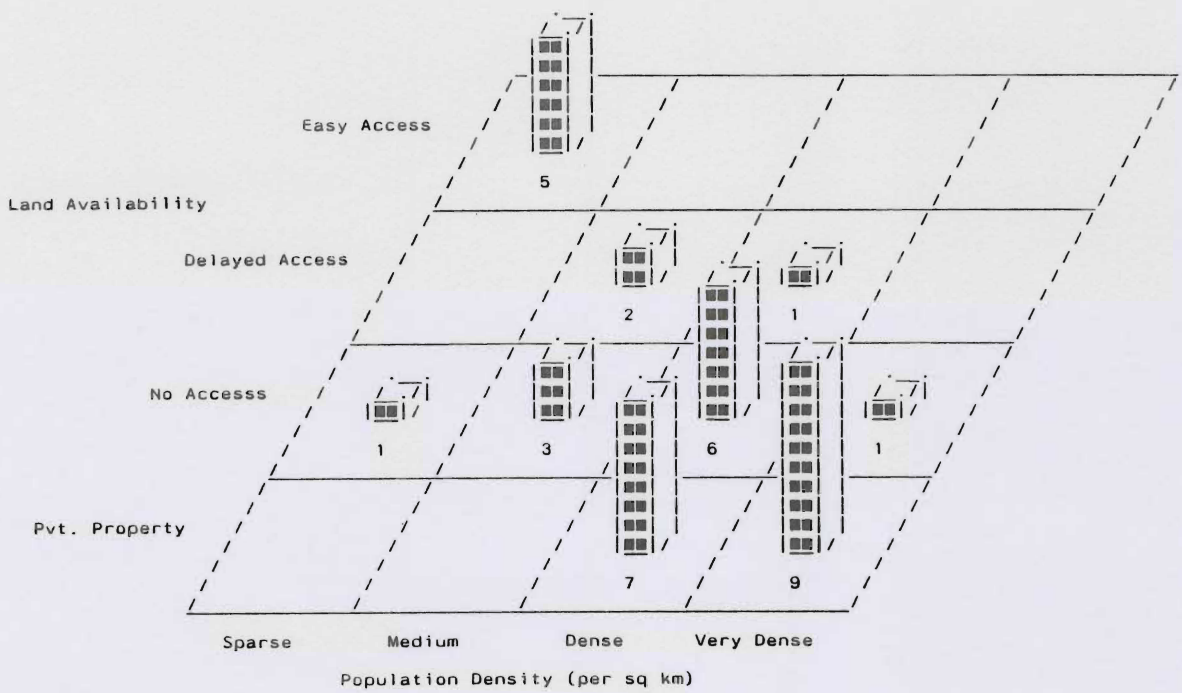
This transition to specific land rights improves incentives to undertake investments into specific plots, investments which are required for the intensification of production and preservation of fertility.

Population growth is not the only process which moves societies toward more specific land rights. Any of the other factors which cause intensification have the same effect. We therefore often see large variations in the number of specific rights allocated to individuals within different parts of the same country, depending on the degree of land fertility and market access.

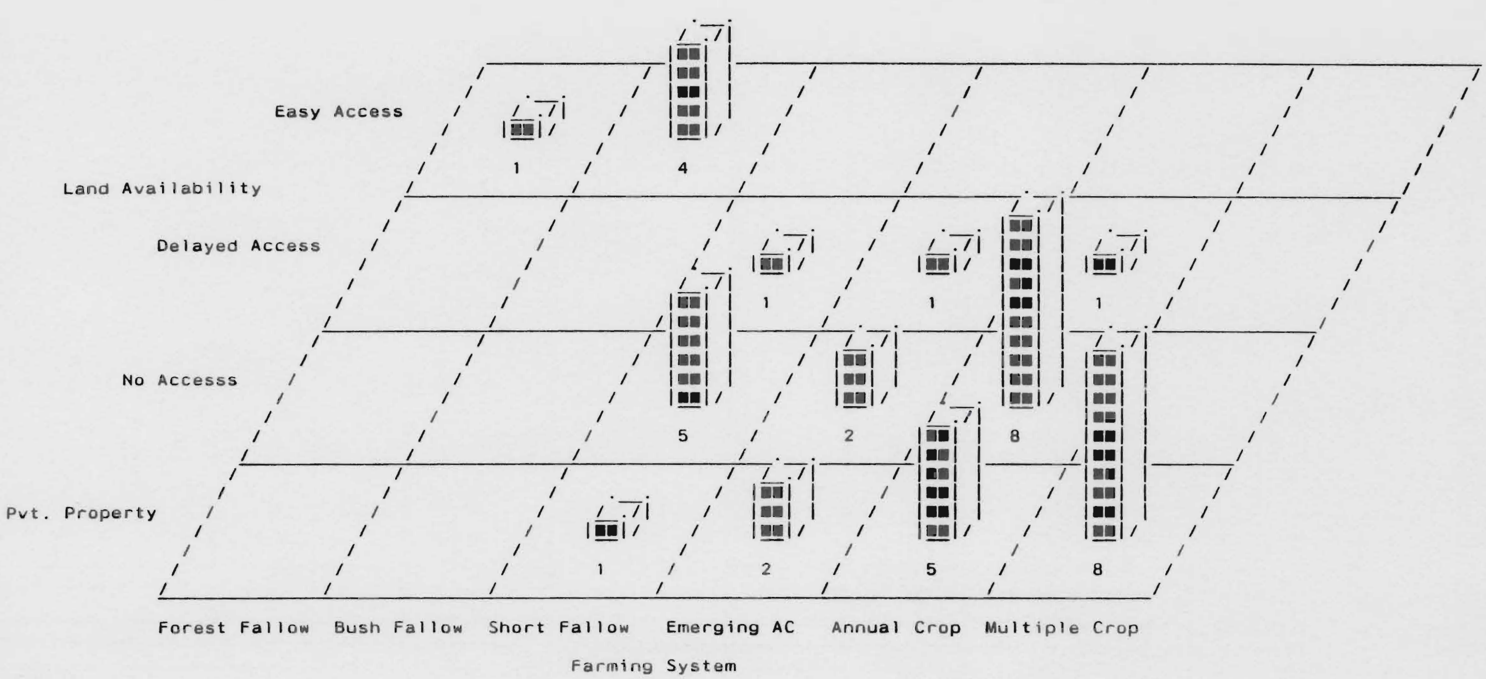
During our field visits in Sub-Saharan Africa, we asked a series of questions that allowed us to determine if and how outsiders could acquire land in a particular society. For this paper we categorized land acquisition as follows: (1) easy access to land, where outsiders could obtain land merely by asking; (2) delayed access to land, where outsiders would have to work for a year or more as farm labor before acquiring the privilege to cultivate their own plots; (3) no access to land, where outsiders cannot acquire any land in the village but there are as yet no direct sales of land; (4) private property, where direct sales of land are possible and prevalent.

The relationship between access to land and population density is presented in Graph 8. As expected it is relatively easier to acquire land in areas with sparse populations than in areas with very dense populations. Among the very densely populated locations, direct sale of land is prevalent in nine of the ten cases, the remaining case has no access to land at all. Of the 14 cases under dense population, one observes the transition to codified private property: six locations have no access to land and seven have switched to private ownership of land. Moving to medium population locations, we find an absence of private ownership and a transition from delayed access to no access to land. It is only in the sparsely populated locations that we find easy access to land to be generally true.

Graph 8: Population Density and Access to Land

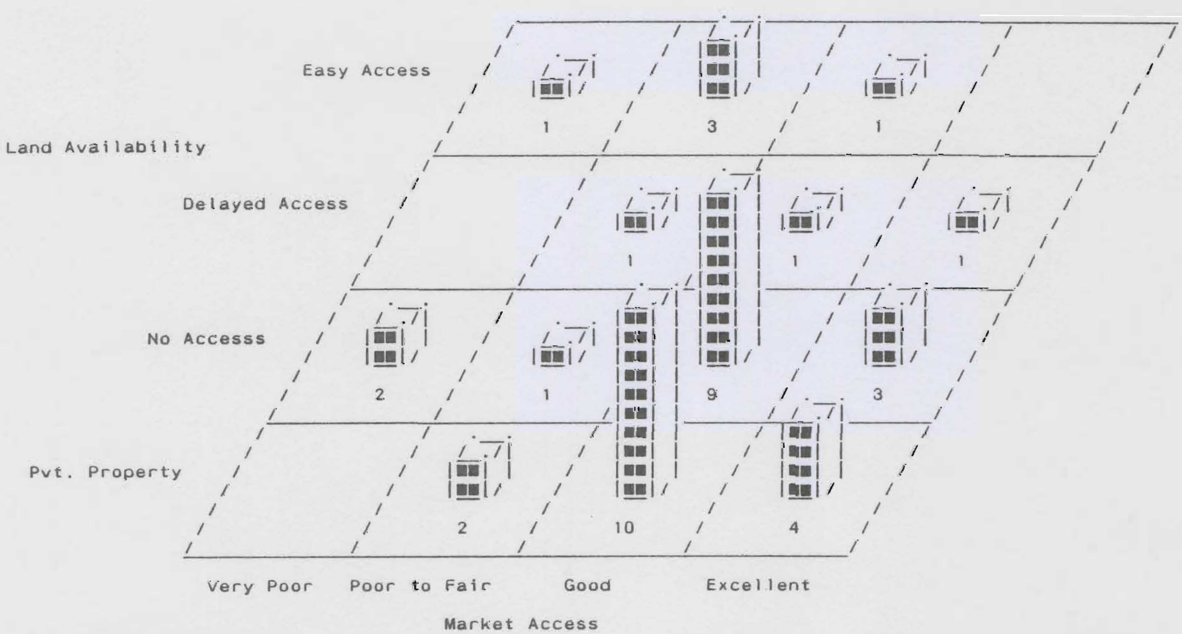


Graph 9: Farming Intensity and Access to Land



The relationship between access to land and the evolution of farming systems is presented in Graph 9. Since both the intensification of farming systems and the access to land are related to population density, the results match the ones in Graph 8. The movement from shifting to permanent cultivation is associated with a parallel movement towards privatization of agricultural land. Also, areas with better access to the market are more likely to deny outsiders access to land and move more rapidly towards codified private property. These results are presented in Graph 10. Of the 29 cases with good or excellent access to markets, 14 reported direct sales of land, 12 reported no access to land for outsiders and 2 reported delayed access to land for outsiders.

Graph 10: Market Access and Access to Land



CONCLUSIONS

1. Far from being immobile and technologically stagnant "traditional" African societies have responded to changes in population densities and external markets with changes in farming systems, land-use patterns, technology and institutions along systematic and predictable patterns.

2. Using data collected through field visits to 56 locations spread across 10 countries in Sub-Saharan Africa and India, this paper provides additional empirical support to Boserup's thesis on the direct relationship between population growth and agricultural intensification. In addition to population growth we show that improvements in market access through better transport infrastructure have similar effects on intensification.

3. Intensification of agricultural systems is associated with a movement from easy to work soils to relatively hard to work soils which are more responsive to labor inputs, purchased inputs and to investments in land such as drainage, erosion control or irrigation. The responsiveness to intensification is higher on deep clayey soils which have higher water and nutrient holding capacity.

4. Intensification is generally associated with increased labor requirements per hectare of cultivated area. Increased labor is required not only for cultivation but also for land investments such as terracing and irrigation, for maintaining soil fertility through intensive manuring techniques, and where feasible, for the maintenance of draft animals.

5. The switch from the hand hoe to animal drawn plows and later to tractors is closely associated with the evolution of farming systems. The switch to animal drawn plows occurs around the short fallow stage and not before because it is only at this stage that the overhead labor costs for destumping and leveling fields and for training, feeding and maintaining animals are the lowest. At the stage of annual cultivation tractors and animals become almost perfect substitutes as it is here and not before that the choice of techniques analysis becomes relevant.

6. The substitution of fallowing first with simple and then with more evolved manuring techniques is likewise related to the evolution in farming systems. The general use of chemical fertilizers, although associated with intensification is not yet common in Sub-Saharan Africa. The select use of fertilizers for specific market oriented crops, however, is on the increase almost irrespective of farming intensity.

7. Finally, we show that the institutional arrangements for the acquisition of land by individuals within the group and by "outsiders" are not rigid but do change as increasing population densities or improved market access makes land scarce. Land acquisition which is extremely easy under shifting cultivation becomes more and more difficult as intensification leads to more narrowly defined groups or lineages and therefore results in the exclusion of large numbers of people from acquiring the rights to cultivate. The ultimate institutional change, and one which commonly occurs under high population densities is one of clearly defined private property rights with the ability to buy and sell land.

A P P E N D I X 2

Table 1: Food supply systems in tropics

Food Supply System[4]	Farming Intensity[1,2] (R-Value)	Population Density Group[2] Persons/km^2	Climatic Zone[3]	Tools Used
G. Gathering	0	0 - 4		
FF. Forest fallow	0 - 10	0 - 4	Humid	axe, matchete, & digging stick
BF. Bush fallow	10 - 40	4 - 64	Humid and semi-humid	axe, matchete, digging stick, and hoe
SF. Short fallow	40 - 80	16 - 64	Semi-humid, semi-arid, and high altitude	hoes, animal traction
AC. Annual cropping	80 - 120	64 - 256	Semi-humid, semi-arid, and high altitude	animal traction, and tractors

1 R = # of years of cultivation *100/# of years of cultivation + # of years of fallow.
Source: Ruthenberg, 1980, p. 16.

2 Source: Boserup, 1981, pp. 19 and 23.

3 Source: Ruthenberg, 1980.

4 <u>Description of food supply systems:</u>
Gathering: wild plants, roots, fruits, nuts
Forest-fallow: one or two crops followed by 15-25 years of fallow
Bush-fallow: one or more crops followed by 8-10 years of fallow
Short-fallow: one or two crops followed by one or two years of fallow, also known as grass fallow
Annual cropping: one crop each year
Multi-cropping: two or more crops in the same field each year

Note 1: The above food supply systems are not mutually exclusive. It is quite possible for two or more of the systems to exist concurrently (e.g., cultivation in concentric rings of various lengths of fallow, as in Senegal).

Note 2: The above population density figures are only approximations; the exact numbers depend on location specific soil fertility and agroclimatic conditions.

Table 2: Causes and consequences of population concentration

Causes			Direct Consequence	Implications
Natural population growth:	improved public health and lack of emigration		Reduction in available area per capita	Reduction in fallow periods: movement from shifting to permanent cultivation
Soil fertility:	immigration to capture the benefits of higher returns to labor input			Mechanization: Plowing: where agro-climatic and soil conditions make it profitable
Transport facilities:*	immigration to capture the benefits of reduced transport costs			Transport: where markets exist for food and other crops
Urban demand:*	immigration to capture the benefits of market proximity			Milling: in response to higher opportunity cost of time for female household members
Health:	avoidance of malaria and tsetse fly	immigration to cooler highlands		Land investments: for soil fertility, drainage, terracing, etc. Increase in the marginal lands brought under cultivation
Historic:	tribal war/ slave trade	immigration to inaccessible highlands		
Land laws, rights:	restrictions on the right to open new land			Land rights: from general use rights to specific land rights

* In the case of improved transport facilities and urban demand one may observe an expansion in the area under cultivation in the absence of immigrations.

Table 3: Farming intensity, agroclimates and soil preferences

Agro-climates	Farming Intensity		
	Forest & Bush Fallow	Grass Fallow	Permanent Cultivation
Arid	Lower slopes and depressions only	Lower slopes and depressions only	Lower slopes and depressions only
Semi-arid	Mid-slopes	+ Lower slopes	+ Depressions
Sub-humid	Upper slopes	+ Mid and lower slopes	+ Depressions
Humid	Upper slopes	+ Mid and lower slopes	+ Depressions

Table 4: Comparison of operations and technology across farming systems

Operations	SYSTEM				
	FF	BF	SF	AC	MC
Land clearance	Fire	Fire	None	None	None
Land preparation	No land preparation, digging sticks used to plant roots and sow seeds	Land is loosened using hoes and digging sticks	Use of plow for preparing land	Animal-drawn plows and tractors	Animal-drawn plows and and tractors
Manure use	- Ash - Household refuse from garden plots	Ash, burnt or un-burnt leaves, other vegetable matter and turf brought from surrounding bushland	- Animal and human waste - Green manuring - Composts - Silt from canals	- Animal and human waste - Composting - Cultivation of green manure crops - Chemical fertilizer	- Animal and human waste - Composting - Cultivation of green manure - Chemical fertilizer
Weeding	Minimal	Required as the length of fallow decreases	Weeding required during the growing season	Intensive weeding required during the growing season	Intensive weeding required during the growing season
Use of animals in farming	None	As length of fallow decreases animal-drawn plows begin to appear	- Plowing - Transport - Intercropping	- Plowing - Transport - Intercropping - Post-harvest tasks - Irrigation	plowing, transport, intercropping, post-harvest tasks, irrigation
Seasonality of labor demand	None	None	Land preparation, weeding and harvesting	Acute seasonal labor demand concentrated around the rainy season and harvest	Acute seasonal labor demand concentrated around land preparation, weeding, harvest, and post-harvest tasks
Fodder supply	None	Emergence of grazing land	Abundant free grazing land	Free grazing during fallow period, crop residues	Intensive fodder management and fodder crop production

Table 5: Examples of labor use with farming intensity rice cultivation

Country	Liberia	Ivory Coast	Ghana	Cameroon	India	Java	Philippines
Region	Gbanga	Man	Begora	Bamunka	Ferozepore	Subang	Laguna
Intensity of Farming	11	24	40	100	121	200	180
Technique	Hoe	Hoe	Hoe	Hoe	Animal plow	Animal plow	Tractor
Time/Operation (hours/hectare)							
Land clearing	418.4	300.8	665	--	--	--	--
Land preparation	--	--	--	714	86.4	494.4	73.6
Sowing/Planting	107.2	142.4	207	536.8	129.6	146	80.0
Fertilizing and Manuring	--	--	--	--	12.8	218	
Weeding	36.8	292	276.8	113	57.6		213
Plant Protection	44	222	--	1,393			96
Harvesting	164	218.4	280	264	128.8	324.4	222.4
Threshing		84		280	76.8		
Other	--	--	--	--	136[1]	70	--
TOTAL	770	1,259.2	1,432	3,300	627.2	1,252	685

1 Irrigation

REFERENCES

Binswanger, Hans P. and Vernon Ruttan. Induced Innovation: Technology, Institutions and Development. Baltimore: Johns Hopkins University Press, 1978.

Boserup, Ester. The Conditions of Agricultural Growth. Chicago: University of Chicago Press, 1981.

Pingali, Prabhu L. and Hans P. Binswanger. Population Density and Agricultural Intensification: A Study of the Evolution of Technologies in Tropical Agriculture. Agriculture and Rural Development Department, Research Unit, Report No.: ARU 22, Washington, D.C.: World Bank, 1984.

Pingali, Prabhu L., Yves Bigot and Hans P. Binswanger. Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa. Draft Manuscript, Agriculture and Rural Development Department, Research Unit; Washington, D.C.: World Bank, January 1985.

Ruttan, Vernon W. Agricultural Research Policy. University of Minnesota Press, Minneapolis, 1982.

CHAPTER THREE

Technological Cycles in Latin American Agriculture

by
Martin Pineiro

TECHNOLOGICAL CYCLES IN LATIN AMERICAN AGRICULTURE*

Martin Pineiro**

Technical change in agriculture is an old phenomenon that started almost with agriculture itself. However, it is only in relatively recent times that the rate and intensity of the innovative process have transformed it into the most important force of economic and social change.

Latin America is no exception to this generalization. Although improved varieties and better cultivation methods have been introduced since the early days of colonization, first by immigrants and later through more formal mechanisms, their impact on productivity has been quite modest. It is only in the 1960s that the agricultural revolution, initiated in the industrialized world and especially in the United States during the 1940s, reached Latin America. At first its impact was modest and extremely selective in regards to crops and regions, but with the passing of time the modernization process caught speed and progressively diffused to a wider set of situations. Today it is fair to say that although technical change and production increases are still quite uneven between crops and agroclimatic regions, in the aggregate, Latin American agriculture is undergoing a profound and rapid transformation which includes significant increases in production and productivity.

The first theme I will address is related to the technology adopted. The agricultural revolution in the industrialized world was the result of wide and simultaneous diffusion of a number of different technologies. In this paper I will argue, using circumstantial and nonsystematic data, that in Latin America this process of agricultural modernization was the result of a number of overlapping but sequential cycles, each one characterized by a dominant technology. Furthermore, I will hypothesize that these cycles were set in motion by the interaction of three interrelated forces: a) the appearance of dominant technology at the international level; b) the relative generality or site specificity of the technology and the capacity of national research institutions to perform the required adaptative functions; and finally c) technical linkages that exist between the different types of technologies that determine, to a certain degree, an obliged pattern or sequence in their adoption.

The second theme is related to the main social actors responsible for the creation and diffusion of the primary technologies that characterize each cycle. I will also show the increasing role of private sector institutions and their strong participation in the creation and diffusion of those technologies that become dominant in the later cycles. Finally, I will explore some implications that emerge from the analysis with regards to the future evolution of the innovative process and the role of the public sector.

TECHNOLOGICAL CYCLES

The technological revolution initiated in the industrialized world immediately after World War II was based on a combination of different technologies that rapidly increased land and labor productivity. Although the technological path followed by different countries was influenced by factor endowment and relative prices, as shown by Ruttan's work, technical change included all available technologies, such as mechanization, fertilizers and improved seeds.[1]

In Latin America, as in most developing countries, these technologies were incorporated into production with a significant lag in relation to the time when they became available at the international level. The interesting element of this observation is that the lag seems to have been different for the different types of technology, depending on how adaptable the technologies were to

---

*The paper borrows a number of ideas from papers by B.P. Reydon, A.C. Ortega and J.G. da Silva, and E. Obschatko. I also acknowledge the discussions held in the Second Workshop of the PROAGRO Project with participation of researchers related to the project and the ideas presented there, specifically by J.G. da Silva, and comments made to a preliminary draft by E. Jacobs.

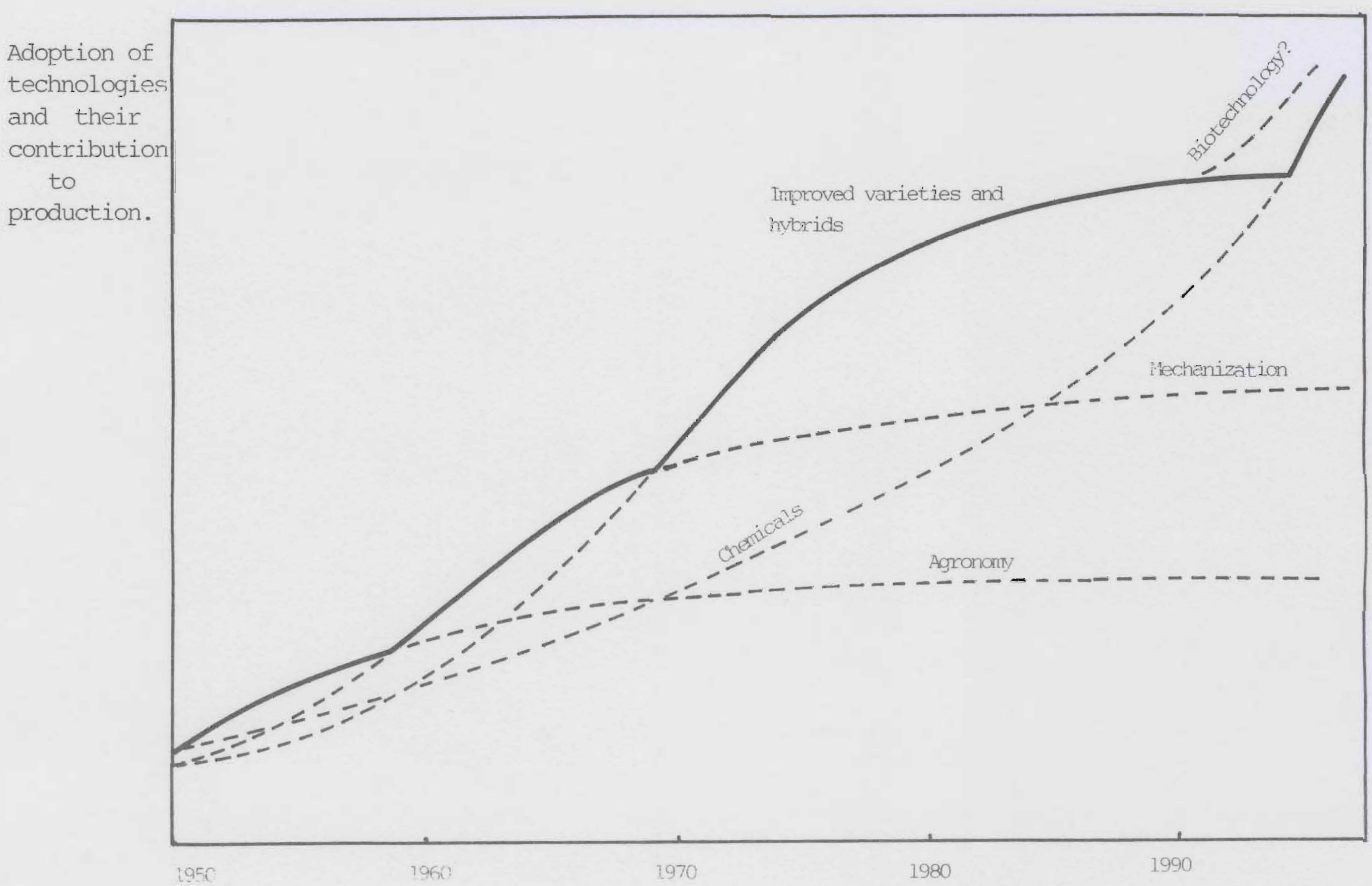
**Coordinator PROAGRO Project ISNAR-CISEA, Buenos Aires.

different production conditions, or in other words how much adaptive research was needed before they could diffuse extensively. The combination of lags has resulted in a diffusion pattern composed by sequential cycles, where each cycle is characterized by one major technology.

On the other hand, diffusion was also related to certain agroclimatic and socioeconomic conditions. In this respect it is useful to recall that Latin American agriculture can be characterized in four main production situations: a) temperate, sparsely populated agriculture; b) Andean agriculture of medium and high altitudes, usually with high population densities and relativly intensive cultivation; c) subtropical valleys and plains with medium population densities; and finally d) sparsely populated and almost uncultivated lowland tropics.

Figure 1 depicts the sequential cycles of technological diffusion. The timing approximately corresponds to the more developed agriculture in Latin America, which coincides with temperate South America and some of the fertile subtropical Andean valleys. It may be seen that our hypothesis is that after a long period, when agronomic practices were the most important technology, mechanization becomes the dominant technology in the late 1960s or early 1970s, giving way after that to the rapid diffusion of improved seeds, especially hybrids. Chemicals, especially pesticides and herbicides, represent the last cycle which still has to reach its inflection point. In the next section we describe these cycles with greater detail.

FIGURE 1: Technological cycles.



The Initial Stage of Technological Diffusion

After World War II technological change in Latin American agriculture was slow and had little impact on production and land productivity. Although production increased at a significant rate, a large proportion of the increase was due to horizontal expansion through the incorporation of new land to crop production. In some situations, such as wheat production in Argentina and sugar cane in Colombia, improved varieties were adopted, but for the most part technical change was restricted to the adoption of better agronomic practices that had only modest effects in land productivity.[2] These technologies were created and diffused mainly by the research departments of the Ministries of Agriculture, which at that time were the primary institutions with responsibility for agricultural research and extension.

Relatively little diffusion of other technologies available internationally took place, in part as a consequence of weakened international relations brought about by the war, inward looking economic policies followed by most of the larger Latin American countries and lack of awareness about the technological revolution that was beginning to take place in the industrialized world.

Agronomic practices were the dominant technology at that time. Many of them were introduced from abroad, while others were developed by local research institutions and the farmers themselves. Agronomic technologies are site and crop specific, thus not surprisingly technical change was concentrated in the temperate agriculture which had similar conditions to most of the agricultural production in the industrialized world.

It is important to note that, because of the disembodied nature of these technologies, it is virtually impossible for those who create and diffuse these technologies to capture the benefits derived from them. Consequently the public sector was and had remained as the main source for the development or adaptation of these technologies. The weakness of public research institutions, especially before the 1960s, probably explains the modest effect of agronomic technology and the consequent stagnation of most of agricultural production in Latin America until the last two decades.

In recent years, however, the role of the public sector in the development and diffusion of these technologies has been complemented by the actions of private institutions closely associated with agricultural producers. The CREAs in Argentina, the federations of coffee and rice producers in Colombia, are examples of organizations that have shown great effectiveness in the development of agronomic and managerial technology designed for the full utilization of yield potential of improved seeds.[3] Although agronomic technologies lost relative importance in the following decades, they remained as a significant component of the technological package that made possible the increases in production obtained in the last two decades.

The Second Cycle: Agricultural Mechanization

The 1950s was a decade of profound transformation in Latin America. Industrialization and urbanization, two dominant elements of the decade, initiated social and economic changes that also affected agriculture. First it represented an increase in the demand of marketable food for the urban sector. Second, governments developed a new awareness about the importance of increasing agricultural production as a means of maintaining relatively cheap food to achieve industrial economic development objectives. This new perception resulted in more favorable economic policies especially directed to the modernization of agricultural production which included, during the 1960s, the development of strong efforts in the creation of research institutions in the public sector. Third, in some countries and regions, the urban migration represented a disruption of labor markets and consequently a new and previously unknown scarcity of labor in the agricultural sector.

These new conditions initiated the second cycle, a significant technological change in agriculture, represented by the diffusion of mechanization. During the 1960s and early 1970s, with the help of subsidized credit from most governments, the number of tractors expanded rapidly (Table 1, page 64). It can be seen that in the 1970s the expansion rate decreased much in the same way as in the USA 10 or 15 years before.[4]

The first question is why mechanization preceeded other types of technologies which, to some extent, were also internationally available at that time. The answer lies in the wide adaptability of mechanization that could be introduced with little or no additional indigenous research. This is not to say that adaptative research was not needed. In some cases, especially under tropical conditions, a number of adjustments and small modifications were required before wide diffusion could take place.

In this respect it is important to note that in the initial period of mechanization, machines were mostly imported. Later, the more industrialized countries of Latin America slowly replaced imports with equipment produced nationally, either directly by international firms or under special agreements with them. A few countries like Argentina and Brazil, and more recently Colombia, have developed significant local industry, especially in lighter equipment, which is also starting to make substantial contributions to the development of machinery especially adapted to local conditions. The public sector had virtually no role in the generation of mechanical technology and have in general allocated very little resources to this type of research. For example the Sao Paulo research system, one of the oldest and more developed in Latin America, allocated only about one percent of its resources to research on agricultural machinery.[5]

Although mechanization can be identified as the main technology in this first cycle of agricultural modernization, the rate of adoption and its impact on productivity and income distribution varied in different countries and regions. As it may be expected, the rate of diffusion of mechanization was related to ecological conditions and especially to the relative availability of labor and its price. Mechanization was rapidly adopted in the temperate, sparsely populated agriculture of the southern cone, less rapidly in the subtropical valleys, and very little in Andean agriculture or in peasant economies in general irrespective of ecology. Thus, although the technology was created outside national boundaries, its final adoption was related to relative factor scarcity and government economic policies.

On the other hand, the impact of mechanization varied widely in each of these conditions. In general the impact on production and land productivity was low except in the case of the lowland tropics, where mechanization made possible the incorporation of new land and consequently the expansion of the agricultural frontiers resulting in production increases. The frontier land in Brazil and Venezuela are prime examples of this situation. On the other hand in the subtropical valleys with rich land and relatively intensive agriculture, mechanization had a considerable impact in labor displacement and the reorganization of agricultural production under more commercialized and competitive conditions. Sugar cane, rice and cotton in Colombia, rice in Ecuador are examples of this situation.[6] In the temperate zones with low population pressures and an agriculture resembling that of the United States, mechanization was an effective way of expanding agriculture under less labor intensive conditions, which were more coherent with the relative scarcity of labor aggravated by the urbanization process that took place during this period. The Argentine pampean region and southeast Brazil are the main representatives of this situation.[7]

These relatively minor and heterogeneous impacts of mechanization, however, should not obscure the fact that by standardizing agricultural production, and making possible the concentration of major activities in a shorter period of time, mechanization paved the way for the adoption of the biological and chemical technologies that came with great intensity a few years later.

The Third Cycle: Improved Seeds

The third technological cycle, and probably the most important one, is dominated by the diffusion of improved varieties and hybrids in some of the most important cultivated species. Significant examples are rice, wheat, corn, sorghum, soybean, sugar cane, coffee, potatoes, cotton and more recently sunflower, palm oil and dry beans.

One of the effects of mechanization was to introduce an element of modernization, disrupting old systems of production and facilitating the adoption of other more complex technologies. It also made possible additional land work required by a more intensive agriculture, consequently increasing the incentive for the adoption of more productive varieties. However, the main element that explains the appearance of the third cycle is the development of an indigenous research capacity and a seed industry which was a precondition for the diffusion of improved seeds.

Although the basis for the development of improved varieties and hybrids was the result of research breakthroughs and breeding work developed internationally by universities in the industrialized world, international centers and multinational seed companies, this technology does not have, in general, the wide adaptability of mechanization or fertilization technology. In most cases some additional and more site specific work is required before the seeds can be used in different agroclimatic conditions.[8]

It is for this reason that, in spite of the fact that the technology was available internationally, the initiation of the third technological cycle based on improved seeds had to wait until the emergence and consolidation of national research systems.

In some cases the Ministries of Agriculture had already begun significant work in crop improvement. However the real development of public research capacity took place during the 1960s and early 1970s when most countries in Latin America created what are now known as the National Research Institutes. The first of them, created in Argentina in 1956 (INTA), in some ways served as an example for the creation of others which were developed following similar organizational molds of decentralization, wide coverage of problems and regions, and relatively generous budgets in comparison to their predecessors.[9]

These institutes organized research in most of the pressing problems of agriculture, including breeding programs in major crops. It is probably not surprising that the degree and earliness in which these programs became successful was related to those crops where basic research and crop improvement had been most developed in the international sphere.

The nature of the third cycle is mainly characterized by the diffusion of more productive varieties and hybrids. Although the main determinant is the availability of the technology at the international level and the indigenous capacity to do the required fine tuning in the breeding and selection work, the actual diffusion of the technology was also determined by other elements related to the structure of production and certain economic and sociopolitical conditions.

A number of studies suggest that the diffusion of this third cycle was especially relevant under three different situations, each with considerably different social and economic effects.[10]

The first of them, mainly associated with temperate agriculture, is represented by situations such as rice in Colombia, corn, wheat, sorghum and sunflowers in Argentina, and sorghum and soybeans in southern Brazil, among others. In these cases, food or export crises motivated by low production levels of the commodities under study initiated strong policy actions by the government in the direction of better pricing policies, the provision of credit and a stronger role in the generation and diffusion of technology.[11]

These processes of social articulation are remarkably similar to those that occurred in the developed countries after the 1950s, and more recently in some Asian countries. The overwhelming need to increase production, and the presence of dominant social sectors capable of implementing public policies consistent with technical change, are the cornerstones of the process.

In these two cases technological articulation was based on: a) the introduction of a technological package based on improved or hybrid varieties developed through research carried out primarily at the international level, by organizations funded and controlled independently of the productive sectors, but for which national public agencies played an important role in diffusion; b) the definition of an economic policy to stabilize prices and to pay high subsidies for direct investment in technology adoption or capital embodied technology. These characteristics of the process, in addition to the qualitative nature of innovations based on improved seeds and the low concentration of supply, resulted in a relatively equitable distribution of the surplus among the different social sectors.

The impact of these processes of technical change on production and yields are notable, even in comparison with international results, and exerted only a minor effect on the organization of the productive process, the relations of production and other aspects of the productive structure, including the degree of concentration and vertical integration.

In the second type of modernization process, mainly associated with subtropical intensive agriculture and illustrated by sugar production in Colombia and palm oil in Ecuador, social articulation was generated from inside the agricultural sector. In both cases, corporate actions enabled these sectors to negotiate with government policies that served their specific interests and enabled them to begin processes of technological innovation. However, the productive sector firmly controlled the quality of these processes by defining their form and appropriating a good part of the benefits of technical change. In every case, the public policies implemented were specifically designed to overcome particular obstacles to development in the dominant productive sectors. In addition, these sectors created organizational mechanisms which gave them a certain amount of control over the supply of technology. Qualitatively, the role of improved seeds was less important than in the previous case and the process of technical change had moderate effects on yields, but production expanded through the vigorous incorporation of new areas. Additionally, important changes took place in the organization of the work process and concentration and vertical integration.

The third type of innovative process is associated with peasant economies. A large study recently completed,[12] and many other studies, suggest that there have been a series of situations in which small farmers have found adequate conditions to capitalize and incorporate more sophisticated technology.

This technology in general has been based on improved seed and some use of chemicals with little or no use of mechanization. The evidence suggests that the main element that set in motion these processes of technical innovation by peasants was related to the existence of favorable terms of trade for the farm sector, which in most cases were brought about by changes in agricultural policies.

The main impact of modernization has been to initiate processes of upward differentiation of peasants where a large proportion of them progressively capitalize and become capitalized family farms and, in some cases, become full-fledged commercial enterprises. In most cases these processes are accompanied by a downward differentiation of a proportion of productive units and consequently have negative effects on income distribution and also result in the partial proletarianization of rural labor.

The degree to which these negative effects took place was associated with the conditions of land availability and its tenure conditions. The evidence suggests that in those cases in which land is scarce the competitive forces set in motion by modernization will imply the deterioration of some household units and an intensification of labor migration. On the contrary, if land is not the major constraint, credit, technical change and favorable terms of trade will make possible a balanced expansion of productive capacity in a large proportion of the farm units of a given region.

The three types of innovative processes just described are based on the incorporation of technical packages based on improved seeds. It is interesting to note that the socioeconomic impact of technical change seems to be associated with the economic conditions and sociopolitical structure that characterize each situation more than the specific characteristics of the technological package adopted.

In regard to the institutional mechanisms by which improved seeds were developed and diffused, it is interesting to note that the main actors seem to have changed through time following a general pattern. We have already mentioned that in the initial stages of this third cycle public research institutions had an important role in the necessary adaptative research.[13]

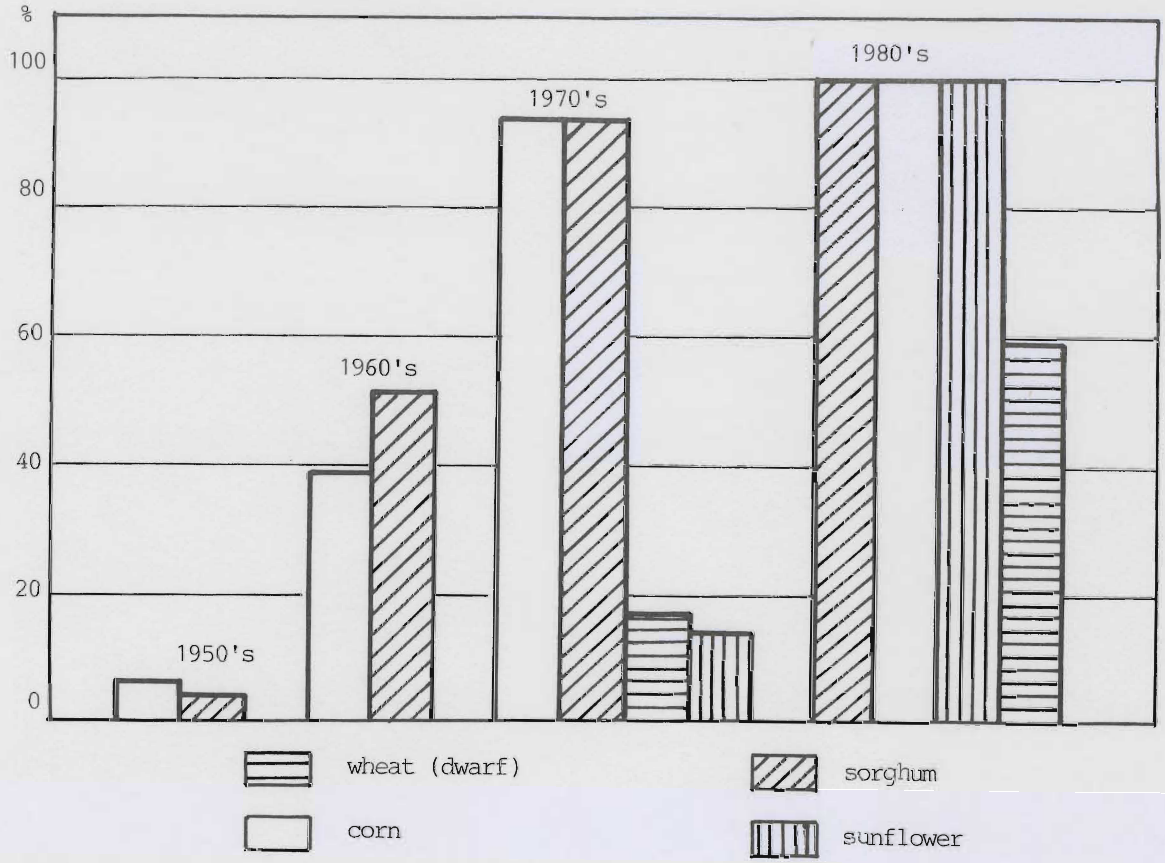
However, after the initial stages and once a number of preconditions such as the size of the market and the availability of trained personnel had been developed, the private sector moved in quite aggressively, particularly replacing--in the case of crops where hybrids are imported--the public sector as the main source of improved seeds. A substantial part of this private sector has been of transnational origin.[14,15]

In other crops where the private appropriation of the benefits derived from improved seeds is more difficult--like wheat, potatoes, soybeans, beans, etc.--the public sector (in some cases with the collaboration of the international centers) continued to play an important role in the diffusion of improved varieties.

Although the diffusion of improved seeds has been a relatively heterogeneous process depending on the crop and the different agroclimatic and sociopolitical conditions of Latin America, the overall process can be described as the third and most important process of technical change.

In Figure 1 we hypothesize that with available basic knowledge the cycle has reached its peak because, in some of the major crops and regions, improved varieties have been adopted by the totality of farmers. Examples of this are cereals in Argentina (see Figure 2),[16] sugar in Brazil and Colombia,[17,18] rice in Colombia,[19] etc.

FIGURE 2: Adoption of improved seeds by farmers. Argentina.



In Figure 1, however, we have also drawn a second possible trend which represents what could happen if biotechnology yields a new generation of improved seeds significantly more productive than the ones presently available.

The Fourth Cycle: Agrochemicals

The fourth and final cycle is dominated by the increasing importance of agrochemicals (especially pesticides, fungicides and herbicides) in the technological package utilized by farmers. These technologies, in a generic sense, have been available for many years and, especially in the case of fertilizers, have been adopted quite extensively in more intensive agriculture such as horticulture and other crops cultivated under irrigated conditions. Data on quantities used is very scant and unreliable and does not permit good estimates about changes in their use. Our perception is that the introduction of more sophisticated, crop specific and highly effective agrochemicals will make them a major source of agricultural productivity in the near future, especially in the more extensive and quantitatively more important agricultural production of Latin America (see Table 2, page 65, for data on Argentina).

The question here is why, if agrochemical technology was available to a certain degree and possessed a wide adaptability to different ecological and productive conditions, especially in the case of fertilizers, it was not adopted more extensively from the very beginning of the modernization process.

We would like to hypothesize that the explanation lies in two interrelated phenomena. The first, which mainly applies to fertilizers, is related to the profitability of the technique under Latin American conditions. Profitability depends on relative prices and crop responsiveness, which in turn depends on the natural fertility of soils and the yield potential of each individual crop. It is widely known that relative prices of fertilizers are in general quite high in Latin America and have been a barrier to their use. On the other hand, yield potential is closely associated with the recent diffusion of the improved varieties that could fully express their production capacity through the use of fertilizers and other chemicals. Thus, it is only logical that the extensive use of agrochemicals had to wait for the diffusion of high yielding varieties before they could become a profitable technology under extensive agriculture conditions and under adverse relative prices, two conditions that characterize much of Latin American food production. This explains why fertilizer use concentrated on the very intensive agriculture or where soil fertility was a major limitation to production as in many parts of Brazil.

The second phenomenon which mainly applied to pesticides and herbicides relates to the recent development of new products more effective and specific to crops and pests that greatly increased crop profitability, especially when applied to the more productive varieties and hybrids extensively used at present. This last element needs to be stressed because product development seems to be one of the research areas that could expand greatly in the future creating new products and developing new methods for more effective and less costly application.

The development of agrochemical technology is in the hands of large pharmaceutical and oil corporations with a transnational organizational structure. The role of the public sector has always been negligible, even in the industrialized countries, except in the development of agronomic recommendations related to rates and methods of applications.

It is important to note that the close association and synergistic effects between improved seeds and agrochemical use allows us to predict that their development and use will be closely tied in the future. This implies a complementary effect both in the research and development phases and in the sales and distribution phases. This perception is probably one of the main explanations behind the active process of conglomeration of the seed industry with the large pharmaceutical and oil industries which has taken place in recent times.

IMPLICATIONS OF THE ANALYSIS

In previous sections I have tried to show that technical change in Latin America has followed a pattern of sequential cycles, each one of them dominated by a specific technology. The reasoning is that once the technologies were developed internationally, the pattern in which they were adopted by the productive system had a certain logic, mainly defined by the research capacity developed in Latin America and general technical linkages between the different technologies.

An attractive element implicit in the identification of cycles is that in a general sense they provide a framework for prediction. If the analysis is correct we should expect that within the limitations imposed by different ecological and structural conditions and the relative strength of local research capacity, the technological path of Latin American agriculture will follow a sequence of the type described in this paper. The expected direction of the innovative process also implies that the relative importance of agrochemicals will increase and in more developed agriculture will probably become a major source of productivity gain. This will have a significant impact on the linkages developed between the agricultural and industrial sectors and will create new environmental problems of the type widely discussed in the industrialized world.

The cycle of improved seeds is still unfolding and could remain the major source of productivity growth, especially if the promise of biotechnology comes true in the near future. The close linkages and synergistic effects of crop improvement and agrochemical use seem to us to be quite evident, as well as their complementary relationships in research and in distribution. We have already indicated that these economic factors explain the fast process of industrial conglomeration by which the seed industry is being absorbed by chemical and pharmaceutical interests.

The seed industry has been until now a highly competitive industry with a large number of firms where technological development has been the main instrument for competition. On the contrary, the chemical and pharmaceutical industry is a highly concentrated, and in many cases, oligopolistic industry, where competition is based on size, patents and marketing services. It is probably fair to ask if the fusion of these two industries, or rather the absorption of the seed industry by the others, will not lead to similar and less desirable industrial behavior in the seed industry as well.

This possibility is not without significance for the developing world because it would imply that a number of countries would depend on a small number of giant corporations that would be providing the technological impulses on the two major components of agricultural production.

The analysis also highlights the relationship between technological development in the industrialized world and local adaptative research activities.

After the first technological cycle dominated by agronomic practices, partly developed through local adaptative research, the dominant technologies of the next three cycles were mainly developed in the industrialized world. Two of the technologies, machinery and agrochemicals, were diffused and adopted with little or no adaptative research. On the contrary, improved seeds required, in most cases, a considerable amount of adaptative research before they could become an important technological breakthrough. In addition, in recent years the local industry in a few countries like Argentina, Brazil and Colombia has made significant contributions in the development of indigenous farm machinery.

The role played in the past by local research in the development of adaptative research activities has to be examined in relation to the predicted characteristics of technical change.

It is quite clear that as national research capacity develops, crop improvement research and the adaptation of farm equipment to local conditions could grow in importance and magnitude. It is less clear what will be the participation of public institutions in these activities or if, as it has happened in the past, the private sector will increase its significance. On the other hand, the dominance of the private sector of transnational origin in the development of agrochemicals is probably irreversible given the complexity and economies of scale of research directed toward the development of new products.

The question of relative site or crop specificity of certain technologies has a number of implications in addition to the obvious one of the need of local research capacity, which implies not only the creation of research institutions but also the allocation of resources to specific regions and/or commodities and the efficient organization of technology diffusion mechanisms. The specificity problem is also related to the fact that technology will diffuse only if public policy for that crop is adequate. A third element is that the size of the market for the technology is more dependent from an homogeneous diffusion of the technology in its domain (region and crop). Consequently, if the size of the market is a constraint to the production and distribution of the technology, the process will require economic and institutional policies sufficiently favorable to promote its rapid and widespread adoption.

The combination of these three elements probably explains why the diffusion of more site or crop specific technology, such as agronomic practices or improved seeds, was more closely related to situations where social articulation between powerful interest groups and the government were able to guarantee favorable conditions.

A P P E N D I X 3

Table 1: Tractors in selected countries and Latin America

Year	Argentina	Brazil	Mexico	Colombia	C. Rica	Total L. America
						120.977[0]
						187.012[1]
1960	110.643	30.502[1]	39.000	14.553[1]	.950[1]	309.460
1961	110.643		39.000	23.539		
1962		65.884		23.539		
1963	150.000[2]	70.680[2]	64.800[2]	24.290[2]	4.454[2]	436.185[2]
1964	150.000	65.884	52.000	23.539	4.454	
1965						
1966	155.000*	81.700	76.000	25.000	4.950	482.490
1967	160.000*	82.600	80.000	25.300	5.100	501.676
1968	172.000*	87.600	84.000	25.521	5.000	522.847
1969	178.000*	91.500	87.000	26.833	5.500	545.386
1970	178.350	156.592	115.230	27.872	5.250	651.798
1971	184.000	166.000	120.000	28.700	5.850	679.299
1972	174.660	186.800	125.000	29.800	5.300	704.811
1973	180.000	197.200	130.000	30.400	5.432	735.303
1974	184.000	236.000	135.000	23.753	5.500	769.449
1975	188.000	254.000	140.000	24.187	5.650	804.707
1976	190.000	270.000	140.000	24.621	5.700	817.052
1977	195.000	280.000	150.000	25.594	5.750	862.384
1978	173.000	300.000	155.000	26.500	5.850	898.488
1979	171.400	320.000	114.000	27.500	5.900	870.287
1980	166.700	330.000	120.000	28.423	5.950	883.018
1981	158.900	340.000	125.000	29.000	6.000	894.382

Notes: 0 Average 1948-1952; 1 Average 1952-1956; 2 Average 1961-1965; * Estimated

Before 1969 figures represent the total for South America plus North America except USA, Canada, Greenland, Bermuda, Bahamas, Virgin Islands (USA & UK).

Source: FAO's Statistical Yearbooks.

Table 2: Fertilizer use in Argentina (Tons)

Years	N	P
1956/7	2.618	2.323
1957/8	.967	2.105
1958/9	2.616	2.701
1959/60	1.382	.996
1960/1	2.045	2.299
1961/2	2.058	2.847
1962/3	1.124	1.851
1963/4	2.940	4.158
1964/5	4.630	4.853
1965/6	5.674	5.548
1966/7	8.038	5.116
1967/8	6.756	4.803
1968/9	9.083	6.240
1969/70	10.808	6.554
1970/1	11.452	5.987
1971/2	10.231	6.605
1972	49.101	20.636
1973	45.264	10.840
1974	35.109	13.358
1975	27.633	4.023
1976	45.719	12.827
1977	40.214	12.092
1978	44.412	14.206
1979	60.576	28.219
1980	65.354	21.826
1981	51.172	12.606
1982	50.926	19.953
1983	64.616	24.495

Source: Department of Agriculture, Argentina.

NOTES

1. In a nonrigorous way, agricultural technologies may be classified in four broad categories. The first three correspond to the embodied type, that is, the technology is carried by a marketable good. They are: a) machinery and equipment; b) improved seeds; and c) chemicals including fertilizers, pesticides and herbicides. The fourth type corresponds to agronomic and management practices like cultivation methods, depth of sowing, etc. In general they relate to the best way of using and combining the embodied technologies.

2. See for example Sábato, J. and Piñeiro, M. et al.

3. See Martínez Nogueira, R. and Balcázar, A. et al.

4. If the number of tractors is standardized by horse power, the curve is less flat because in Latin America, as in the USA, the average power has significantly increased in the last decade.

5. Reydon, B.Ph., Ortega, A.O. and da Silva, J.G.

6. See for example Piñeiro, M. et al. and Balcázar, A. et al.

7. See Sábato, J. for Argentina and da Silva, J.G. et al. for Brazil.

8. In some crops like sunflowers or soybeans in Argentina, imported seed was used directly by farmers.

9. See Piñeiro for a description of the development of the institutes.

10. For a presentation of this subject see Piñeiro, M. and Trigo, E. (ed.).

11. For a detailed treatment of the subject, see Piñeiro, M. and Trigo, E. (ed.), 1983.

12. PROTAAL, second phase. See Piñeiro, M. and Chapman, J. for a discussion of the main results.

13. A description of this role in the case of Argentina for cereals can be seen in Jacobs, E. and Gutiérrez, M. and Obschatko, E.; for sugar in Colombia in Piñeiro, M. et al.; in Brazil for sugar, wheat and a number of other crops in Reydon, B.P. et al.; and in Ecuador for potatoes and palm oil in Barsky, O. and Llovet, and Carrión, L. and Cuvi, M. respectively.

14. See Jacobs, E. and Gutiérrez, M., and da Silveira, J.M.F.J. for a discussion of this topic in Argentina and Brazil respectively.

15. The importance of transnational firms in the seed industry is part of an overall process of growth of transnational corporations in Latin America.

16. Obschatko, E.

17. Belik, W.

18. Piñeiro, M. et al.

19. Scobie, G.

REFERENCES

Balcazar, A. et al. Estudio del proceso de generación, difusión y adopción de technología en la producción de arroz en Colombia. PROTAAL Document Nr. 41, IICA, Bogotá, 1980.

Belik, W. A pesquisa agrícola no setor de acúcar e álcool en São Paulo. PROAGRO Project, DEPE/UNICAMP, Campinas, 1984.

Da Silva, J.G. et al. Diferenciación campesina y cambio technológico. El caso de los productores de frijol en Sao Paulo. PROTAAL Document Nr. 88, DEPE/UNICAMP, Campinas, 1983.

Evenson, R. Cycles in research productivity in sugarcane, wheat and rice, in *Resource Allocation and Productivity*, edited by R. Arndt, D. Darlymple and V. Ruttan.

Jacobs, E. and Gutieerez, M. La industria de semillas en la Argentina. PROAGRO Project, Doc. Nr. 2, 1984.

Martinez Nogueira, R. Los consorcios rurales de experimentación agrícola: evolución e impacto. PROAGRO Project, Doc. Nr. 6, 1984.

Obschatko, E. Los hitos technológicos en la agricultura pampeana y el sector privado. PROAGRO Project, Doc. Nr. 10, 1984.

Piñeiro, M. et al. Articulación social y cambio técnico: la producción de azúcar en Colombia. IICA, San José, 1982.

Piñeiro, M. and Trigo, E. Public policy and technical change in Latin American agriculture, in *Food Policy*, 1983.

Piñeiro, M. and Trigo, E. (ed.). *Technical change and social conflict in agriculture. Latin American perspectives*. Westview Press, Boulder, Colorado, 1983.

Piñeiro, M. and Trigo, E. (ed.). Cambio téchnico en el agro latinoamericano. Situación y perspectivas en la década de 1980. IICA, San José, 1983.

Piñeiro, M. and Chapman, J. Cambio técnico y diferenciación en las economías campesinas. Un análisis de seis estudios de caso en América Latina, in "Estudios Rurales Latinoamericanos," Vol. 7, Nr. 1, 1984.

Reydon, B., Ortega, A.O. and da Silva, J.G. Inovacões tecnológicas nas principais culturas do Estado de São Paulo. PROAGRO Project, Doc. Nr. 12, DEPE/UNICAMP, Campinas, 1984.

Sabato, J. La pampa pródiga: claves de una frustración. CISEA, 1981.

Scobie, G.M. nad Posada, T.R. El impacto de las variedades de arrox con altos rendimientos en América Latina con énfasis especial en Colombia. CIAT, 1977.

Trigo, E. and Piñeiro, M. Dynamics of agricultural research organization in Latin America, *Food Policy*, 6 2-10, 1981.

CHAPTER FOUR

The Changing Economy and the Family

by
Theodore W. Schultz

THE CHANGING ECONOMY AND THE FAMILY*

Theodore W. Schultz**

The economics of the family is not blissful. It seems doubtful that the family can survive the dismal propensities of economists. It is not that we belong to the Club of Rome. We stay true to our classical vows. Being true to our logic, our findings are not cheerful. We find the stability of the family being impaired by increases in human capital, by the secular rise in the value of human time, and by generous income transfers, U.S. divorce rate doubled since 1960, and the illegitimate birth rate also doubled.[1] The better the performance of the economy and the larger the earning power of women, the greater the decline of the family. It would be premature, however, to infer from all of this that the family is fading away.

For better or worse, the bearing and rearing of children will not fade away. The comparative advantage of producing one's own children is not in doubt. As yet, there is no acceptable biological substitute for bearing them and no all-inclusive social substitute for rearing them. We have the theory and supporting evidence to explain fewer children per family. How few are enough is not revealed to us. Even China with her centrally controlled society is not capable of enforcing her "one-child family" policy.

The family is not an economic entity on a par with that of the firm, the household or the market. The family is in essence a biological, cultural, legal and economic institution. But we do not treat these characteristics of the family as an institution. Marriage, however, is much less troublesome whether it is sanctioned by Church or by civil authorities including common law marriages. When it comes to data and empirical work, it is inconvenient to find that large numbers of couples who are living together are not married.[2] Marriage as an institution has not been a fruitful source of economic hypotheses, whereas the marriage market idea has opened an important new research area.

The family as a biological, cultural and legal entity has a long history in dealing with political and economic changes. The short view of this process is heavy with pessimism, stated succinctly by Becker at the outset in <u>A Treatise on the Family</u>. The Family in the Western World has been radically altered, some claim almost destroyed, by events of the last three decades.[3] In his last chapter on "The Evolution of the Family," the long view emerges based on many historical accounts. It implies a strong survival capacity on the part of the family.

By no means are all aspects of the recent decline of the family bad, hard as it is to distinguish the bad from the good. Taking the long view, the survival ability of the family is more than Darwinism.

Family Entrepreneurship

It will not suffice to treat the family as a passive entity. Its actions are not wholly routine and repetitive. The family is not a robot. It is a calculating entity; decisions are made and actions are taken. I find it useful to think of the family as dealing with changes in conditions that originate either from within the family or from outside of the family. A placid society, serenely free of disturbing changes has not been the lot of families during the past. In my view it is inevitable that future families will also be dealing with changes.

In reality there are few if any families that manage throughout their family life span to attain and maintain at all junctures an equilibrium as changes occur. What we should endeavor to determine

---

*I am indebted to Mary Jean Bowman, John Letiche, Margaret Reid, Vernon Ruttan and T. Paul Schultz for their critical comments. This paper is a slightly revised version prepared for a Conference on the Family and the Distribution of Economic Rewards, Salt Lake City, Sept. 20-22, 1984. The official conference papers will appear as a special issue of the <u>Journal of Labor Economics</u>, April 1986.

**Professor of Economics, the University of Chicago.

are the incentives that induce the members of the family to bring it into equilibrium. The disequilibria are not restricted to the economic domain since they also occur in the biological, cultural and legal domains of the family.

Since we specialize on the economic behavior of families, I find it hard to understand why the entrepreneurial function of families has been omitted in our family economic research. Milton Friedman's studies have not been in the mainstream of the family economics here under consideration, and yet he, in his classic "consumption function" book,[4] features entrepreneurial families in both the theoretical and the empirical parts of that book.

Our economic approach tends not to get at the interacting effects of the performance of the economy and the behavior of the family. It is not that we postulate a wholly self-sufficient family. What we tend to do, however, is to abstract from the changes in the economy by treating them as data that are given. Much and perhaps most of what we want to know about the economics of the family, in addition to what is now known, are the effects of the performance of the economy on the opportunities, on the composition and on the functions of the family. A part of the supporting argument is that the options, roles and economic importance of the family are strongly linked to the performance and achievements of the economy over time. The family is not spared from even short run periodic changes, be they business cycles, fluctuations in employment, good and bad monsoons (India) or from large shifts in the rates of economic growth. Studies of long periods of accumulative economic changes, with notable large increases in per capita income, would substantially increase our understanding of U.S. families at this juncture.

When we take a long view of changes in the family, during which economic possibilities were being extended, we observe that the market specializes and produces at a lower cost many services that families formerly produced for themselves. Specialization also alters the composition of families as prime adults, other than wife and husband, leave the family and establish separate households. Accumulative increases in family income make it financially possible for parents to support the marriages and the separate households of their children at an age before they are prepared to earn enough to do it on their own. The favorable personal income also makes it possible for retired couples and individuals to maintain a household that is separate from that of their adult children. Thus, the composition of the family changes as the number of adults who are in it declines as a consequence of the increases in opportunities created by economic growth. The entrepreneurial function of families continues to be important as a consequence of the changing economic conditions that characterize economic growth.

Decline of the Family

The number of kinfolk attached to the wife-husband family core declines. The economic self-sufficiency of the family declines. The support that adult children provide their parents over the last years of their parents' lives, and earlier when adversities strike, declines. Since research on these issues is still fragmented, these changes in the family may be viewed as an hypothesis. For reasons already presented, I see it as an acceptable proposition on a par with the widely observed worldwide decline of the economic importance of the agricultural sector, and closely related, on a par with declines in the share of national income derived from the Ricardian "original properties of the soil," in the form of land rent.

Research on the economics of the family has reached the state that it should be possible to give a provisional answer to the question, "When will these particular declines pertaining to the family have completed their downward course?" The increase in the fraction of married women who are in the labor force, part or full-time, has as yet not peaked. There are no apparent reasons for believing that the value of the time of women will not continue to rise as a consequence of modern economic growth. As the demand for labor requiring brute strength declines and that for skills requiring less physical effort increases, it is plausible that the value of the productivity of the time of women will rise relative to that of men and in so doing narrow the gap in wages or salaries between them. As yet, a general economic equilibrium in the allocation of the time of women among bearing children, household activities (including the rearing of children) and work in the labor market, is not at hand.

The utility implications of these various elements in the decline of the family as an economic entity, await analysis. Meanwhile, the accumulative increases in personal family income, taking the long view, are likely to continue. With respect to the observable decline in family economic self-sufficiency over time, I have no doubt that a careful reckoning would show that families enhance the utility they derive from their increasing dependency on the performance of the market. Fewer kinfolk and less dependency on one's children during old age are also sources of some utility.

Interactions Between the Economy and the Family

Applications of economics to the behavior of families have produced an impressive body of new knowledge. But our theory has not been extended to deal with the nature and significance of economic changes that originate not from within the family but from within the rest of the economy and also to deal with the infractions between them. Consider the following unsettled issues.

1. The Life Span Boom. In most low income countries since the late 1940s, the cost of acquiring a longer life has declined relative to the value that people place on their own additional life time. The resulting observable increases in life expectancy must be viewed as an extraordinary achievement. It took Western Europe and North America very much longer than it has many low income countries more recently. In India, as a case in point, the life expectancy at birth of males increased 43 percent and that of females, 41 percent between the 1951 and 1971 censuses.[5] By 1981, life expectancy at birth of the Indian population was 52, as estimated by the World Bank,[6] an increase of 63 percent over that in 1951. India exemplifies this "life-span boom" of the last three decades. It has enhanced human well-being, unevenly to be sure. A large part of it has had its origin in advances in knowledge. Families benefited from collective efforts to suppress malaria, to reduce tuberculosis and various endemic diseases, from the availability of modern drugs, from the service of health centers and from improvements in nutrition from more and better food. We want to know, so it seems to me: (1) the economics of the observed decline in the price of an additional year of expected life; (2) the economics of the rate at which families respond to this lower price; and then (3) the economics of the resulting changes in family composition, in age profiles of its members and in the functions of the family. My assumption is that an important part of the explanation of the "life-span boom" is in the economics of the decline of the price of the extensions in life expectancy.

I am always on my guard when I am with an economist who is reluctant to be associated with changes in relative prices. If he is beholden to a centrally managed economy, it is the better part of wisdom to discuss poetry. In reality, changes in relative prices are the mainspring that produce the necessary incentives for economic efficiency in the process of modernization.

We, too, in many of the applications of our approach to family behavior have for reasons of empirical convenience concentrated on changes in earned income (wages and salaries). But the origins and the effects of changes in relative prices of commodities, changes in the relative rents paid for the use of property (houses, automobiles, household durables), and changes in relative prices of services, are rarely being analyzed.

Changes in relative prices create the incentives that result in changes in composition and the size of the stock of capital and in the sources of family income. The interactions between these changes and that of the family, as the following cases suggest, should be on our research agenda.

2. Wheat-rice Price Ratios. Wheat and rice are the world's major food grains. Wheat has become very cheap, much more so than rice. Half and more of family income of most rice eaters is spent on food; many, if not most, wheat eaters spend a small fraction of their income on food. In the U.S. only 16 percent of personal income goes for food.

On the London "World Market," during 1867-77, wheat prices exceeded those of rice by 30 percent, by 1911-14 they were about the same. For some years now, world wheat prices have been half of rice prices.[7,8] Since the nutritional value per ton of these two food grains is virtually the same, there is the dual puzzle: Why has the cost of producing wheat declined so much relative to that of rice? Why has wheat been a weak substitute for rice?

In reckoning the changes in the demand for labor, in the case of wheat it has become a man's job; in rice, however, in the parts of Asia, where people are poor, much of the work in planting and harvesting rice is a woman's job. What are the male and female labor demands and earnings implications for family behavior?

3. Labor in Corn and Milk Production. In the U.S. between 1929 and 1979, the hours of labor required to produce 100 bushels of corn dropped from 115 to 3 hours, and to produce 100 pounds of milk it fell from 3.3 hours to .3 of an hour. The deflated corn price declined 30 percent while that of milk rose 13 percent. Real farm wages rose over 3 fold ($.49 to $1.59; nominal $.25 to $3.41 per hour). There is only a small demand for the labor of women in corn production; in milk production, however, (dairy farming) the demand for the labor of farm women is sufficient to reduce their off-farm employment compared to that of women on farms that specialize in producing field crops. Sumner's off-farm labor supply and earnings of farm family members study based on a sample of Illinois farms, shows "that wives of dairy farmers are less likely to work off the farm" than wives on other types of farms.[9]

4. Evidence to test the role that changes in relative prices play in the behavior of families is hard to come by. A recent study by T. Paul Schultz, based on evidence for Sweden, 1860-1914, shows that the decline in the price of rye relative to butter led to increases in the wages of women relative to that of men and to the fertility transition.[10] The conclusion is that "...country level data for this 50 year period in Sweden suggests that the appreciating value of women's time relative to men's, played an important role in the Swedish fertility transition, holding constant for real wages of men, child mortality, and urbanization."[11]

Family Entrepreneurship and Transitory Income

Explain, if you can, why the theory and empirical work on the permanent and transitory components of family income have been so grossly neglected in our research on the economics of the family. I have in mind the neglect of the family income studies of Dorothy S. Brady based on U.S. 1935-36 data covering small cities, villages and farms;[12] and the neglect of the analyses of the large differences in the transitory component in the income of families in various data sets by Margaret G. Reid.[13] Even more serious has been the neglect of the advance in theory and the applications of that theory by Milton Friedman.[14]

Dorothy Brady's transitory income clue is in the changes in assets and liabilities of urban, village and farm families during 1935-36. Margaret Reid extended the search by examining various forms of capital formation by families and by analyzing the behavior of other families at other dates and locations. Milton Friedman drew in part on Brady's and Reid's findings and proceeded to establish a strong linkage between entrepreneurship and transitory income, namely that the ratio of permanent consumption to permanent income has been decidedly higher for families of wage earners than for entrepreneurial families and that the difference between entrepreneurial and nonentrepreneurial families in the ratio of permanent consumption to permanent income, "...seems larger and better established than any other we have examined."[15]

Having given thought to the possible reasons for this neglect, I rule out intellectual hostility on our part to the concepts of permanent and transitory income. I also rule out that family income studies using these concepts were not known by us. The reason is that Brady, Reid and Friedman were analyzing the economic behavior of families under a wide array of changes in economic conditions. In their approach they did not exclude events that required entrepreneurship to reestablish an economic equilibrium. On this important issue, the analytical domain of our approach to the economic behavior of families is decidedly more restrictive.

On Distribution of Economic Rewards

For me the observable changes in the distribution of economic rewards as income or as wealth are in part a consequence of what is done by families during a generation and over two or even more generations in distributing their endowments. Both in theory and its application, our knowledge pertaining to this part is substantial and useful.

Another part of this distribution of economic rewards is a consequence of changes in economic conditions over time. Clearly, it is this part that is central in my thinking on the issue at hand. A decline in the price of food improves the economic lot of poor people more than that of people who are not so poor. In Ricardo's day, the families of laborers were giving up half and more of their wages for food. In North America and most of Western Europe, as modernization has proceeded, the fraction of family income spent on food has dropped to less than one-fifth of personal family income. Gains in the productivity and economic efficiency of agriculture, for reasons stated, reduce the inequality in the personal distribution of income. The share of national income going to landlords declines as Ricardian land rents become smaller relative to other sources of income. Here, too, income inequality is reduced. Kuznets takes a fairly long view of the decline in the share of national income derived from property from about 45 to 25 percent while labor's part rose from 55 to 75 percent.[16]

My hypothesis is that the fivefold increase in real wages per hour of work in the U.S. since 1900 has swamped the within family and the intergeneration personal distributions of income. Thus, what matters most are the increases in the value of human time over time.

* * *

What I've done is to leave family reform to others.

Producing one's own children is a family matter. The family is not about to fade away. The family in its economic behavior is a flexible and robust entity. By no means have all of the recent changes in the family been bad; quite the contrary, most of them are not inconsistent with optimal economic behavior.

While we have learned a great deal from our economic approach to family behavior, it is my contention that our analytical work should be extended to relate the economic changes in the rest of the economy to that of the family exemplified by the "life span revolution," and by large shifts in relative prices in commodities, durables and services. There is the hard to explain neglect of the highly competent family income studies based on the permanent and transitory income concepts. Then, too, the entrepreneurial behavior of families as economic conditions change is being neglected in our analytical work.

What families do to the distribution of their economic endowments is far less important than the distributional effects of the general increases over time in real per capita incomes, the changes in the composition of that income, its permanent and transitory components, and the increases in the ratio of that income derived from human capital, namely from wages, salaries and entrepreneurial rewards relative to that from property.

NOTES

1. Gary S. Becker, A Treatis on the Family, Harvard University Press, 1981, Chapter II, "The Evolution of the Family," pp. 237-256. Figures 11.1 and 11.5.

2. Becker, ibid, Figure 11.6, p. 248. The number of such couples is now about 2 millions.

3. Becker, ibid, in the Introduction, first sentence, p. 1.

4. Milton Friedman, A Theory of the Consumption Function, Princeton University Press, 1957.

5. Rati Ram and Theodore W. Schultz, "Life Span, Health, Savings, and Productivity," Economic Development and Cultural Change, Vol. 27, April, 1979, pp. 399-421.

6. World Development Report, 1983, issued by the World Bank, July 1983, Table 23, pp. 192-3.

7. A.J.H. Latham and Larry Neal, "The International Market in Rice and Wheat, 1868-1914," The Economic History Review, 2nd Series, Vol. 36, May 1983, pp. 260-280. See, Appendix 2, Cols. B and G. The text shows the market linkages between rice and wheat in India and in London.

8. Theodore W. Schultz, "On Economics and Politics of Agriculture," Appendix A, p. 21, in Distortions of Agricultural Incentives, Indiana University Press, 1978, edited by Theodore W. Schultz. Updated based on U.S.D.A. official statistics.

9. Daniel Sumner, "Off-Farm Labor Supply and Earnings of Farm Family Members," Ph.D. dissertation, Department of Economics, University of Chicago, December 1977.

10. T. Paul Schultz, "Changing World Prices, the Wages of Women and Men, and the Fertility Transition: Sweden 1860-1914." April 4, 1984, paper presented at the Population Association of America meetings, Minneapolis, May 4, 1984.

11. Ibid, p. 22.

12. Consumer Purchases Study, Urban, Village and Farm," Changes in Assets and Liabilities of Famility, Five Regions, Misc. Pub. No. 464, U.S. Dept. of Agriculture, 1941, 225 pages, Dorothy S. Brady, senior author. Also, Family Income and Expenditures, Five Regions, Farm Series, Misc. Pub. No. 465, 1941, 366 pages.

13. Margaret G. Reid, "Effect of Income Concept upon Expenditure Curves of Farm Families," Studies in Income and Wealth, National Bureau of Economic Research, New York, Vol. 15, 1952, pp. 133-174.

14. Milton Friedman, A Theory of the Consumption Function, Princeton University Press, Princeton, 1957.

15. Ibid, p. 227.

16. See, Simon Kuznets, Modern Economic Growth, Yale University Press, 1966; also, see my elaboration on Kuznets' analysis in my Investing in People, Chapter 4, "The Economics of the Value of Human Time," California University Press, 1980, pp. 59-84.

CHAPTER FIVE

The Adaptive Development of Public Educational Systems: Intercountry Estimates of the Effects of Income, Input Prices, and Population Growth

by
T. Paul Schultz

THE ADAPTIVE DEVELOPMENT OF PUBLIC EDUCATIONAL SYSTEMS: INTERCOUNTRY ESTIMATES OF THE EFFECTS OF INCOME, INPUT PRICES, AND POPULATION GROWTH*

T. Paul Schultz**

A distinctive development of the last 25 years is the rapid expansion of school systems in all parts of the world. Despite the unprecedented rate of growth in the population reaching school age, enrollment rates at these ages have increased in virtually every country. This paper examines these developments to understand their origins and how economic and demographic factors may be governing this rapidly growing dimension of world investment.

To put these developments in perspective, this paper proposes a production-demand framework for explaining the level and distribution of national expenditures on schooling and enrollment rates. Incomes, relative factor prices, production technology, and demographic structure are interrelated as constraints and conditions affecting the costs of, and demands for, educational services. Data for 89 countries from 1960 to 1980 are then used to test empirically a variety of hypotheses within this framework, including whether rapid population growth, which contributes to an increase in the relative size of a school-aged cohort, thereby affects that cohort's educational opportunities and achievements. Differences in school enrollment between males and females are also examined. Finally, regional and religious deviations in educational expenditures and achievements are calculated, based on the fitted model. The uniformity and quality of the intercountry data and the simplicity of the statistical treatment of this mix of cross sectional and time series materials leave much room for future analytical improvements. Nonetheless, this initial examination of educational systems confirms that these institutions are being induced to adapt to the constraints imposed by incomes, relative factor prices and population growth.

The hypothesis has been advanced that rapid population growth makes it more difficult for a society to educate its youth (Jones, 1971, 1975; Robinson, 1975; World Bank, 1974, 1984). Obviously, a reduction in fertility leads to a reduction in the number of children of school age in six to eight years. This demographic development reduces in this sense the need for schools, and these potential public savings due to fertility declines can be used to achieve other social goals (Coale and Hoover, 1958, p. 25). To quantify the consequences of population growth on the educational system and society, it is often assumed that the allocation of resources to this public sector activity is fixed and does not respond to the changing private demands of the society for these services.

Perhaps, a more plausible institutional hypothesis is that public expenditures on the educational system respond to private demands for schooling and one determinant of these demands is the size of school-aged cohorts. But the public sector responds imperfectly and with lags, due to bottlenecks, as for example, the time required to increase the supply of trained teachers to educate a growing student population. According to this view, educational expenditures and achievements per child may fall short of long-run desired trends (equilibrium) in periods when the school-aged population is a relatively large and growing fraction of the total population, and the opposite tendency may emerge when school staff and structures exceed requirements temporarily due to a decline in fertility. At issue is how important is the relative size of the school-aged population for the allocation of resources to the national educational system (e.g., Freeman, 1979; Lee, 1979; Welch, 1979; Easterlin, 1980; Simon and Pilarski, 1979). Empirically measuring the elasticity of educational inputs and outputs with respect to the relative size of school-aged cohorts is, therefore, an important objective of this study.[1]

---

*This paper is a revised version of a background paper (Schultz, 1986) for the National Academy of Sciences working group on Population Growth and Economic Development. The research assistance of L. Karoly, A. Levin, and P. McGuire are appreciated. The comments of A. Kelley, M. Rosenzweig, T. W. Schultz, and J. Strauss were valuable. The research was supported by a grant from the General Service Foundation.

**Professor of Economics, Yale University.

The statistical problem is to hold constant for other exogenous factors that might explain the level and distribution of public expenditures on schooling and school achievement across countries and over time. It is particularly important to measure and hold constant those factors that might help to account for educational priorities in a society or that represent supplementary private inputs to the educational process. When these other factors are omitted from the empirical analysis and they are also associated with the relative size of the school-aged population, the observed partial association between schooling and cohort size will be a biased measure of the hypothesized demographic effect of cohort size on schooling per child. The challenge is to minimize this potential source of bias.

One reason it is difficult to measure the relationship between relative cohort size and educational inputs and outputs is because the size of the school-aged cohort is primarily a lagged measure of period fertility rates. The fertility of parents is inversely related to what parents privately invest in the schooling of each of their children, and this trade-off of quantity and quality has attracted the attention of many social scientists (e.g., Wray, 1971; Belmont and Marolla, 1973; Terhune, 1974; Becker and Lewis, 1974). The observation that fertility and schooling are inversely related does not imply "one" causes the "other." Indeed, both are jointly chosen to some degree by parents in response to their economic and biological endowments, constraints and preferences. It is important, therefore, that the inverse correlation between fertility and child schooling must not be mistaken for evidence confirming the effect of relative cohort size on public educational expenditures or enrollments (Schultz, 1971, 1981; Rosenzweig and Wolpin, 1980). The analytical problem is how to distinguish between two possible parallel associations: the first at the level of family choice between increases in parent investments in the schooling of their children and declines in their fertility, and the second at the aggregate level between the relative size of a school-aged cohort and the resultant squeeze on available school inputs and outputs per child. The strategy adopted here for separating these two relationships is to estimate the partial correlation between relative school-age cohort size and indicators of school expenditures and outputs, holding constant for current total fertility rates. Estimates are reported elsewhere (Schultz, 1986) without controlling for current period fertility. Information on a better indicator of the lifetime reproductive performance of the parents of the school-aged cohort is not available from the majority of countries. If the estimated "effect" of school-aged cohort size remains important after controlling for current total fertility, the aggregate "squeezing out" causal hypothesis is tentatively sustained.

This empirical strategy should be more successful when fertility and child mortality are in flux. At such times it should be possible to discriminate statistically between (1) the covariance of current fertility and current parent investments in child schooling and (2) the repercussions of lagged fertility (and child mortality) on cohort size and thus on the schooling system. The framework may therefore be more discriminating in the study of the effects of cohort size on schooling at the secondary level rather than at the primary level, because the lag separating fertility and the size of these school-aged cohorts is longer, about 12 compared to 8 years, on average.

The next section of the paper reviews world trends in school enrollments and central government expenditures on education and identifies a number of issues for further study. The determinants of demand for public schooling are then modeled to specify how to proceed with the empirical analysis. The empirical analysis follows with data from about 90 countries in the last three decades, and the concluding section uses these results to predict the recent trends over time. A data appendix describes the sources, character and limitations of these data, and provides supplementary tables.

World Trends

Table 1 (page 96) summarizes the level and increase in enrollment ratios at the primary, secondary and higher education level for countries grouped by income level, market/nonmarket economy, and oil exporter status. For summary comparison of overall levels of schooling, a synthetic cohort measure is constructed and called hereafter the "expected years of schooling." It is defined as the sum of six times the primary, six times the secondary, and five times the higher educational enrollment ratios; where these weights, i.e., 6, 6 and 5, correspond to the average number of single-year age groups combined in the denominators of these three standardized enrollment ratios.

Expected years of schooling increased 32 percent from 1960 to 1981 in the low income class of countries; 46 percent gains were achieved in the middle income countries who imported oil, and 50 percent gains occurred in the upper middle income class. The East European non-market countries increased their expected years of schooling by 35 percent, while the industrial market high income countries advanced 16 percent. Oil exporters in the middle income class achieved a doubling of expected schooling levels, while nearly a fourfold increase was reported in the high income oil exporters.

In general, the percentage gains in schooling were greater for those countries that started from a lower level in 1960. The gap in expected years of schooling between the low and high income countries is therefore closing, on average, whether expressed in relative terms or even as an absolute difference in years. This closure in the education gap appears to be even more rapid in relative terms than that achieved in health, analogously summarized by life expectation at birth. The gap in expected education and life at birth between the lowest income countries (excluding India and China in the World Bank categories) and the high income industrial market economies decreased markedly in the last two decades. Life expectation stood at about 43 and 71 years in 1960, and had increased to roughly 51 and 75 years by 1982 in these two groups of countries, respectively. Expected years of schooling, on the other hand, increased for these two groups of countries from almost 3 and 11.5 years in 1960, to almost 6 and 13.3 years in 1982, or from one-to-four to one-to-two. These achievements were recorded despite the fact that income (GNP) per capita in constant prices grew in the same period three times faster in the high income countries than it did in this lowest income group of countries.[2]

The salient fact is that all classes of countries, and indeed every country for which overall comparisons can be drawn, increased the expected schooling that it provided to the "average" child over these two decades, despite the extraordinarily rapid growth in the number of school-aged children in many of the poorest countries. The number of children between the ages of 6 and 17 more than doubled in the less developed regions from 1950 to 1980. The proportion of the population in these ages increased from 24.5 percent in 1950 to 29.1 percent in 1980, or by 19 percent.[3] That the poorest countries and those that have suffered actual declines in their real income in this period were nonetheless able to expand their schooling systems rapidly enough to accommodate an increasing fraction of their children is a remarkable achievement.

However, a less sanguine picture of recent educational progress emerges from World Bank data assembled in Table 2 (page 97). Central governmental expenditures on education (and health), when expressed in terms of constant GNP prices, have declined in many countries in the past decade. Among low and middle income countries who are not oil exporters the share of government expenditures allocated to education (and health) declined (columns 1-4). The share of total government expenditures in GNP also declined in the low income countries and increased only slightly in the middle income oil importers (columns 5 and 6). Resources allocated to education per capita by central governments appear to have declined markedly in real terms in the low income countries (including or excluding India and China) and increased by only 22 percent in the middle income oil importing countries. In contrast, oil exporting middle income and upper middle income countries were able to more than double their per capita real public expenditures for education, while the high-income industrial countries raised their real outlays on education by 88 percent. Central government expenditures on health experienced a comparable decline in the low income countries and grew less rapidly than educational expenditures in all other classes of countries (column 9, Table 2).

The puzzle is how did the poorer countries sustain the growth in enrollments in an era when central government real outlays for education per capita were tapering off? Several developments could be responsible for these seemingly divergent trends. The unit costs of producing educational services may have declined, such as might occur if the price of educational inputs declined relative to the GNP deflator, or production economies of scale in school systems were realized. Alternatively, the quality of schooling services may have deteriorated.

The dominant cost of primary and secondary school systems is the salary of teachers (World Bank, 1983). Teacher wages may have declined relative to the general wage level with development, as they have in the 20th century in the United States (Williamson and Lindert, 1980, p. 308). The supply of teachers may have "outgrown" the demand in many countries, while highly paid expatriates were replaced by less expensive indigenous personnel. Alternatively, the quality (and pay) of teachers may have deteriorated. Both may have occurred. In the first case, the real resources available to the school system may not have fallen as rapidly as (or grew more rapidly than) the figures suggest in Column 8 of Table 2. Human and physical capital may also have been used more intensively over time, with teacher-to-student ratios increasing and capital expenditures as a share of total expenditures falling. These developments would be associated with larger classes, and perhaps less effective or lower quality instruction.

Other developments may also explain the aggregate trends. Private school expenditures may have increased as a share of total educational outlays. But this appears unlikely, because private school enrollments are generally modest, and are a declining share of total enrollments in most low income countries.[4] Tuition and fees may also transfer some of the resource costs of public schools from public expenditures to parents.[5] The reliance on such user fees, though increasingly debated as an auxiliary means of supporting educational expansion, has nonetheless been eroded by recent inflation and policy changes even in Africa (Jiminez, 1984). Sub-national and local public expenditures on education are excluded from the worldwide figures reported in Table 2, and local expenditures may have replaced central government outlays on education in recent years as oil shocks and trade imbalances have forced central governments to retrench.

In sum, many factors could be behind the decline in central governmental expenditures on education in the lowest income countries: (1) the actual quality of schooling per student may have declined; (2) the price of constant quality educational services relative to the general price level (GNP deflator) may have declined; (3) central government revenues for education may have declined relative to other local sources of support for public education; (4) private school expenditures may have increased their share of the market, though enrollment data do not support this conjecture; and (5) the underlying data may be in error. The subsequent cross country empirical analysis of public educational systems is restricted to countries for which there appear to be consistent data on enrollments, teachers, expenditures on current and capital account, estimates of GNP in constant prices, urbanization and the population's age composition. The restricted data are believed to be more reliable than the comprehensive estimates reported in Table 2, but possibly less representative. Although UNESCO public expenditure data also represent the sum of government outlays at all administrative levels, they probably in fact frequently omit local resources provided in kind to construct and maintain basic school structures. Estimates are later obtained of changes in relative prices (2) and changes in factor intensity or quality (1) in the use of teachers and physical capital. However, there is no unambiguous way to distinguish between changes in the quality of school inputs and changes in the prices of quality-constant inputs, since the capacity of schools to raise the market productivity and to augment the utility of students remains unobserved.

The question raised in this review of world trends is how were enrollment rates increased, when central government expenditures decreased in real per capita terms or rose more slowly than did the school-aged population. Before considering patterns in these data from various countries, it is useful to have an overall framework within which to account for variation in the provision of educational services. The framework involves three parts: an interpretation of the political economy translating private demands into public expenditure decisions, a production technology linking educational inputs to outputs, and the determinants of household demand for public educational services.

Adjustment of the Educational System to Demand and Supply

Analyses of the private demand for public goods have generally assumed that citizens know about the costs of production and the benefits of government spending (e.g., Borcherding and Deacon, 1972). The political process is assumed to be more or less democratic, in the sense that entrepreneur-politicians seek "election" to deliver efficiently the public goods and services and the associated tax burden that command jointly the support of a majority of voters.[6] The essential idea is that public, as well as private, institutions are constrained in their input allocation and production decisions by consumer incomes and perceived benefits of outputs, on the one hand, and given technological possibilities and relative input prices, on the other.

The private demand for public education, however, involves several special features that warrant additional discussion. First, education is demanded both as a consumer good that yields direct utility and as a producer good that is expected to enhance the future productivity of the educated individual (T.W. Schultz, 1961). Private demand of consumer goods depends on consumer income, relative prices and tastes. The taste for education is conventionally assumed uncorrelated with observed demand determinants, though this can be relaxed, if an exogenous proxy for taste can be distinguished; the examination later of male and female enrollment rates conditional on religion might be viewed as assuming religion is such a proxy for exogenous cultural taste.

Education is also a produced means of production, and economists have reasoned that the private and social demand for education should be influenced by its private and social rates of return, relative to alternative investment opportunities (Becker, 1964). However, the cross-sectional relationship observed between the rate of return to schooling and the public (and private) expenditures on schooling need not represent only the private supply function of investment in this means of production. The rate of return is also affected by the aggregate economy's derived demand for more and less educated workers. Unless factors can be specified a priori that shift one and not the other side of this market for more educated labor, it is not generally possible to identify statistically the individual's investment supply response function from the aggregate derived demand function for educated labor. It would be useful for our purposes if we could specify exogenous endowments to the economy, such as natural resources, or technological dimensions to the development process, such as the age of the capital stock, that affect the derived demands for relatively better educated labor and hence raise or lower the producer returns to education. However, there is as yet no agreement on what these factors might be. In the later empirical analysis, income, relative prices and technological constraints are seen as influencing the consumer's demand for education, but they may also shift the derived demand for educated labor and thereby vary the rate of return to education as a producer good.[7]

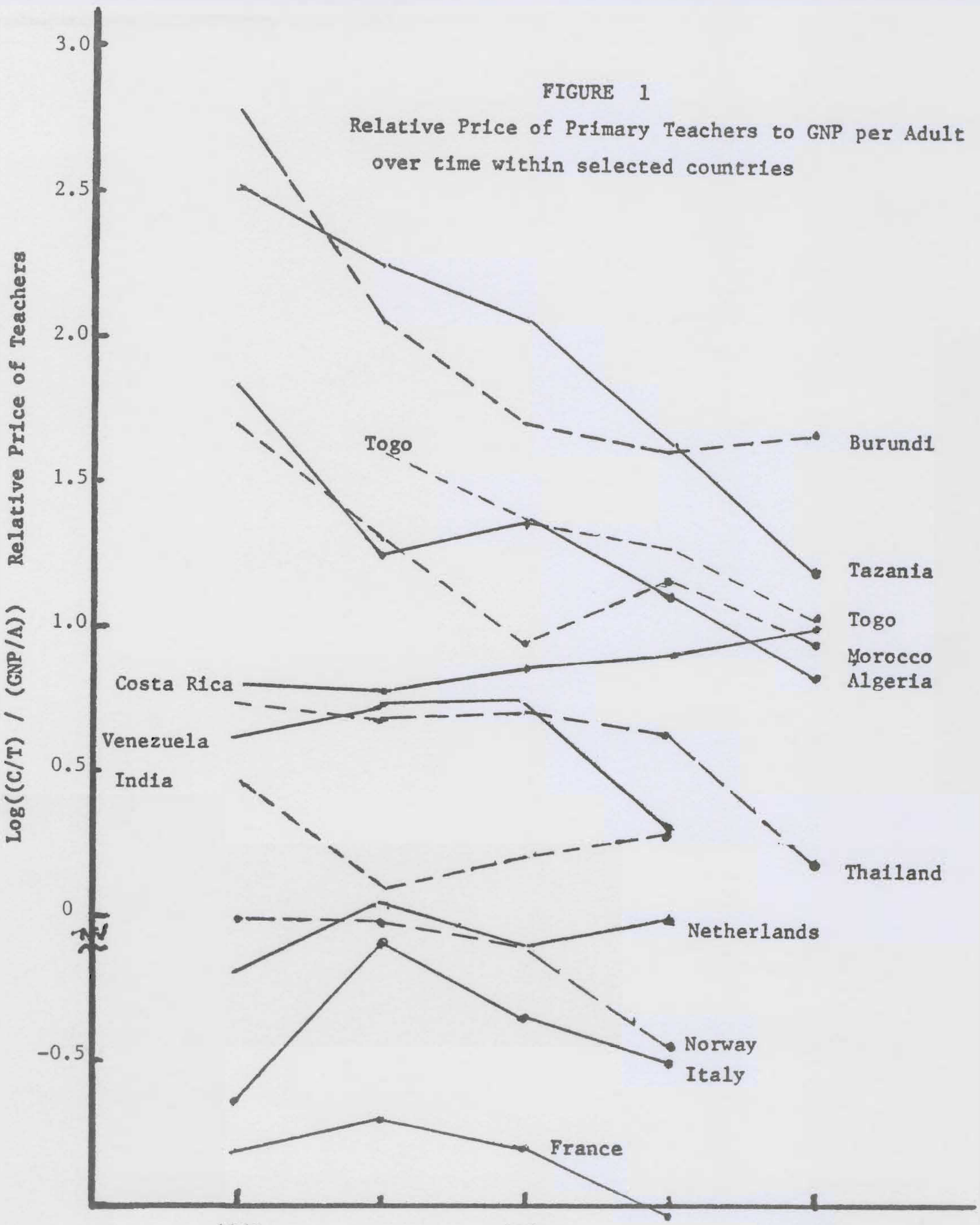
The approach adopted here is to assume simply that the demand for educated labor is primarily a function of the current level of national income per worker, and other specified technological and demographic constraints. Within these general long run constraints, the political system seeks to allocate the resources to the educational system that are economically justified and privately demanded. Hence, consumer demand for schooling is itself a reduced-form relationship that embodies structural parameters from an individual investment supply relationship and an aggregate derived demand for relatively educated labor. Identifying these underlying structural parameters is not attempted here.

A second unusual feature of the educational system is that it produces its own main input, teachers. It thereby affects by its past production the current wage required to retain the services of teachers and consequently the unit cost of producing further education, other things being equal. This feedback effect of output on future unit costs suggests that choosing the best expansion path for education involves issues of intertemporal optimization and intergenerational equity, topics that implicitly arise in the educational planning literature, but which have not been explicitly incorporated into empirical analyses (Bowles, 1969; Freeman, 1971). For example, to expand a school system rapidly from a very limited national educational base involves inevitably bidding up temporarily the cost of teachers and may even require the costly importation of trained personnel. These high initial costs of expansion tend to decline as the pool of domestically trained secondary school graduates increases and these new graduates compete for available teacher posts. This decline in the relative price of teachers then encourages, along with rising incomes, more private demand for public education as both a consumption and investment activity. Figure 1 illustrates this downtrend in the relative price of teachers in a number of African countries which have recently expanded their national educational systems. The wages of teachers relative to the average worker showed less obvious trends in the middle income countries, such as in Latin America. In the high-income market economies this relative wage of public school teachers followed a variety of paths, but there was often a tendency for the relative wages of teachers to increase temporarily in the 1960s as the educational system expanded to accommodate the large cohorts of babies born after the Second World War.

Although there is no established framework for dealing with these dynamic and recursive features of national educational systems, the current wage of teachers clearly depends on the curent level of demand for schooling. Consequently, the price of teachers is endogenous to a model determining the demand for educational services. To estimate without simultaneous equation bias the effect of this price on current demand, instrumental variable methods will be adopted. The instruments will be selected such that they are correlated with the current wage of teachers but are not correlated with the errors in the equation determining current educational demands.

A Model of the Educational System

The technological possibilities for producing educational services are assumed to be identical across countries. This production function for educational services is also assumed in the long run to exhibit constant returns. This does not seem to be an unrealistic assumption, if we exclude very



small countries, say, of less than a million persons, and concentrate separately on the primary and secondary school systems (see Data Appendix). The production function may then be expressed in standard Cobb-Douglas form:

$$X = Z L^{\alpha} K^{1-\alpha} \qquad (1)$$

where X is the output of educational services, L is the labor input, K is the physical capital input, and α is the share of wages in output, and $1-\alpha$ is the capital share, while Z is a set of exogenous technological shifters that affect the unit costs of producing schooling in different environments, but are neutral with respect to labor and capital productivity and use. One such technological factor might be the distribution of the population. Dispersed populations may incur greater private and public transportation costs, in terms of both time and money, to provide the same effective schooling services.

Another technological factor that appears to influence the effectiveness of the school's resources is the home environment of the school children, and notably the education of their parents (Leibowitz, 1974; Rosenzweig, 1982). Consequently, I anticipate that if other things were equal, the effective demand for schooling services would be higher in a more urbanized population, and in one where parents are better educated. Finally, reductions in mortality increase the expected returns from schooling to the parent, child and society (Schultz, 1971; Ram and Schultz, 1979). Although this actuarial effect on average returns to education may not be large, since recent mortality declines occur disproportionately among pre-school aged children, returns might nonetheless increase in recent decades by one-tenth in a typical low income country due to this factor alone (Preston, 1980).

However, parent education and life expectation are both factors that also contribute to the market productivity of the parents and hence to the current level of real GNP per person. Moreover, with increased income, more resources in both the public and private sector may be allocated to health expenditures which augment the expectation of life. If the education and expectation of life of parents are included as explanatory variables in an educational expenditure or output equation, both of these variables would be causally related to income in complex ways. It would be unrealistic, therefore, to expect that country level data could separately distinguish the effects of parent income, parent education, and expectation of life on the performance of the schooling system. Merged family level data and aggregate community data might be able to sort out the effects of these interrelated factors (Schultz, 1984). Only the technological effects of urbanization on schooling costs will be estimated here.

If the educational sector minimizes its unit costs, that is, produces efficiently, the marginal cost or price of schooling services, P_x, can be expressed as a multiplicative function of the wage rate paid labor in the educational sector, W, and the return, r, required on public capital (e.g., Borcherding and Deacon, 1972):

$$P_x = \left(\frac{1}{Z}\right)\left(\frac{W}{\alpha}\right)^{\alpha}\left(\frac{r}{1-\alpha}\right)^{1-\alpha} \qquad (2)$$

To some degree, world capital markets work to equalize the rental rate on educational physical capital, and then the only remaining constraints that would influence the marginal cost of education across countries and over time are the real wage paid to teachers, W, and the exogenous technological conditions denoted by Z. Teacher salaries are the bulk of recurrent expenses for most school systems. In recent years about 95 percent of current expenses in the primary school systems of low income countries were teacher salaries, whereas in high income countries the proportion is about 75 percent (World Bank, 1983, p. 99). Current expenditures in a school system divided by the number of teachers is, therefore, a useful approximation of the wage paid for labor by the educational system and is the principal factor determining the relative price of educational services in a country. The price equation can be rewritten as the following, if the rental rate on capital does not vary:

$$P_x = e^{\beta_o} Z^{\beta_1} W^{\alpha} e^{u_1}, \qquad (3)$$

where β_o is a constant, $\beta_1 = -1$, and u_1 is a multiplicative error in the production technology affecting unit costs. Because labor's share of educational expenditures, α, can be observed, the effect of price variation can be estimated from data on teacher wages (Gramlich and Rubinfeld, 1982).

Educational services are assumed to flow equally to all citizens. The quantity demanded is defined as q,

$$q = X/P^{\gamma}, \tag{4}$$

where P is the population of children of school age, and γ is the "public good" parameter, equal to unity if it is a private good, and zero if it is a pure public good. Public externalities of basic education are often cited as a reason for public subsidization of education, suggesting that $\gamma < 1$.

The median voter is assumed to pay a share to finance the output of educational services for each of his or her children:

$$t = (P_x X)/(FAq) = P_x P^{(\gamma-1)}, \tag{5}$$

where t is the tax share per tax paying adult A, who has on average F children of school age, and hence FA = P.

Finally, the demand function for schooling of the median voter is conventionally assumed to be log-linear in the tax, t, paid (or price), in the taxpayers' income, Y, and possibly in technological factors, Z,[8]

$$q = Dt^{\eta} Y^{\delta} Z^{\varepsilon} e^{u_2}, \tag{6}$$

where u_2 is a multiplicative error in the demand relationship.

Combining (4) and (5) with (6), to eliminate the tax rate, an expenditure (E) function is obtained per school-aged child in terms of income, prices, children, and technological constraints:

$$\frac{E}{P} = tq = DY^{\delta} P_x^{(\eta+1)} P^{(\eta+1)(\gamma-1)} Z^{\varepsilon} e^{u_2}. \tag{7}$$

To simplify the interpretation of the effect of the relative size of the cohort of school-aged children, X is assumed to be a purely private good, that is, $\gamma = 1$. In this case, after substituting (3) in for the price of educational services, logarithms are taken of (7) and the partial effects of income per adult, relative prices, (teacher wage), and technological shifters on public educational expenditures per child can be expressed as a combination of household demand and production technology parameters:

$$\ln(E/P) = b_o + b_1 \ln Y + b_2 \ln W + b_3 \ln Z + v, \tag{8}$$

where $b_o = (\eta + 1)(\beta_o) + \ln D$,

$b_1 = \delta$,

$b_2 = \alpha(\eta + 1)$

$b_3 = \beta_1(\eta + 1) + \varepsilon$.

In sum, equation (8) is a reduced-form relationship derived from both the education production technology (1) and the form of household demands (6). The production and demand errors u_1 and u_2, are assumed to be independently distributed and serially uncorrelated and uncorrelated with Y, Z and lagged Y, Z and S/P, defined below. The income elasticity, δ, that is directly estimated from a regression in the form of (8) would capture the effect of income on public expenditures for education that is due to both consumption demands and producer demands induced by increasing rates of return to educated labor. Since α is known from the input share of labor in total educational expenditures, the Cobb-Douglas form of the technology permits one to identify the price elasticity, η. But the wage of teachers is likely to be endogenous and hence correlated with v, and it is later transformed into a relative price of schooling that is defined in terms of income and the component of current shool expenditures per teacher. Ordinary least squares estimates of η and δ may thus be biased due to simultaneity and by errors-in-variables that are likely to generate spurious correlations among measured relative price, income, and school expenditure variables. An asymptotically unbiased instrumental variable estimator is therefore later proposed.

The net effects of Z factors on educational inputs and outputs can also be inferred from estimates of (8). The estimated impact of the relative size of the school-aged population on schooling expenditure per child is an estimate of the cohort size effect squeezing out educational expenditures as hypothesized in the demographic-development literature. Alternative interpretations could also be attached to a negative estimate of the relative cohort size effect.[9] The proportion of the population living in urban areas is a second technological variable.

An Empirical Decomposition of Educational Expenditures

It is of practical interest to evaluate how the composition of educational expenditures varies with price, income and demographic factors, in addition to the behavior of overall educational expenditures. For this purpose, it is convenient to divide school expenditures per school-age child (E/P) into a multiplicative function of four observable components:

$$\frac{E}{P} = (\frac{S}{P})(\frac{T}{S})(\frac{E}{C})(\frac{C}{T}) \qquad (9)$$

The first term on the right-hand side is the ratio of students enrolled to the number of children of school age, the enrollment ratio, which can be computed in many countries for boys and girls separately. The second term is the teacher to student ratio, that will be treated as an indicator of the human capital "quality" of schooling (Pryor, 1968; Bowles, 1969), which may be contrasted with the "quantity" response in terms of enrollments. The third term is the ratio of total expenditures to current expenditures, or an index of the physical capital intensity of the educational system. The fourth and final term is the current expenditures per teacher. Logarithms of the four component ratios in question (9) are then regressed on the same income, price, technology, and population composition variables used to explain expenditures per child. The sum of the log-linear regression coefficients for each conditioning variable in these four component regressions is equal to that variable's coefficient in the overall expenditure per child function. In this way, the effect of income, price and other factors on overall educational expenditures estimated from equation (8) may be decomposed into the additive effects of that conditioning variable operating on quantity, quality, capital intensity and teacher salaries.[10]

Educational expenditures are deflated to constant local prices using the GNP deflator and converted to 1970 U.S. dollars according to the prevailing average foreign exchange rate in 1969-71 (see Data Appendix for details).[11] The wage of primary and secondary school teachers is defined as the public current expenditures on that level of schooling divided by the number of teachers at that level. This "average" teacher salary should then be deflated by the local price level to obtain a relative price. I have used the national productivity of the average adult as a numeraire for the teacher's salary. Thus, this relative price of teachers is defined as the ratio of teacher salaries to GNP per person of working age (age 15 to 65).

This measure of the relative price or cost of educational services is likely to be determined jointly and simultaneously with production costs and consumer demands for schooling. The endogeneity of the relative price of teachers is reflected in the likelihood that unexplained variation in either production costs (u_1) or consumer demands (u_2) will be correlated with observed relative prices of teachers. Ordinary least squares (OLS) could overestimate b_2 in equation (8), because of the resulting simultaneous equation bias. Consequently, the model is estimated first by OLS, under the assumption that the relative price of teachers is exogenous, and then by instrumental variable (IV) techniques, under the assumption that the price variable is endogenous, but that the instrumental variables, specifically secondary school enrollment rates, incomes, and urbanization, all lagged ten years, are uncorrelated with production and demand errors in the current schooling system equations.[12] It is also anticipated that the relative price of teachers today is an inverse function of the supply of potential teachers trained in the country in previous years. The IV estimates have the additional attraction of being consistent despite the systematic errors-in-variable problem that arises because the logarithmic transformation of relative prices, incomes, and teacher wages are linearly dependent on each other.[13] Although the auxiliary instrumental variable equations for wages undoubtedly simplify the structural process underlying time series of educational systems, these simultaneous equation techniques should provide consistent estimates of the school expenditure equation (8) and its subcomponents in equation (9).[14]

Income is measured as GNP in local constant prices, expressed in 1970 dollars by conversion at the average foreign exchange rate prevailing from 1969 to 1971.[15] To avoid definitional dependence on fertility, this measure of real GNP is divided by the population of working age, 15 to 65. Population density is measured as the proportion of the population living in an urban area, as defined by the World Bank and estimated from national censuses. The relative size of the school-aged cohort is the proportion of the population age 6-11 for primary school, the proportion age 12-17 for secondary school, following UNESCO conventions. For the consolidated expenditure and enrollment equations, the child cohort is defined as the proportion of the population age 6 to 17. Period fertility is measured by the total fertility rate, which is equivalent to the sum of age specific birth rates for women age 15 to 49.

Data were first collected for 155 countries with populations greater than one million in 1983, for each five years from 1950-1980. Data on all required series were obtained for at least one year in 89 countries, of which 30 were in Africa, 19 in Latin America, 21 in Asia, 2 in Oceania, 1 in North America and 16 in Europe (see Table 1). The maximum number of country-year observations was 321 for primary schools and 258 for secondary schools. In pooling of time series observations from a cross section, it is clear that all observations are not independent; neglect of covariation across observations on a particular country undoubtedly biases reported tests of statistical significance and may bias estimates as well.

The variables are defined and sample characteristics summarized by region for primary and secondary school systems in Tables 3A and 3B (pages 98,99), respectively. Beneath the mean of the variable is its standard deviation in parentheses, and if the variable is expressed in logarithmic form, the antilog of the mean is reported as the third value in brackets to provide an absolute measure of level. For example, primary enrollment ratios are 59 percent in Africa and 95 percent in Latin America, while the teacher student ratios and capital intensity are similar, .024 and .030, and 1.22 and 1.15, respectively. Primary school teachers are paid about the same in the two regions, but because GNP per adult is one-third as large in Africa, the relative price of teachers is twice as high in Africa as it is in Latin America. Expenditure per primary school aged child is $20 in Africa compared with $51 in Latin America. The potential explanatory role of income and relative prices in determining school expenditures and achievements is suggested from such gross regional comparisons. The large differences between enrollment ratios for boys and girls in Africa compared with Latin America may also stem from economic differences between regions. The next section proceeds to fit the multivariate production/demand relationships across country observations to estimate the magnitude of price and income effects as well as the effects of urbanization and population growth.

Estimates of School Expenditure Equations

The empirical findings are reported in two basic specifications, one that assumes the relative price of teachers is exogenous and measured without error, and a second that treats this price variable as endogenous and potentially measured with error. Under the first set of assumptions, ordinary least squares (OLS) estimates of the parameters to equation (8) may be satisfactory, and they are reported in column (7) of Tables 4, 5, and 6 (pages 100,101,102) for the primary, secondary and overall public educational expenditures per school aged child. Columns (3) through (6) provide the component regressions designated in equation (9), although in the case of the total school system the transformation of enrollment rates to expected years of schooling, and the general gaps in data on teachers in the public higher educational systems imply that the analogous total components will not "add up." Because the relative price of school teachers is defined as the wage of teachers divided by GNP per adult, the logarithm of the teacher wage component in column (6) is precisely equal to the sum of the logs of the income and price variables in the OLS estimates for the primary and secondary school systems.

The second set of regressions in Tables 7, 8 and 9 (pages 103, 104, 105) report instrumental variable (IV) estimates, which are preferred because they are consistent under more realistic assumptions specified above regarding the endogeneity of relative prices. However, since these estimates depend on the availability of information on income and secondary school enrollments a decade earlier, the working sample for which these estimates can be obtained is reduced from 321 to 186 at the primary level, from 258 to 139 at the secondary level, and from 250 to 132 at the level of the total school system. Nonetheless, the countries in the samples do not change appreciably, only the time period shifts with the frequent omission of the 1960s and emphasis given to the 1970s. OLS estimates from the larger samples are nearly identical to those reported here. Analogous OLS and IV estimates excluding total fertility rates and restricting the sample to low income countries yielded similar findings (Schultz, 1986).

According to the OLS estimates the income elasticity of expenditures (δ) on primary, secondary and total school systems exceed unity; they are specifically 1.37, 1.55 and 1.41, respectively. The IV estimates are similar, 1.37, 1.47 and 1.35. The share of income expended on each level of schooling tends to increase with real GNP per adult. The elasticity of educational expenditures with respect to the relative price of teachers is .60, .50 and .49 at the three school levels, if we accept the assumptions underlying the OLS estimates. The preferred IV estimates of price elasticities are, as expected, substantially lower at .16, .24 and .17. According to these IV estimates the elasticity of the quantity of schooling services demanded with respect to the price of labor, in my model η, is equal to -.80, -.70 and -.80.[16]

The expenditure components underlying these income and price effects on total public expenditures per school aged child differs slightly by school levels. In the primary schools, the income elasticity is about twice as large for enrollments as for teacher-student ratios; the IV estimates are .31 for quantity and .17 for quality (columns 3 and 4). The physical capital intensity index is not well explained by any of the economic or demographic variables, and may contain largely transitory variations in capital appropriations or unsystematic measurement error (column 5). There is no evidence of complementarity or substitutability of capital for labor. Teacher salaries increase five percent faster than do incomes per adult (column 6), contributing to the elasticity of the income-expenditure relationship (column 7).

At the secondary school level (Table 8), the income elasticity is four times larger for quantity (.43) than for quality (.11). The price elasticity of secondary enrollment is substantially larger in absolute value, -.97, than that at the primary level, -.70. The price elasticity of total expected years of schooling is also large, -.82 (Table 9, column 3), falling between the primary and secondary school estimates. A decline in the price of school teachers relative to national productivity is associated with a substantial increase in enrollment and modest increase in the ratio of primary school teachers to students.

Urbanization exhibits a relatively weak, but consistent, relationship with public expenditures on schooling. According to the IV estimates, a country which has ten percent or more of its population in urban areas, tends to expend six percent less on schooling per child, at both the primary and secondary school level. This is accomplished at the primary level by a reduction in enrollments and in teacher-to-student ratios, whereas at the secondary school level most of the reduction occurs through lower enrollments. These estimates, however, are based on the specification that permits urbanization a decade earlier to help determine the relative price of teachers today, and lagged urbanization is significantly associated with lower current relative prices for teachers. Thus, this indirect role of urbanization is to reduce the price of teachers and thereby induce an offsetting, but lagged, effect increasing enrollment rates. If urbanization is excluded from the list of instruments to estimate price effects, the net contemporary effect of urbanization on school expenditures is to reduce current outlays per teacher, with little net effect on enrollments or teacher-student ratios.[17] Expenditures per child, in either case, are systematically lower in more urbanized countries when income levels and relative prices are held constant.

The data examined here do not indicate precisely how urban school systems reduce the public costs of education. Consolidation of schools into more efficient sized units to exploit specialized teaching functions in more densely populated areas is often cited as an important source of economies of scale in public schools.[18] Higher population densities could also reduce the private opportunity cost or travel time for students. But the lack of large effects of urbanization reducing teacher-student ratios in secondary schools, or increasing enrollments, suggests that economies of scale or reductions in private student time costs may not be important.

The relative size of the school aged cohort, which is highly correlated with recent levels of population growth, is associated with lower expenditures on primary, secondary and total school systems, and according to the preferred IV estimates, reported in Tables 7, 8 and 9, the effect is statistically significant and of a substantial magnitude. An increase in the proportion of the population of primary school age by ten percent, from .153 to .168, is associated with an eleven percent decline in primary school expenditures per child. In other words, the IV estimates suggest primary school expenditures do not increase in response to an increase in the size of the school aged cohort. There are offsetting tendencies for primary school enrollment rates to increase for the larger cohorts, whereas teacher-student ratios fall. Teacher salaries, in addition, are substantially lower (ten percent) for the larger school-aged cohort, and this appears to be the main factor explaining the lower expenditures per child.

The IV estimates imply a ten percent larger cohort is associated with an even larger decline in expenditure per secondary school-aged child, of about 17 percent. Secondary enrollments are unaffected, but teacher salaries and teacher-student ratios are notably lower. In the OLS estimates the cohort size effects are substantially smaller and less statistically significant, but similar offsetting movements in enrollment rates and teacher-student ratios are still evident (see Tables 4, 5 and 6). Larger birth cohorts do not seem to receive fewer years of schooling, as attested to by the pattern of enrollment ratios, but they do appear to receive schooling of lower human and perhaps physical capital intensity.

This adjustment in the factor intensity in schooling is a plausible economic response to the relative scarcity of both forms of capital in many poor countries recently experiencing rapid population growth. Much thought has been given to how health care delivery systems might be encouraged to use less human- and physical-capital intensive technologies in low income countries, rather than borrow directly the highly capital intensive procedures used in the industrially advanced high income countries. The current adoption of western medical technologies in low income countries is cited as contributing both to great inefficiencies and also inequities, since the services of this modern medical system are so costly that they can only be provided to the elite living in a few metropolitan areas of the low income world. The tendency noted in this paper of low income countries to substitute away from human- and physical-capital intensive educational production technologies appears, therefore, to be a reasonable innovation on economic grounds to different relative factor scarcities (e.g., Binswanger and Ruttan, 1978, Hayami and Ruttan, 1984). Until stronger evidence is presented than I have seen that the productive benefits (i.e. wage differentials) for persons being schooled by these less capital intensive methods are greatly diminished,[19] the adjustment of factor proportions in schools appears to be one among several economic responses to the scarcity of funds and the high private returns to school enrollment.

To determine which country observations are giving rise to this pattern, the model is reestimated within the small strata of high income industrially advanced countries and within the rest of the sample (about 80 percent). The relative cohort size variable exhibits the same statistically significant effect on primary, secondary and total school expenditures in the sample of low income countries, and increases in magnitude by five to ten percent. In the small sample of industrially advanced countries cohort size is also generally significant. Among only the low income countries, for whom variation in cohort size relates clearly to the pressures of rapid population growth, the relative number of school-aged children is associated with lower teacher-student ratios, and lower wages per teacher. Income and price elasticities based only on the less developed countries are similar to those reported above (Schultz, 1986).

Fertility, as anticipated, is inversely associated in the OLS estimates with school expenditures per child, and this correlation appears to stem from an inverse association between enrollment and fertility, particularly at the secondary level. Such a pattern could be expected if the private substitution by parents of more schooling resources per child in place of having additional children led to an increase in the private demand for schooling, and hence to greater enrollment rates. But the preferred IV estimates indicate no relationship between fertility and school enrollments or expenditures, except perhaps for primary enrollments of girls. The deletion of fertility from equation (8) leads to slightly larger (more negative) estimates of the effect of cohort size on schooling inputs, as anticipated, but the differences are not substantial (less than 10 percent).

Sex Differences in School Enrollment Rates

Differences in the school enrollment rates of boys and girls may have much to do with the level of child mortality and fertility, the rate at which women migrate from rural to urban areas, leave family and domestic productive activities for employment in the market labor force, and in particular, for jobs in the nonagricultural sector. The future economic status of women relative to men depends heavily on their enrollment in school and their ability thereby obtained to benefit directly from the increased productive opportunities created by modern economic growth.

First, all of the estimates imply that the income elasticity is larger for female enrollment rates than for male enrollment rates. The preferred (IV) point estimates for female and male enrollment rates are .43 and .24 at the primary level, .65 and .30 at the secondary level, and .50 and .28 for total expected years of schooling. Second, the price enrollment elasticities are greater in absolute value for female than for male enrollments: -.76 and -.63 for primary, -1.07 and -.91 for secondary, and -.86 and -.77 for total expected years of schooling. A 50 percent increase in incomes per adult from the sample mean of 721 (1970 U.S. dollars) would raise primary enrollment rates for girls from 69 to 83 percent, while the rate for boys would increase from 88 to 97 percent. The girls would improve their relative achievement from .78 of boys to .85. The "gender gap" in secondary schools would also close by one-fourth, with girls increasing their enrollment rates from 17 to 22 percent, while the rate for boys would increase from 26 to 30 percent. Reducing the relative price of schooling has an effect of improving female enrollments relative to males that is similar to that of raising incomes. According to these cross sectional estimates of income and price elasticities, economic development with its effects on adult income and relative wages of teachers is likely to be associated with an equalizing of schooling opportunities between boys and girls; these tendencies are also evident in the restricted sample of less developed countries.[20] Here may be a potent dimension of the development process that unleashes demands for the schooling of girls and young women that in turn play a pivotal role in governing the timing and pace of the demographic transition.

Religion is often cited as a traditional cultural force that influences the status of women and their educational opportunities relative to men. Moslem culture, in particular, is often singled out for its distinctive attitudes toward women's status, education, employment and, consequently, fertility (Kirk, 1966). Adding to our framework the percentage of the population that is Moslem and the percent that is Catholic leads to the auxillary regressions reported in Table 10 (page 106).

At the primary school level and for total expected years of schooling the difference in the Moslem coefficient for men and women is statistically significant at the 10 percent level. Moving from a country with the sample average percentage of Moslems at 37 percent to a country that is entirely Moslem is associated with a decline in primary enrollments for males from 88 to 76 percent and for females from 69 and 50 percent. In relative terms, the ratio of female enrollment rates to male would decline in this case from .78 to .66. The regression coefficient on the Catholic variable is not statistically significant, but works in the direction of increasing female relative to male enrollment rates. The general direction of income and price effects is not altered by the inclusion of the two religion variables, though the effect of population growth via cohort size is eliminated because of multicollinearity.[21]

Patterns in Residuals

In Table 3 the average characteristics of the primary school sample were presented by region. It is now possible to examine the deviations of regions from the patterns explained by the model. In other words, holding constant for national incomes per adult, prices, urbanization, and age composition, as estimated in Tables 7 and 8 for primary and secondary school systems, how do the regions of the world differ in their level and pattern of school expenditures and enrollments?

Table 11 and 12 (pages 107, 108) report the regional averages of the residuals or deviations in country-level observations from those predicted by the fitted model. Since all of the educational input and enrollment variables are in logarithmic terms, the average residuals can be interpreted as approximately the proportion a region lies above or below that predicted. Expenditures per primary school-aged child are 9 to 14 percent above average in East Asia and Africa, but 24 percent below average in South and West Asia. Enrollment rates at the primary level are also notably above average in Africa and East Asia, but 41 percent are below average in South and West Asia and 14 percent are below in Latin America. In the East Asian region, which has invested heavily in basic education for a number of years, the ratio of teachers to students is surprisingly below average, whereas the capital intensity is slightly above average. Teacher wages are higher than expected in Latin America and South and West Asia, but lower than expected in the developed countries.

At the secondary school level, the equations generally fit enrollments more closely than at the primary level, but do less well in explaining teacher-student ratios and teacher wages. Secondary school expenditures per child are about 16 percent above average in Africa, and about 18 percent below average in Latin America. Enrollment rates show more variation, with Latin America and South and West Asia again reporting rates far below that which is expected. In contrast, Africa and East Asia again exhibit enrollment rates well above expectations. The teacher-student ratio is above average in Latin America, but below average in East Asia and Africa. Teacher wages are again higher in regions such as South and West Asia and Latin America which have invested less than the predicted amount in secondary schooling in the past.

The primary and secondary school regressions are consistent. They suggest a large and unexplained underinvestment in primary and secondary schooling in the South and West Asian region and in Latin America. Enrollment rates, in particular, are below the expected levels in these regions, while teacher-student ratios remain relatively high in Latin America at the secondary level, and while capital intensity is high in South and West Asia. The high level of teacher wages in Latin America and South and West Asia may be traced in part to the failure to enroll more children at the secondary level in earlier years. The higher current wage paid for teachers contributes to the higher price of educational services today which deters current public expenditures on the school system in these regions.

Deviations from the pattern predicted by the model based on income, price, demographic and distributional characteristics of the population may signal a disequilibrium that might encourage the private sector to provide schooling. I could not obtain sufficient information to test this conjecture, but private schools in Latin America and portions of Asia and Africa are not increasing their share of enrollments in response to the sluggish public sector provision of schooling services (see Table 11). Another hypothesis might be that stagnant economic conditions were not propitious for rewarding education in the workforce, and that depressed social and private rates of returns to education could explain the regional patterns of low investment in schooling. Returns to education may not increase with modern economic growth because of limited regional and occupational mobility rewarding individuals on the basis of their skills and education. Public policies may also have failed to encourage technological change through adaptive research and development.

Finally, the absence of competitive domestic factor and product markets, or distorting trade and foreign exchange regimes, may have eroded the incentives to invest in education or skewed the distribution of income so as to discourage broadly based educational programs. Exploring these possibilities would take me far beyond the scope of this paper, but at least in the case of Latin America, studies do not support the view that the underinvestment in secondary schooling is due to a low return to this activity. Indeed, substantial private returns accrue to those in Latin America who manage to get a secondary education (Psacharopoulos, 1981). If the overall framework proposed in this paper is tenable, then further study of regional and country level educational outlays and achievements is warranted, both to discover why expenditures on schooling deviate from the economic pattern estimated here and to determine if these deviations could help to account for the rate and structure of modern economic growth occurring in these countries.

Conclusions

The empirical association between school expenditures and enrollments, on the one hand, and real incomes per adult and the relative price of teachers, on the other, confirms the view that income and price variables contribute to determining the equilibrium level of expenditures on schooling within a country. The working hypothesis that private demands for educational services explain public expenditures is not rejected. Holding constant for these dominant income and price constraints on the public educational system, urbanization is found to be associated with lower expenditures per school-aged child, and this reduction in outlays on education in more urbanized countries is associated with a lower price of teachers relative to other goods. A plausible interpretation of this pattern would presume that there are economies in using teachers in the larger scale urban schools and perhaps compensating amenities in urban areas that teachers value, such as attractive employment opportunities for teachers when schools are not in session.

The proportion of the population of school age is associated with lower levels of public expenditures per child. Rapid population growth which tends to increase the youthfulness of the population plays an indirect role, therefore, in diluting public resources allocated to the school system. This demographic squeeze induced by a relatively large birth cohort depresses the teacher-student ratio at both the primary and secondary school level. But primary school enrollment ratios tend to be higher for relatively large cohorts, leaving public outlays per primary school aged child less severely depressed.

The separate examination of patterns of enrollment among girls and boys confirms that female enrollments tend to increase more rapidly with income per adult than do male enrollment rates. Correspondingly, the decline in the relative wage of teachers, a measure of the relative price of educational services, is associated with larger gains in schooling for girls than for boys. Thus, the rise in incomes and the decline in relative prices of schooling that appear to occur at the onset of modern economic growth contribute reinforcing gains to the educational attainment of women that exceed those achieved by men. If these cross section patterns estimated here hold over time with development, the relative improvement in women's education is a major and underemphasized concomitant of the development process, with likely consequences for the rate of decline in child mortality and fertility, and the long term decline in population growth rates.

Certain regions have been able to advance educational expenditures and enrollments beyond that which one might have expected, based on incomes, the cost of teachers, population distribution, etc. East Asia and Africa stand out in this regard as "overachievers," while South and West Asia and Latin America are below the levels expected on the basis of the fitted model. Africa's relative performance, according to the criteria captured in the model, is in striking contrast to the portrayal of a region suffering from administrative inertia, an inability to achieve targets of universal primary schooling, and an overpaid cadre of teachers (Jimenez, 1984; Lee, 1984; Sai, 1984). Since Africa has confronted relatively high prices for teachers, given the described dynamics of expanding their school systems, it appears likely that the decline in teacher-relative prices will continue in Africa to help this continent increase enrollments without necessarily increasing outlays per student.

One method for evaluating the overall framework proposed in this paper is to calculate how well the educational changes in the last decade are explained by (1) the cross section estimates of the model and (2) the actual changes in the conditioning variables that occurred in this period. Cross section patterns do not always satisfactorily simulate changes over time. For this purpose only the small number of countries that report sufficient data for the decade of 1965 to 1975 are examined. Actual proportionate changes in public expenditures per child and enrollment ratios are reported in the first column of Table 13 (page 109). The second column is the sum of columns 3 through 7, which report the predicted changes due to the actual changes in each of the five conditioning variables multiplied by the IV estimates in Tables 7, 8 and 9. The last column of Table 13 indicates how much of the change from 1965 to 1975 is accounted for by the predicted or simulated change. There are several possible reasons for divergence. First the model is fit to a pooled combination of cross section data from several time periods, and not to just the 1965-1975 time series changes within countries. Second, the sample of countries for which the 1965-1975 comparisons can be performed is more restricted than the sample used in estimating the model. A third reason is, of course, the omission or misspecification of explanatory factors.

This parameterized model simulates the changes in expenditures and enrollments quite well for the primary school systems, that is, 93 and 104 percent of the growth is explained from 1965 to 1975 in expenditures and enrollments, respectively. Public expenditures per child at the primary level increased by a third in this decade. The decade increase in incomes per adult of about a fourth would have contributed by itself to an even larger increase in expenditures, but this increase was moderated slightly by the relative decline in primary school teacher salaries and urbanization. The slight decrease in school cohort size increased expenditures marginally, whereas the decline in fertility was asociated with a small decrease in school expenditures. Enrollment rates at the primary level responded predominantly to the decline in relative prices (of teachers), but also increased with incomes, particularly for females. Urbanization, relative cohort size, and fertility had relatively minor effects on primary enrollments.

At the secondary school level the model underpredicts the substantial increases in expenditures and enrollments that actually occurred in this sample of 48 countries.[22] Again, income growth alone would have suggested a more rapid increase in expenditures than actually occurred, whereas the decline in prices, urbanization and a small increase in cohort size restrained the growth in secondary school expenditures per child. Enrollments at the secondary level respond strongly to the decline in relative price of teacher salaries; these price effects are larger at the secondary level than they were at the primary level. Enrollments at the secondary level are not greatly affected by the changing demographic characteristics of the population.

When analysis focuses on the total school system, for which our data is less satisfactory, the underprediction of the fitted model remains substantial. Response patterns lie between those estimated for the primary and secondary school separately. Disaggregating enrollments by sex (expressed as expected years of schooling) indicates again how the increase in income per adult and decline in the relative price of teachers help to account in this decade for the more rapid proportionate increase in the enrollment of girls than of boys.

In concluding, let me stress the need for much further work on these largely unexplored data and issues. There is no substitute for reliable data, be they across countries or across individuals or over time on either countries or individuals. The national observations examined here could undoubtedly be reconstructed from underlying government accounts and records for each country and they might thereby be made more comparable and precise. But I am doubtful that the salient patterns in the published compilations of data that are estimated in this paper would thereby be reversed.

The statistical significance of the relationships fit to the country observations may also be misstated somewhat, because the repeated observations from some countries at five year intervals are not independent; the "true" sample size might thus be viewed as less than that numerically reported. If observations are restricted to an average for each country, that is we base our analysis on a simple cross section of country averages, the estimated coefficients are not greatly affected, but their standard errors increase somewhat, and thus significance levels decline.[23]

The main finding of this analysis of international data from educational systems is that public expenditures on schools have conformed to regular patterns with respect to consumer incomes, relative factor prices, and demographic constraints. Clearly at the secondary level, and probably also at the primary level, rapid population growth has depressed levels of expenditures per child of school age. This has occurred by increasing class size and lowering teacher salaries, but not by restricting notably enrollments. The next step is to clarify the origins for many of the departures from this international standard and to determine the extent to which the decline in public school expenditures per student that is associated with rapid population growth is an inefficient distortion in the allocation of social resources.

A P P E N D I X 4

Table 1: Growth in educational enrollments by school level and countries by income classes, 1960-1981

World Bank Country Class[1] (Number)	Primary (6-11) Education		Secondary (12-17) Education		Higher (20-24) Education		Expected years of Enrollment[2]		Percent of increase in enrollment ratios (1960 - 1981)			
	1960	1981	1960	1981	1960	1981	1960	1981	Primary	Secondary	Higher	Expected
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Low Income (34)	.80	.94	.18	.34	.02	.04	5.98	7.88	18	89	100	32
Excluding China and India[3]	.38	.72	.07	.19	.01	.02	2.75	5.56	89	171	100	102
Middle Income (38)												
Oil exporters	.64	1.06	.09	.37	.02	.08	4.48	8.98	66	311	300	100
Oil importers	.84	.99	.18	.44	.04	.13	6.32	9.23	18	144	225	46
Upper Middle Income (22)	.88	1.04	.20	.51	.04	.14	6.68	10.0	18	155	250	50
High Income - oil exporters (5)	.29	.83	.05	.43	.01	.08	2.09	7.96	186	760	800	281
Industrial Market (18)	1.14	1.01	.64	.90	.16	.37	11.5	13.3	-11	41	131	16
East European Non-market (8)	1.01	1.05	.45	.88	.11	.20	9.31	12.6	4	96	82	35

Notes: [1] The low income class has an annual GNP per capita of less than US $410 in 1982 prices. The middle income class includes countries with GNP per capita between $410 and $1650, while the upper middle income class ranges from $1650 to about $6000.

[2] Synthetic cohort concept defined as six (years) times the sum of primary and secondary enrollment ratios plus five (years) times higher educational enrollment ratio.

[3] The lack of expenditure data for China and India in Table 2 justifies our consideration of the "low income" class of countries excluding these two large states.

Source: 1984 World Development Report, World Bank Staff, New York. Oxford University Press, 1984. Table 25, pp. 266-267.

Table 2: Central government expenditures: 1972, 1981

World Bank Country Class[1] (Number)	Percent of Government Expenditures on: Education		Health		Total Government Expenditures as Percent of GNP		Percent of Growth in Real per Capita GNP	Percent of Growth in per Capita Real Expenditures 1972-81 on:	
	1972	1981	1972	1981	1972	1981	1972-1981[2]	Education	Health
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Low Income (34)[3]	16.4	5.9	6.2	2.9	21.0	15.4	26	-67	-57
Excluding China and India[3]	16.4	11.5	6.2	4.4	21.0	17.6	7	-63	-41
Middle Income (38)									
Oil Exporters	15.4	16.6	5.7	5.6	17.2	27.8	34	+133	+113
Oil Importers	11.0	10.0	6.9	4.6	20.7	21.8	28	+22	-10
Upper Middle Income (22)	10.8	14.3	7.0	5.5	15.0	20.6	32	+140	+42
High Income - Oil Exporters (5)	13.5	9.2	5.5	5.5	36.6	26.3	0	-51	-28
Industrial Market (18)	4.3	5.1	9.9	11.4	21.7	28.3	21	+88	+81
East European Non-market (8)	NR	NR	NR	NR	NR	NR	NR	NR	NR

Notes: 1 The low income class has an annual GNP per capita of less than US $410 in 1982 prices. The middle income class includes countries with GNP per capita between $410 and $1650, while the upper middle income class ranges from $1650 to about $6000.

2 Annual Growth. Rate on per capita real GNP derived for 1970 to 1982 from Bank Tables, and interpolated for the nine years corresponding to expenditure data, 1972-1981.

3 The lack of data for China or for India throughout this period makes the overall "Low Income" country class comparisions of limited value.

Source: 1984 World Development Report, World Bank Staff, Oxford University Press, New York, 1984. Appendix, Table 2, 19 and 26.

Table 3A: Characteristics of sample of primary schooling systems from 1960 to 1980, by region

Region	Africa	Latin America	East Asia	South and West Asia	Europe, Canada and Oceania	Total Sample
(Sample size)	(62)	(43)	(21)	(24)	(36)	(186)
Dependent Variables:						
Enrollment Ratio - Total (S/P)	-.523 (.538) [.593]	-.0506 (.198) [.951]	.0150 (.111) [1.02]	-.398 (.470) [.672]	.0315 (.0708) [1.03]	-.229 (.440) [.743]
Enrollment Ratio - Male (S/P)	-.339 (.479) [.713]	-.0235 (.181) [.977]	.0370 (.103) [1.04]	-.145 (.353) [.865]	.0332 (.0763) [1.03]	-.126 (.355] [.882]
Enrollment Ratio - Female (S/P)	-.737 (.619) [.479]	-.0717 (.231) [.930]	-.00466 (.121) [.995]	-.835 (.823) [.434]	.0277 (.0744) [1.03]	-.365 (.604) [.694]
Teacher-Student Ratio (T/S)	-3.73 (.266) [.0238]	-3.51 (.260) [.0299]	-3.48 (.238) [.0308]	-3.49 (.318) [.0305]	-3.06 (.345) [.0469]	-3.49 (.366) [.0305]
Capital Intensity Index (E/C)	.199 (.238) [1.22]	.141 (.162) [1.15]	.188 (.108) [1.21]	.270 (.184) [1.31]	.192 (.114) [1.21]	.192 (.184) [1.21]
Current Expenditures per Teacher (C/T)	7.03 (.667) [1130.]	7.35 (.613) [1156.]	7.44 (1.02) [1703.]	6.17 (.961) [478.]	8.86 (.723) [7044.]	7.39 (1.10) [1620.]
Real Expenditures per Child (E/P)	2.97 (.885) [19.5]	3.94 (.675) [51.4]	4.16 (1.16) [64.1]	2.55 (1.38) [12.8]	6.02 (.847) [412.]	3.87 (1.51) [47.9]
Expenditure Share of GNP	.0219 (.0087) -	.0190 (.0067) -	.0192 (.0063) -	.0145 (.0095) -	.0227 (.0098) -	.0201 (.0087) -
Explanatory Variables:						
GNP per Adult Real 1970 $	5.74 (.619) [311.]	6.83 (.502) [925.]	6.79 (.877) [889.]	5.86 (.785) [351.]	8.09 (.510) [3262.]	6.58 (1.08) [721.]
Relative Price of Teacher	1.29 (.565) [3.63]	.518 (.421) [1.68]	.644 (.387) [1.90]	.306 (.468) [1.36]	.771 (.482) [2.16]	.813 (.606) [2.25]
Proportion Urban Population	.227 (.137) -	.479 (.155) -	.533 (.320) -	.284 (.183) -	.626 (.169) -	.404 (.240) -
Proportion of Population Age 6-11	.165 (.0119)	.170 (.0179)	.148 (.0271)	.167 (.0106)	.104 (.0127)	.153 (.0292)
Total Fertility Rate	6.62 (.986)	5.37 (1.18)	3.88 (1.47)	6.29 (.996)	2.35 (.541)	5.15 (1.91)
Proportion Adults Literate	.329 (.193)	.726 (.166)	.798 (.124)	.364 (.202)	.948 (.0733)	.598 (.299)
Life Expectation at Birth (yrs)	47.9 (6.40) -	60.6 (6.81) -	65.0 (6.92) -	51.3 (8.88) -	72.0 (1.97) -	57.9 (11.2) -

Table 3B: Characteristics of sample of secondary schooling systems from 1960 to 1980, by region

Region	Africa	Latin America	East Asia	South and West Asia	Europe, Canada and Oceania	Total Sample
(Sample size)	(49)	(35)	(18)	(16)	(21)	(139)
Dependent Variables:						
Enrollment Ratio - Total (S/P)	-2.45 (.836) [.0863]	-1.21 (.455) [.298]	-.779 (.455) [.459]	-1.59 (.612) [.204]	-.278 (.177) [.757]	-1.49 (1.00) [.225]
Enrollment Ratio - Male (S/P)	-2.13 (.807) [.119]	-1.20 (.424) [.301]	-.714 (.392) [.490]	-1.20 (.525) [.301]	-.271 (.141) [.763]	-1.33 (.882) [.264]
Enrollment Ratio - Female (S/P)	-2.95 (.956) [.0523]	-1.24 (.507) [.289]	-.852 (.523) [.427]	-2.35 (.960) [.0954]	-.295 (.233) [.745]	-1.78 (1.25) [.168]
Teacher-Student Ratio (T/S)	-3.05 (.284) [.0474]	-2.90 (.363) [.0550]	-3.22 (.276) [.0400]	-3.14 (.255) [.0433]	-2.67 (.275) [.0693]	-2.98 (.341) [.0508]
Capital Intensity Index (E/C)	.205 (.261) [1.23]	.127 (.113) [1.14]	.181 (.110) [1.20]	.304 (.171) [1.36]	.197 (.144) [1.22]	.192 (.193) [1.21]
Current Expenditures per Teacher (C/T)	8.76 (.589) [6374.]	8.09 (.725) [3262.]	8.19 (1.01) [3605.]	7.38 (.940) [1604.]	9.18 (.628) [9701.]	8.42 (.903) [4537.]
Real Expenditures per Child (E/P)	3.47 (.867) [32.1]	4.11 (.914) [60.9]	4.37 (1.45) [79.0]	2.96 (1.27) [19.3]	6.42 (.931) [614.]	4.14 (1.47) [62.8]
Expenditure Share of GNP	.0286 (.0113) –	.0195 (.0098) –	.0225 (.0017) –	.0174 (.0105) –	.0358 (.0108) –	.0253 (.0123)) –
Explanatory Variables:						
GNP per Adult Real 1970 $	5.75 (.611) [314.]	6.87 (.439) [963.]	6.84 (.938) [934.]	5.85 (.796) [347.]	7.96 (.565) [2864.]	6.52 (1.01) [679.]
Relative Price of Teacher	3.01 (.615) [20.3]	1.22 (.501) [3.39]	1.35 (.570) [3.86]	1.53 (.538) [4.62]	1.21 (.315) [3.35]	1.90 (.979) [6.69]
Proportion Urban Population	.220 (.137) –	.489 (.153) –	.567 (.326) –	.290 (.196) –	.560 (.166) –	.392 (.237) –
Proportion of Population Age 6-11	.135 (.0102) –	.143 (.0114) –	1.37 (.0199) –	1.39 (.0074) –	.0996 (.0108) –	.132 (.0185) –
Total Fertility Rate	6.68 (.973) –	5.34 (1.17) –	3.88 (1.57) –	6.70 (.600) –	2.41 (.602) –	5.34 (1.87) –
Proportion Adults Literate	.328 (.183) –	.744 (.146) –	.798 (.119) –	.285 (.123) –	.936 (.0854) –	.581 (.293) –
Life Expectation at Birth (yrs)	47.9 (6.39) –	61.3 (6.73) –	65.3 (7.44) –	49.0 (7.59) –	71.4 (2.28) –	57.2 (11.0) –

Table 4: Estimates of primary school expenditures and components, with the price of teachers exogenous[1]

Dependent Variables in Logarithms	Enrollment Ratio Male (S/P)	Enrollment Ratio Female (S/P)	Enrollment Ratio Total (S/P)	Teacher-Student Ratio (T/S)	Capital Intensity Index (E/C)	Teacher Salary (C/T)	Total Expenditure per Child Age 6-11 (E/P)
Explanatory Variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GNP per Adult in 1970 (log)	.158 (3.79)	.332 (5.07)	.224 (4.66)	.145 (3.75)	-.0002 (.01)	1.0	1.37 (26.5)
Relative Price of Teachers (log)[1]	-.188 (5.13)	-.153 (2.67)	-.194 (4.61)	-.158 (4.65)	-.0428 (1.72)	1.0	.606 (13.4)
Proportion of Population Urban	.0898 (.54)	-.0173 (.07)	.0390 (.20)	-.308 (2.00)	-.0925 (.82)	0.0	-.362 (1.76)
Proportion of Population Age 6-11	2.44 (1.88)	7.87 (3.88)	4.25 (2.86)	-4.03 (3.36)	-1.22 (1.39)	0.0	-1.00 (.63)
Total Fertility Rate	-.0130 (.55)	-.110 (2.97)	-.0508 (1.87)	-.0270 (1.23)	.0155 (.97)	0.0	-.0623 (2.13)
Intercept	-1.36 (4.15)	-3.05 (5.97)	-1.95 (5.19)	-3.44 (11.3)	.372 (1.68)	0.0	-5.01 (12.4)
R^2	.430	.517	.511	.539	.029	1.0	.952
Sample Size is 186							
Dependent Variable							
Mean (Standard Deviation)	-.126 (.355)	-.365 (.604)	-.229 (.440)	-3.49 (.366)	.192 (.184)	7.39 (1.10)	3.87 (1.51)

1: The price is treated as exogenous and estimated with ordinary least squares. Absolute value of t ratio reported in parentheses beneath regression coefficients.

Table 5: Estimates of secondary school expenditures and components, with the price of teachers exogenous[1]

Dependent Variables in Logarithms	Enrollment Ratio Male (S/P)	Enrollment Ratio Female (S/P)	Enrollment Ratio Total (S/P)	Teacher-Student Ratio (T/S)	Capital Intensity (E/C)	Teacher Salary (C/T)	Total Expenditure per Child Age 12-17 (E/P)
Explanatory Variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GNP per Adult in 1970 (log)	.399 (4.97)	.766 (9.13)	.526 (7.03)	.0377 (.69)	-.0132 (.37)	1.0	1.55 (27.8)
Relative Price of Teachers (log)[1]	-.354 (6.84)	-.403 (7.45)	-.389 (8.05)	-.0927 (2.63)	-.0225 (2.99)	1.0	.496 (13.8)
Proportion of Population Urban	-.219 (.71)	-.575 (1.78)	-.380 (1.32)	-.0181 (.09)	-.0766 (.56)	0.0	-.474 (2.21)
Proportion of Population Age 12-17	1.69 (.63)	10.5 (3.74)	4.53 (1.81)	-9.69 (5.29)	-2.14 (1.81)	0.0	-7.29 (3.91)
Total Fertility Rate	-.104 (2.91)	-.192 (5.13)	-.134 (4.03)	.0454 (1.87)	-.0113 (.72)	0.0	-.0775 (3.12)
Intercept	-2.84 (4.05)	-6.15 (8.40)	-3.92 (6.00)	-2.01 (4.20)	.574 (1.86)	0.0	-5.35 (11.0)
R^2	.763	.872	.839	.261	.039	1.0	.959
Sample Size is 139							
Dependent Variable:							
Mean (Standard Deviation)	-1.33 (.882)	-1.78 (1.25)	-1.49 (.999)	-2.99 (.341)	.192 (.193)	8.42 (.903)	4.14 (1.47)

1: The price is treated as exogenous and estimated with ordinary least squares. Absolute value of t ratio reported in parentheses beneath regression coefficients.

Table 6: Estimates of total school system expenditures and components, with the price of teachers exogenous

Dependent Variables in Logarithms	Enrollment Ratio Male (S/P)	Enrollment Ratio Female (S/P)	Enrollment Ratio Total (S/P)	Teacher-Student Ratio (T/S)	Capital Intensity (E/C)	Teacher Salary (C/T)	Total Expenditure per Child Age 6-17 (E/P)
Explanatory Variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GNP per Adult in 1970 (log)	.237 (4.66)	.457 (5.98)	.314 (5.66)	.114 (3.22)	-.0085 (.23)	.919 (24.0)	1.41 (24.4)
Relative Price of Teachers (log)[1]	-.250 (5.21)	-.239 (3.31)	-.267 (5.09)	-.103 (3.08)	-.0154 (1.50)	1.17 (32.4)	.485 (8.87)
Proportion of Population Urban	-.0471 (.25)	-.314 (1.08)	-.161 (.76)	-.161 (1.20)	-.108 (.78)	-.0642 (.44)	-.334 (1.51)
Proportion of Population Age 6-17	.432 (4.52)	3.31 (2.64)	1.47 (1.61)	-2.92 (5.05)	-1.03 (1.73)	-.551 (.88)	-2.81 (2.96)
Total Fertility Rate	-.0381 (1.46)	-.127 (3.26)	-.0746 (2.62)	.0130 (.72)	.0166 (.89)	.0478 (2.43)	-.0365 (1.23)
Intercept	.885 (2.05)	-1.11 (1.71)	.221 (.469	-3.09 (10.3)	.565 (1.83)	.527 1.62	-4.82 (9.82)
R^2	.660	.693	.717	.527	.043	.948	.956
Sample Size is 132							
Dependent Variable:							
Mean (Standard Deviation)	2.03 (.461)	1.72 (.728)	1.90 (.551)	-3.31 (.271)	.195 (.196)	8.80 (.886)	3.89 (1.45)

1: The price is treated as exogenous and estimated by ordinary least squares. Absolute value of t ratio reported in parentheses beneath regression coefficients.

Table 7: Estimates of primary school expenditures and components, with price of teachers endogenous

Dependent Variables in Logarithms	Enrollment Ratio Male (S/P)	Enrollment Ratio Female (S/P)	Enrollment Ratio Total (S/P)	Teacher-Student Ratio (T/S)	Capital Intensity (E/C)	Teacher Salary (C/T)	Total Expenditure per Child Age 6-11 (E/P)
Explanatory Variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GNP per Adult in 1970 (log)	.239 (3.96)	.430 (4.84)	.314 (4.53)	.168 (4.12)	.0008 (.03)	.870 (33.7)	1.35 (20.2)
Relative Price of Teachers (log)[1]	-.627 (4.81)	-.760 (3.96)	-.698 (4.67)	-.181 (2.06)	-.0106 (.16)	1.05 (18.8)	.161 (1.11)
Proportion of Population Urban	-.286 (1.14)	-.520 (1.41)	-.389 (1.35)	-.351 (2.08)	-.0736 (.60)	.193 (1.80)	-.620 (2.23)
Proportion of Population Age 6-11	1.93 (1.08)	6.39 (2.43)	3.50 (1.71)	-2.98 (2.48)	-.773 (.88)	-7.07 (9.26)	-7.33 (3.71)
Total Fertility Rate	.0450 (1.23)	-.0277 (2.43)	.0163 (.39)	-.0268 (1.08)	.0102 (.57)	-.0120 (.76)	-.0116 (.29)
Intercept	-1.60 (3.62)	-3.20 (4.92)	-2.18 (4.31)	-3.71 (12.5)	.291 (1.34)	1.75 (9.27)	-3.86 (7.87)
F	16.05	25.03	21.78	38.06	.46	1383.	441.
Sample Size is 186							
Dependent Variable:							
Mean (Standard Deviation)	-.126 (.355)	-.365 (.604)	-.229 (.440)	-3.49 (.366)	.192 (.184)	7.39 (1.10)	3.87 (1.51)

1: The price is treated as endogenous and estimated with instruments of secondary enrollment ratio, urbanization, and GNP per adult, all lagged ten years. Absolute value of asymptotic t ratio reported in parentheses beneath regression coefficients.

Table 8: Estimates of secondary school expenditures and components, with price of teachers endogenous[1]

Dependent Variables in Logarithms	Enrollment Ratio Male (S/P)	Enrollment Ratio Female (S/P)	Enrollment Ratio Total (S/P)	Teacher-Student Ratio (T/S)	Capital Intensity (E/C)	Teacher Salary (C/T)	Total Expenditure per Child Age 12-17 (E/P)
Explanatory Variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GNP per Adult in 1970 (log)	.304 (2.70)	.649 (5.13)	.428 (3.85)	.105 (1.53)	-.0087 (.24)	.942 (51.4)	1.47 (21.9)
Relative Price of Teachers (log)[1]	-.905 (6.58)	-1.07 (6.92)	-.964 (7.11)	.194 (2.33)	-.0082 (.19)	1.02 (45.5)	.242 (2.97)
Proportion of Population Urban	-.776 (1.76)	-1.25 (2.52)	-.963 (2.22)	.238 (.89)	-.661 (.47)	.143 (1.99)	-.649 (2.49)
Proportion of Population Age 12-17	-2.19 (.58)	5.67 (1.33)	.593 (.16)	-6.16 (2.67)	-1.87 (1.53)	-5.22 (8.42)	-12.7 (5.61)
Total Fertility Rate	-.0049 (.09)	-.0597 (.98)	-.0203 (.38)	.0093 (.28)	.0087 (.50)	-.0114 (1.28)	-.0322 (1.00)
Intercept	1.02 (.97)	-3.92 (3.31)	-2.04 (1.97)	-3.27 (5.12)	.492 (1.46)	1.03 (6.04)	-3.78 (6.08)
F	48.99	86.87	69.58	6.42	.88	1264.	419.
Sample Size is 139							
Dependent Variable:							
Mean (Standard Deviation)	-1.33 (.882)	-1.78 (1.25)	-1.49 (1.00)	-2.98 (.341)	.192 (.193)	8.42 (.903)	4.14 (1.47)

1: The price is treated as endogenous and estimated with instruments of secondary enrollment ratio, urbanization, and GNP per adult, all lagged ten years. Absolute value of asymptotic t ratio reported in parentheses beneath regression coefficients.

Table 9: Estimates of total school expenditures and components, with price of teachers endogenous[1]

Dependent Variables in Logarithms	Enrollment Ratio Male (S/P)	Enrollment Ratio Female (S/P)	Enrollment Ratio Total (S/P)	Teacher-Student Ratio (T/S)	Capital Intensity (E/C)	Teacher Salary (C/T)	Total Expenditure per Child Age 6-17 (E/P)
Explanatory Variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GNP per Adult in 1970 (log)	.277 (3.80)	.496 (5.03)	.357 (4.54)	.126 (3.40)	-.0018 (.05)	.756 (2.9)	1.35 (20.8)
Relative Price of Teachers (log)[1]	-.767 (5.0)	-.863 (4.37)	-.816 (5.14)	.0267 (.36)	.0223 (.30)	1.43 (12.0)	.168 (1.28)
Proportion of Population Urban	-.473 (1.59)	-.821 (2.03)	-.614 (1.19)	-.0763 (.50)	-.0927 (.62)	.280 (1.17)	-.513 (1.93)
Proportion of Population Age 6-17	-.479 (.39)	2.02 (1.23)	.501 (.38)	-2.22 (3.57)	-.792 (1.31)	-3.13 (3.20)	-5.21 (4.80)
Total Fertility Rate	.0450 (1.06)	-.0292 (.51)	.0137 (.30)	-.0122 (.10)	.0142 (.67)	-.0286 (.84)	-.0073 (.19)
Intercept	1.27 (2.04)	-.529 (.63)	.623 (.93)	-3.49 (11.0)	.423 (1.37)	2.28 (4.57)	-3.40 (6.15)
F	27.85	36.23	34.25	23.38	.69	134.	414.
Sample Size is 132							
Dependent Variable:							
Mean (Standard Deviation)	2.03 (.461)	1.72 (.728)	1.90 (.551)	-3.31 (.271)	.195 (.196)	8.08 (.886)	3.89 (1.45)

1: The price is treated as endogenous and estimated with instruments of secondary enrollment ratio, urbanization, and GNP per adult, all lagged ten years. Absolute value of asymptotic t ratio reported in parentheses beneath regression coefficients.

Table 10: Enrollment ratios for males and females including proportion of population Moslem and Catholic, with price endogenous

	Primary		Secondary		Expected Years	
	Male	Female	Male	Female	Male	Female
Explanatory Variables:						
GNP per Adult in 1970 (log)	.234 (3.63)	.404 (4.18)	.337 (3.11)	.607 (4.42)	.274 (3.50)	.450 (4.09)
Relative Price of Teachers (log)[1]	-.664 (4.79)	-.857 (4.14)	-.874 (6.68)	-1.07 (6.49)	-.796 (5.11)	-.966 (4.42)
Proportion of Population Urban	.228 (.85)	.422 (1.06)	.895 (2.13)	1.24 (2.33)	-.417 (1.32)	-.632 (1.43)
Proportion of Population in School Age	1.25 (.69)	4.07 (1.40)	-1.13 (.31)	4.52 (.98)	-.700 (.53)	.840 (.46)
Total Fertility Rate	.0763 (1.86)	.0477 (.78)	-.0283 (.52)	-.0573 (.83)	.0679 (1.43)	.0479 (.72)
Moslem Percent	-.0024 (2.22)	-.0053 (3.27)	.0031 (1.73)	-.0002 (.08)	-.0018 (1.35)	-.0059 (3.16)
Catholic Percent	-.0002 (.22)	.0010 (.70)	-.0001 (.10)	.0025 (1.30)	-.0004 (.35)	.0007 (.45)
Intercept	-1.56 (3.26)	-2.94 (4.11)	-1.27 (1.27)	-3.59 (2.82)	1.29 (1.94)	-.144 (.15)
F	11.08	18.01	39.90	55.54	17.49	24.15

1: The price is treated as endogenous and estimated with instruments of secondary enrollment ratio, urbanization, and GNP per adult, all lagged ten years. Absolute value of asymptotic t ratio reported in parentheses beneath regression coefficients.

Table 11: Regional average deviation of primary school expenditures and outputs from those predicted with prices endogenous

Region	Africa	Latin America	East Asia	South and West Asia	Europe, Oceania & Canada
(Sample Size)	(62)	(43)	(21)	(24)	(36)
Dependent Variable:					
Total Enrollment Ratio (log)	.172	-.142	.147	-.409	.0605
Male Enrollment Ratio (log)	.151	-.164	.110	-.276	.0558
Female Enrollment Ratio (log)	.227	-.106	.202	-.663	.0601
Teacher-Student Ratio (log)	-.0002	-.0256	-.0599	.0633	.0234
Capital Intensity Index (log)	-.0062	-.0370	.0132	.0632	.0051
Teacher Relative Wage (log)	-.0303	.155	-.0058	.0385	-.155
Total Expenditures per Child (log)	.135	-.0492	.0941	-.244	-.0664

Source: Estimates from Table 7 and data.

Table 12: Regional average deviations of secondary school expenditures and outputs from those predicted with prices endogenous

Region	Africa	Latin America	East Asia	South and West Asia	Europe, Oceania & Canada
(Sample Size)	(49)	(35)	(18)	(16)	(21)
Dependent Variable:					
Total Enrollment Ratio (log)	.299	-.437	.184	-.239	.0555
Male Enrollment Ratio (log)	.292	-.502	.170	-.0742	.0671
Female Enrollment Ratio (log)	.356	-.355	.235	-.615	.0289
Teacher-Student Ratio (log)	-.129	.227	-.188	.0707	.0295
Capital Intensity Index (log)	-.0030	-.0424	.0199	.0966	-.0130
Teacher Relative Wage (log)	-.0123	.0753	.0104	.0338	-.132
Total Expenditures per Child (log)	.155	-.177	.0258	-.0383	-.0596

Source: Estimates from Table 8 and data.

Table 13: Actual and predicted proportionate changes in expenditures per child and enrollment ratios

School Level (Sample Size) Dependent Variable	Actual Change (1)	Predicted Change (2)	Predicted Change Due to Variable: Adult Income (3)	Relative Price (4)	Urban-ization (5)	Relative Cohort Size (6)	Total Fertility (7)	Predicted to Actual Change (8)=(2)/(1)
Primary Schools (63)								
Expenditures/Child	.343	.319	.379	-.027	-.036	.010	-.007	.93
Enrollment Ratio								
- Total	.160	.166	.088	.115	-.023	-.005	-.009	1.04
- Male	.128	.125	.067	.108	-.017	-.003	-.026	.98
- Female	.228	.224	.121	.125	-.030	-.008	.016	.98
Secondary Schools (48)								
Expenditure/Child	.385	.234	.413	-.079	-.038	-.081	.018	.61
Enrollment Ratio								
- Total	.592	.393	.121	.313	-.056	.004	.011	.66
- Male	.504	.323	.086	.294	-.045	-.014	.003	.64
- Female	.663	.528	.183	.347	-.072	.037	.034	.80
Total School System (46)								
Expenditures/Child	.497	.287	.364	-.030	-.027	-.023	.004	.58
Expected Years								
- Total	.303	.186	.096	.131	-.036	.002	-.008	.61
- Male	.255	.142	.075	.123	-.028	-.002	-.025	.56
- Female	.375	.249	.134	.139	-.049	.009	.016	.66

Source: Estimates from Col. 1, 2, 3 and 7, Tables 7, 8, and 9. Change data from separate tabulation of sample for all countries with complete 1965 and 1975 information. See note 22. for list of countries included in secondary school sample.

NOTES

1. Pryor (1968) considered for a relatively small sample (20) of countries, market and centrally planned socialist, the level of public expenditures on education. In his effort to explain the share of GNP publically expended on education he observed a significant partial correlation with per capita income levels and share of population age 5-15. Simon and Pilarski (1969) regressed primary and secondary enrollment ratios and educational expenditures against per capita income, the crude birth rate, life expectancy, and several other variables. They found enrollments and expenditures per child positively related to income and inversely related to birth rates. The partial correlation with crude birth rates was statistically significant only for secondary school enrollments. Because fertility and the schooling of children are partially determined by parents in response to similar constraints and related preferences, the covariation of these two choice variables does not confirm or reject the hypothesized causal effect of a relatively large cohort of school aged children depresses the average educational resources and school achievements of that cohort. Lall (1969) and Kelley (1976) also explore patterns of government expenditures across low income countries.

2. These illustrative figures are drawn from World Development Report 1984, World Bank Staff, Oxford University Press, 1984, Tables 1, 23, and 25. See also Preston's (1980) comparisons of life expectation across more uniform and reliable data from a smaller number of countries.

3. The population of primary and secondary school age, according to UNESCO conventions, ages 6 to 17, increased by an estimated 131 percent from 1950 to 1980 in the less developed regions of the world, while the total population increased 95 percent (UN, 1982b). From 1960 to 1980 the corresponding figures were 68 and 58 percent.

4. See Schultz (1986) for regional breakdown of existing data on private school enrollments and its limitations as an unweighted average over a relatively small set of reporting countries.

5. UNESCO Yearbook figures on public expenditures are generally designed to include all public sector outlays, including subsidies from the public sector to private schools. Footnotes also indicate, particularly for some African countries, that school fees paid by parents to the public schools are included in public sector expenditures. The data on public expenditures on education that are analyzed in the subsequent regressions are thus designed to include state and local government spending on schools.

6. The political process may not assign everyone's vote an equal weight, however. For example, urban populations in many low income countries appear to exercise greater influence on public sector decisions than do dispersed rural populations (Lipton, 1977). Without data on the distribution of income, public services, or taxes across subgroups within countries, it is not fruitful to speculate further here on the distributional implications of how this political process works.

7. Since relatively few studies have estimated the private or social returns to education, it is not possible here to even examine the correlation between unexplained deviation in public investments in schooling and the level of private and public returns to schooling. The most comprehensive comparison of rate of return studies is that by Psacharopoulos (1973, 1981). Differences in methodology across even these summarized country studies undermine the comparability of the return calculations.

8. For example, urbanization was hypothesized to reduce the unit costs of education for technological reasons. But it might also be associated with higher relative demand for educated labor, and hence higher producer rates of return to schooling. Urbanization, which is one variable in Z, could thus influence education both by altering production technology and by increasing household demands.

9. Note that if the demand for educational services is relatively inelastic, $\eta > -1$, and education is a public good, $\gamma < 1$, the 'cohort size effect' could be interpreted as a scale effect of schooling as a public good, i.e. $(\eta + 1)(\gamma - 1)$.

10. Equation (9) may be rewritten in logarithms:

$$\ln(E/P) = \ln(S/P) + \ln(T/S) + \ln(E/C) + \ln(C/T)$$

and regressions would be calculated of the following form at each level of schooling:

$$\ln(E/P) = \beta_{11} + \beta_{12}\ln Y + \beta_{13}\ln P_x + \beta_{14}Z$$

$$\ln(S/P) = \beta_{21} + \beta_{22}\ln Y + \beta_{23}\ln P_x + \beta_{24}Z$$

$$\ln(T/S) = \beta_{31} + \beta_{32}\ln Y + \beta_{33}\ln P_x + \beta_{34}Z$$

$$\ln(E/C) = \beta_{41} + \beta_{42}\ln Y + \beta_{43}\ln P_x + \beta_{44}Z$$

$$\ln(C/T) = \beta_{51} + \beta_{52}\ln Y + \beta_{53}\ln P_x + \beta_{54}Z$$

The adding up of component effects implies that

$$\beta_{1i} = \sum_{j=2}^{5} \beta_{ji} \qquad \text{for } i = 1, \ldots, 4.$$

11. It may be argued that the use of foreign exchange (FX) rates in 1969-71 to translate GNP from local currencies into the common unit of dollars gives insufficient weight to nontraded commodities. The tendency is to exaggerate differences across countries in real consumer income per adult. Recent work to construct a purchasing power parity (PPP) basis for comparing incomes across countries by Kravis, Heston and Summers (1982) is built on a sample of countries for which price indexes were constructed and then generalized and revised to apply to other countries by Summers and Heston (1984). For example, FX translated GNP per adult is forty-three times larger in the U.S. than in India in 1970, whereas the PPP real income per adult difference is only thirteen to one. Consumer welfare may be better approximated by the PPP income deflator and therefore the PPP deflated figures were used in reestimating the schooling equations reported in this paper. In general, PPP income elasticities of school expenditures increased by as much as a quarter, as would have been expected since the sample variance in log PPP incomes is markedly less than the variance in log FX incomes. Price elasticities were reduced somewhat, suggesting that some of the differences in the relative price of teacher salaries are captured in the PPP adjustment procedure. No systematic changes occurred in the coefficients on relative size of school aged cohorts, nor were the estimated effects of urbanization noticeably changed by this substitution of one measure of real GNP for the other. Substantive conclusions of this paper are not particularly sensitive, therefore, to this choice of procedure for translating GNP across countries into common welfare units.

12. The disturbances in the equation determining current demand for schooling that would affect today's wages of teachers might also be correlated with the unexplained disturbances in the equation determining enrollment rates ten years earlier, such as might arise from a persistent country-specific unobserved effect. This form of error structure would imply that the lagged enrollment variable was not actually exogenous to the wage equation. The two-stage estimates based on the lagged enrollment instrument would then be subject to the classical simultaneous equation bias and also would be inconsistent. Although I cannot be confident of the direction of this bias on the price elasticity, it would seem likely to bias positively the estimate of the enrollment effect on wages. In fact, the enrollment effect is estimated to be negative and appears statistically significant for both the primary and secondary teacher wage rates as reported in footnote 14.

13. An analogous errors-in-variable bias arised in the study of labor supply, where earnings are divided by hours worked to obtain a wage rate that is specified by theory as a determinant of hours.

14. The implicit primary and secondary school logarithmic wage equations for teachers were estimates as conditioned on the secondary school enrollment rate, income per adult and proportion of the population urban, all of which explanatory variables were evaluated ten years earlier:

$$\ln W_{p_t} = \underset{(3.38)}{-1.84} - \underset{(6.22)}{.349} \ln E_{s_{t-10}} + \underset{(4.30)}{.355} \ln GNP/A_{t-10} - \underset{(2.67)}{.808} U_{t-10}$$

$$n = 186 \qquad R^2 = .264$$

$$\ln W_{s_t} = \underset{(1.18)}{-.931} - \underset{(8.25)}{.646} \ln E_{s_{t-10}} + \underset{(2.61)}{.305} \ln GNP/A_{t-10} - \underset{(3.22)}{1.25} U_{t-10}$$

$$n = 139 \qquad R^2 = .601$$

where $E_{s_{t-10}}$ refers to the secondary school enrollment proportion ten years ago, GNP/A_{t-10} indicates GNP per adult (age 15 to 65) measured ten years earlier, U_{t-10} is the urban proportion of the population ten years ago, and W_{pt} or W_{st} are the school current expenditures per primary or secondary school teacher divided by GNP per adult today.

15. See footnote 11.

16. From equation (8) the coefficient on the relative price or teacher wage variable in the expenditure function is $b_2 = \alpha(\eta + 1)$, and thus the estimated price elasticity, $\eta = (b_2/\alpha) - 1$. The sample mean of α is .82.

17. It appears to be generally cheaper to hire teachers in a more urbanized area, though GNP per adult augments teacher wages more than proportionately. Urban amenities including summer employment opportunities may be valued particularly highly by teachers and thus it is costly to assign them to provincial rural schools where teachers must do without these amenities and relocate during vacations to obtain employment for their educated skills.

18. Economies of scale in producing school services might be distinguished at three levels: (1) with the size of the national educational system, (2) with the size of the school measured in terms of its number of full time teachers, and (3) with the size of the teacher's span of control or student-teacher ratio. The importance of (1) in primary and secondary school systems was assumed at the outset to be negligible. The number of primary schools is reported for some recent years in the UNESCO Yearbook. If the system's average school size (i.e. log of teachers per school) is added to equation (8), one might expect this added scale variable to diminish the coefficient on urbanization, if larger urban schools realized economies that reduced unit costs. In a sample of 60 countries for which these data are recently available, school size is associated with greater expenditures per child due to higher teacher-student ratios and higher current outlays per teacher. The coefficients on urbanization are not reduced in magnitude by the addition of school size. Consolidation economies, however, could remain important at the secondary level, but no data were found to test this conjecture.

19. Standardized test comparisons do confirm that spending far less per student in low income countries is associated with lower test scores. (Heyneman and Loxley, 1983). What is now needed is estimates of the marginal gains from additions to school quality and quantity that can be purchased with marginal increments in educational expenditures, and what are the effects of these alternative expenditures on the future productivity of students.

20. The income elasticities are further apart for girls and boys in the low income sample than for the entire sample, whereas price elasticities are closer together for boys and girls in the low income sample at the primary level and further apart at the secondary level. The relatively large standard errors on the estimated income elasticities of male enrollment reduce our confidence that male and female enrollments respond differently, whereas the price elasticity estimates are sufficiently precise to infer that they differ between sexes at a ten percent confidence level, in the low income sample.

21. It should be noted the religion variables are strongly intercorrelated with incomes, and thus income elasticity estimates are generally reduced by the inclusion of the religion variables. It should also be stressed that religious preference estimates are not precise in many populations. Here I have relied on Russet _et al_. (1964) and _The Encyclopedia Britannica, 15th Ed_. (1983).

22. The countries included were: Burundi, Kenya, Mauritius, Rwanda, Somalia, Uganda, Tanzania, Cameroon, Algeria, Morocco, Sudan, Tunisia, Ghana, Liberia, Togo, Sierra Leone, Jamaica, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Argentina, Bolivia, Colombia, Ecuador, Paraguay, Peru, Venezuela, Hong Kong, South Korea, Singapore, Thailand, Afghanistan, Iran, Nepal, Pakistan, Iraq, Kuwait, Syria, Finland, Ireland, Italy, Portugal, Yugoslavia, and France.

23. Standard error-component models of time series of cross sections cannot be estimated here, because the number of observations per country varies.

DATA APPENDIX

Data were initially compiled at five year intervals from 1955 to 1980 for 155 countries with an estimated population of one million or more in 1983. Ten of these countries were eliminated for lack of numerous data series.* Eleven non-market economies of Eastern Europe were also not examined, in part because they did not have convertible currencies and thus a free exchange rate with which to express their national income or educational expenditures (where available) in common currency units (1970 U.S. Dollars). Yugoslavia is included. Since the basis for many demographic indicators such as age composition and literacy are population censuses which occur approximately every ten years, data were linearly interpolated for up to ten years and extrapolated for up to five years. Out of a possible 930 observations for all countries and years, complete data were obtained for only 321 observations for primary schooling systems (see Table 1) and 258 observations for secondary school systems and 250 observations for combined systems including primary, secondary and higher. Many countries have anomalous gaps in their published data that might be eliminated with further research, such as the omission of Taiwan because of the proscription of data from this country in recent U.N. data compilations.

More serious than these idiosyncratic gaps in the sample, which probably do not distort substantially the patterns I wish to describe, are the poor quality and incomparability of some of the reported data. Biases are obviously present in most school systems that work to overstate initial enrollments or at a minimum contribute to a variable gap between initial enrollment and average daily attendance rates. But attendance rates are not available from most countries, precluding reasonable adjustments. Enrollment is associated with changing numbers of days attendance over time and across countries. Expenditure data is probably still less reliable, with changes in administrative regimes leading to some unlikely year-to-year variations. Series for only recurrent or current educational expenditures appear more stable and reliable compared with capital account expenditures that embody year to year variations that are not readily explained by the economic and demographic constraints emphasized here.

Total educational expenditures are often divided among primary, secondary (academic, vocational and normal schools combined) and higher educational institutions. Those expenditures not allocated among these three levels, such as central administrative expenses, are proportionately distributed to the three levels according to their relative shares in the allocated total. Current and capital expenditure shares of this total are also assumed constant at the three levels, for lack of cross-tabulations of capital expenditures. The consolidation of educational expenditures at various levels of government may introduce further error, for in federal governmental structures, state and local expenditures on schools may not always be reported uniformly to the central government and hence not consistently included as intended in UNESCO figures across countries. The role of the private sector in providing educational services may also be an important factor in determining the amount and quality of public sector support for education and vice versa. Figures on the numbers of teachers by level are also available for many countries, but the treatment of part- and full-time teachers may not be consistent across countries (Pryor, 1968) nor how many days per year they are required to teach. With all these misgivings, it is not possible in this background paper to more than summarize existing data as reported by governments on their educational systems and published in the UNESCO Statistical Yearbooks. The wide range and variety of UNESCO data appear, nonetheless, to warrant more comparative study than they have received.

The second major source of data is the World Bank Data Tape (version dated April 1984). From this source, I extract data on GNP, both in current market, constant local prices, the implicit GNP deflator (price index), and the foreign exchange rate into U.S. dollars (official IMF figure). Real GNP in constant U.S. dollars is then defined as the constant local price GNP converted at the average exchange rate prevailing in 1969, 1970, and 1971. The GNP deflator and exchange rate are also used to derive estimates of the U.S. dollar equivalent of government educational expenditures.

---

* Mozambique, Lesotho, Nambia, Guinea-Bissau, China, Mongolia, North Korea, Kampuchea, Laos and Viet Nam. The omission of particular series for the U.S. and Taiwan will be corrected in future work, and aggregations of early data for portions of Malaysia were compiled. Several countries were eliminated because of instability in its domestic GNP deflator over time, such as Chile and Argentina, although it should be possible to include these countries in the future.

To approximate the "price" of public sector educational services, I have divided the current educational expenditures per teacher by the current value of GNP per adult age 15 to 64. This relative "price" of teachers is defined for the primary and secondary public school systems separately, and averaged for the total system. UNESCO figures for educational expenditures are not always expressed in the same local currency units employed in the national income accounts reported by The World Bank. In some countries with substantial inflation and foreign exchange revaluations, such as Chile and Argentina, comparable expenditure and national income figures were not reconstructed, and these observations are omitted from this analysis.

Population figures are drawn from the UN Demographic Indicators of Countries: Estimates and Projections as Assessed in 1980, and are linearly interpolated across decades as required or across ages to obtain the population of children age 6 to 11 for primary school, 12 to 17 for secondary school and 20 to 24 for higher education. These age groupings of potential students might differ from country to country given local schooling systems, but are standardized here to match with the average definition of UNESCO enrollment ratios. Since children outside of a specific school age group may enroll in such schools, these ratios may exceed 100 percent. Enrollment ratios may also exceed 100 percent due to the upward reporting bias referred to earlier. To summarize school enrollments at all levels, a synthetic measure of cohort expected years of exposure to schooling is calculated. It is defined, as stated in the text, as the weighted sum of primary, secondary and higher school enrollment rates, where the weights are 6, 6 and 5. The proportion of the population living in urban areas is drawn from the World Bank Data Tape. Educational attainment of the parents of school-age children is not readily available from standardized sources. Adult literacy rates are often published, but can be of doubtful reliability and are rarely disaggregated by age or sex. The adult literacy rates considered here are interpolated from the 1983 World Development Report, and augmented from early UN Demographic Yearbooks.

REFERENCES

Becker, G.S., (1963), Human Capital, New York: Columbia University Press (2nd Edition, 1975).

Becker, G.S. and H.G. Lewis, (1974), "Interactions Between Quantity and Quality of Children," Economics of The Family, (ed.) T.W. Schultz, Chicago, Ill.: University of Chicago Press.

Behrman, J.R. and N. Birdsall, (1983), "The Quality of Schooling," American Economic Review, 73:5 (December), 923-946.

Belmont, L. and F.A. Marolla, (1973), "Birth Order, Family Size and Intelligence," Science, 182, pp. 1096-1101.

Bergstrom, T.C. and R.P. Goodman, (1973), "Private Demand for Public Goods," American Economic Review, 63:3 (June), 280-296.

Bergstrom, T.C., D.L. Rubinfeld and P. Shapiro, (1982), "Microbased Estimates of Demand Functions for Local School Expenditures," Econometrica 50:5 (September), 1183-1206.

Binswanger, H. and V.W. Ruttan, (1978), Induced Innovation: Technology: Institutions and Development. Baltimore, MD: Johns Hopkins University Press.

Borcherding, T.E. and R.T. Deacon, (1972), "The Demand for the Services of Non-Federal Governments," American Economic Review, 62:5 (December), 891-901.

Bowles, S., (1969), Planning Educational Systems for Economic Growth. Cambridge, MA: Harvard University Press.

Coale, A.J. and E.M. Hoover, (1958), Population Growth and Economic Development in Low Income-Countries. Princeton, N.J.: Princeton University Press.

Easterlin, R., (1980), Birth and Fortune. New York: Basic Books.

Freeman, R., (1979), "The Effect of Demographic Factors on Age-Earnings Profiles," Journal of Human Resources, 14:3, 289-318.

Freeman, R.B., (1971), The Market for College-trained Manpower. Cambridge, MA: Harvard University Press.

Gramlich, E.M. and D.L. Rubinfeld, (1982), "Microestimates of Public Spending Demand Functions and Tests of the Tiebout and Median Voter Hypothesis," Journal of Political Economy, 90:3 (June), 536-560.

Harbison, F. and C.A. Myers, (1964), Education, Manpower and Economic Growth. New York: McGraw-Hill.

Hayami, Y. and V.W. Ruttan, (1984), "Population Growth and Agricultural Productivity," mimeo, University of Minnesota.

Heyneman, S., (1984), "Research on Education in the Developing Countries," International Journal of Educational Development 4(4):293-304.

Heyneman, S. and W. Loxley, (1983), "The Effects of Primary School Quality on Academic Achievement Across 29 High and Low Income Countries," American Journal of Sociology, 88:6 (May), 1162-94.

Jimenez, E., (1984), "Pricing Policy in the Social Sectors: Cost Recovery for Education and Health in Developing Countries," Mimeo, University of Western Ontario and the World Bank, Washington, D.C.

Jones, G., (1971), "Effects of Population Growth on the Attainment of Educational Goals in Developing Countries," in Rapid Population Growth, National Academy of Sciences. Baltimore, MD: Johns Hopkins University Press.

Jones, G., (1975), Population Growth and Educational Planning in Developing Nations. NYC: Irvington Publications.

Kelley, A.C., (1976), "Demographic Change and Size of the Government Sector," Southern Economic Journal, 43, pp. 1056-1066.

Kirk, D., (1966), "Factors Affecting Moslem Natality," in Family Planning and Population Programs. Chicago: University of Chicago Press.

Kravis, I.B., A. Heston, R. Summers (1982), World Product and Income. Baltimore, MD: Johns Hopkins University Press.

Lall, S., (1969), "A Note on Government Expenditures in Developing Countries," Economic Journal, 79:314 (June), 413-417.

Lee, R., (1979), "Causes and Consequences of Age Structure Fluctuations: The Easterlin Hypothesis," in Economic and Demographic Change: Issues for the-1980's. Liege, Belgium: Ordina Publications, IUSSP.

Lee, K.H., (1984), "Universal Primary Education: An African Dilemma," Mimeo, The World Bank, Washington, D.C.

Leibowitz, A., (1974), "Home Investment in Children," in Economics of the Family, (ed.) T.W. Schultz. Chicago: University of Chicago Press.

Lipton, M., (1977), Why Poor People Stay Poor: Urban Bias in World Development. Cambridge, MA: Harvard University Press.

McMahon, W.W., (1970), "An Economic Analysis of Major Determinants of Expenditures on Publication Education," Review of Economics and Statistics, 52:3 (August), 242-252.

Preston, S.H., (1980), "Causes and Consequences of Mortality Declines in LDCs During the Twentieth Century," in Population and Economic Changes in Developing Countries, (ed.) R.A. Easterlin, Chicago: University of Chicago Press.

Pryor, F.L., (1968), Public Expenditures in Communist and Capitalist Nations. Homewood, Ill.: Richard Irwin, Inc.

Psacharopoulos, G., (1973), Returns to Education. San Francisco: Jossey Bass-Elsevier Pub.

Psacharopoulos, G., (1981), "Returns to Education: An Updated International Comparison," Comparative Education Review, 17:3, 321-341.

Ram, R. and T.W. Schultz, (1979), "Life Span, Health, Savings and Productivity," Economic Development and Cultural Change, 27:3 (April), 399-421.

Robinson, W.C., (1975), Population and Development Planning. New York: The Population Council.

Rosenzweig, M.R., (1982), "Educational Subsidy, Agricultural Development, and Fertility Change," Quarterly Journal of Economics, 97:1 (February), 67-88.

Rosenzweig, M.R. and K.I. Wolpin, (1980), "Testing the Quantity Quality Model of Fertility. The Use of Twins as a Natural Experiment," Econometrica, 48:1, (January), 227-240.

Russet, B.M., R.A. Hayward, K.W. Deutsch, and H.D. Lasswell, (1964), World Handbook of Political and Social Indicators. New haven, CT: Yale University Press.

Sai, F.T., (1984), "The Population Factor in Africa's Development Dilemma," Science, 226, (16 November), 801-805.

Schultz, T.P., (1971), "An Economic Perspective on Population Growth," in Rapid Population Growth. National Academy of Sciences, Baltimore, MD: Johns Hopkins University Press.

Schultz, T.P., (1981), Economics of Population. Reading, MA: Addison Wesley Publication Co.

Schultz, T.P., (1984), "Studying the Impact of Household Economic and Community Variables on Child Mortality," Population and Development Review, 10, Supp. (August), 215-235.

Schultz, T. P. (1986), "School Expenditures and Enrollments, 1960-1980," in Population Growth and Economic Development. National Academy of Sciences, National Academy Press, Washington, D.C. 1986.

Schultz, T.W., (1961), "Investment in Human Capital," American Economic Review, 51:1 (March).

Simon, J.L. and A.M. Pilarski, (1979), "The Effect of Population Growth Upon the Quantity of Education Children Receive," Review of Economics and Statistics, 61:4 (November), 572-584.

Simmons, J. and L. Alexander, (1978), "The Determinants of School Achievement in Developing Countries," Economic Development and Cultural Change, 26:2 (January), 341-58.

Summers, R. and A. Heston (1984), "Improved International Comparisions of Real Product and Its Composition, 1950-80," Review of Income and Wealth, Series 30: 2 (June), 207-262.

Tan, J.P. and M. Haines, (1983), "Schooling and Demand for Children: Historical Perspective," mimeo, World Bank, Washington, D.C.

Terhune, K.W., (1974), A Review of the Actual and Expected Consequences of Family Size. Report to the Center for Population Research, NICHD, Washington, D.C.

United Nations Department of International Economic and Social Affairs, (1982a), Model Life Tables for Developing Countries. Population Studies, No. 77, New York City: United Nations.

United Nations, Department of International Economic and Social Affairs, (1982b), Demographic Indicators of Countries: Estimates and Projections as Assessed in 1980. New York.

United Nations, (various years), Demographic Yearbook. New York.

United Nations Education and Social Commission, (various years), UNESCO Statistical Yearbook. New York.

Welch, F., (1979), "The Baby Boom Babies' Financial Bust," Journal of Political Economy, 87:5, pt. 2 (October), 568-598.

Williamson, J.G. and P.H. Lindert, (1980), American Inequality. New York: Academic Press.

World Bank Staff, (1974), Population Policies and Economic Development. Baltimore, MD: Johns Hopkins University Press.

World Bank Staff, (1980), Education Sector Policy Paper. 3rd Edition, Washington, D.C. (April).

World Bank Staff, (1983), World Development Report 1983. New York City: Oxford University Press.

World Bank Staff, (1984), World Development Report 1984. New York City: Oxford University Press.

Wray, J.D., (1971), "Population Pressure on Families," Rapid Population Growth. National Academy of Sciences, Baltimore, MD: Johns Hopkins University Press.

CHAPTER SIX

Induced Institutional Innovation

by
Vernon W. Ruttan

INDUCED INSTITUTIONAL INNOVATION*

Vernon W. Ruttan**

Over the last several decades economists have made major contributions to our understanding of the impact of natural science knowledge on technical change and the impact of technical change on economic growth. We have also significantly advanced our understanding of the sources of demand for and supply of technical change.

In work published in the early 1970s Yujiro Hayami and I extended the theory of induced technical change and tested it against the history of agricultural development in the United States and Japan (Hayami and Ruttan, 1971; Binswanger and Ruttan, 1978; Wade, 1981). It is now generally accepted that the theory of induced technical change provides very substantial insight into the process of agricultural development for a wide range of developed and developing countries. Economic historians are increasingly drawing on the theory of induced technical change in attempting to interpret differential patterns of productivity growth among countries and over time (Cain and Paterson, 1981; Phillips, 1982).

The demonstration that technical change can be treated as largely endogenous to the development process does not imply that the progress of either agricultural or industrial technology can be left to an "invisible hand" that drives technology along an "efficient" path determined by relative resource endowments. The capacity to advance knowledge in science and technology is itself a result of a product of institutional innovation--"the great invention of the 19th century was the invention of the method of invention" (Whitehead, 1925:96).

In the case of agriculture, for example, in both Japan and the United States, much of the technical change that has led to growth of output per hectare has been produced by public sector institutions. These institutions--state (or prefectoral) and federal (or national) agricultural experiment stations--obtain their resources in the political market place and allocate their resources through bureaucratic mechanisms. The success of the theory of induced technical change gives rise, therefore, to the need for a more careful consideration of the sources of institutional innovation and design.

In this paper I elaborate a theory of institutional innovation in which shifts in the demand for institutional change are induced by changes in relative resource endowments and by technical change. I also consider the impact of advances in social science knowledge and of cultural endowments on the supply of institutional change. After examining the forces that act to shift the demand and supply of institutional change I then present the elements of a more general model of institutional change. The perspective on the role of institutional change in the process of economic development presented in this paper is much more positive than the views that were held by the American institutional school or in the recent literature on social choice and collective action (Zingler, 1974; Seckler, 1975; Olson, 1982).

What is Institutional Innovation?

Institutions are the rules of a society or of organizations that facilitate coordination among people by helping them form expectations which each person can reasonably hold in dealing with others. They reflect the conventions that have evolved in different societies regarding the behavior of individuals and groups relative to their own behavior and the behaviour of others.[1] In the

---

* This paper draws on Chapter 4 "An Induced Innovation Theory of Agricultural Development" in Yujiro Hayami and Vernon W. Ruttan, Agricultural Development: An International Perspective 2nd ed. (Baltimore: Johns Hopkins University Press, 1985). See also Vernon W. Ruttan and Yujiro Hayami, "Toward a Theory of Induced Institutional Innovation," The Journal of Development Studies 20 (July 1984), pp. 203-223.

** Professor, Department of Economics and Department of Agricultural and Applied Economics, University of Minnesota.

area of economic relations they have a crucial role in establishing expectations about the rights to use resources in economic activities and about the partitioning of the income streams resulting from economic activity--"institutions provide assurance respecting the actions of others, and give order and stability to expectations in the complex and uncertain world of economic relations."[2]

In order to perform the essential role of forming reasonable expectations in dealings among people, institutions must be stable for an extended time period. But institutions, like technology, must also change if development is to occur. Anticipation of the latent gains to be realized by overcoming the disequilibria resulting from changes in factor endowments, product demand, and technical change represents a powerful source of demand for institutional innovation (North and Thomas, 1970; Schultz, 1975). Institutions that have been efficient in generating growth in the past may, over time become obstacles to further economic development.[3] The growing disequilibria in resource allocation due to institutional constraints on the opportunities for economic growth create an environment in which it becomes profitable for political entrepreneurs or leaders to organize collective action to bring about institutional change.

This perspective on the sources of demand for institutional change is similar, in some respects, to the traditional Marxian view.[4] Marx considered technological change as the primary source of institutional change. My view is somewhat more complex. I consider that changes in factor endowments and product demand are equally important sources of institutional change. Nor is my definition of institutional change limited to the dramatic or revolutionary changes of the type anticipated by Marx. Basic institutions such as property rights and markets are more typically altered through the cumulation of "secondary" or incremental institutional changes such as modifications in contractual relations or shifts in the boundaries between market and non-market activities (Davis and North, 1971:9).

There is a supply as well as a demand dimension in institutional change. Collective action leading to changes in the supply of institutional innovations may be generated by tension among interest groups. Clearly, the process is much more complex than the simple class conflict between those who derive their income from the ownership of property and those who derive their income from labor as assumed by Marx. The supply of institutional innovations is strongly influenced by the cost of achieving social consensus (or of suppressing opposition). The cost of institutional change is dependent on the distribution of political resources. And it also depends critically on cultural tradition and on ideology.

Advances in knowledge in the social sciences (and in related professions such as law, administration, planning, and social service) can reduce the cost of institutional change in a somewhat similar manner as advances in the natural sciences reduce the cost of technical change. (Education, both general and technical, that facilitates a better understanding among people of their common interests can also reduce the cost of institutional innovation.)

Our insistence that important advances in the understanding of the processes of institutional innovation and diffusion can be achieved by treating institutional change as endogenous to the economic system represents a clear departure from the tradition of modern analytical economics.[5] This does not mean that analytical economics must be abandoned. On the contrary, it is suggested that the scope of modern analytical economics be expanded by treating institutional change as endogenous.

Demand for Institutional Innovation--Property Rights And Market Institutions

In some cases the demand for institutional innovation can be satisfied by the development of new forms of property rights, more efficient market institutions, or even by evolutionary changes arising out of direct contracting by individuals at the level of the community or the firm. In other cases, where externalities are involved, substantial political resources may have to be brought to bear to organize non-market institutions in order to provide for the supply of public goods. It may be useful to illustrate, from the agricultural history of a number of countries, how change in factor endowments, technical change, and growth in product demand have induced change in property rights and contractual arrangements in order to promote more efficient resource allocation.

The agricultural revolution that occurred in England between the 15th and the 19th centuries involved a substantial increase in the productivity of land and labor. It was accompanied by the enclosure of open fields and the replacement of small peasant cultivators, who held their land from manorial lords, by a system in which large farmers used hired labor to farm the land they leased from the landlords. The First Enclosure Movement, in the 15th and 16th centuries, resulted in the conversion of open arable fields and commons to private pasture in areas suitable for grazing. It was induced in substantial part by expansion in the export demand for wool. The Second Enclosure Movement in the 18th century involved conversion of communally managed arable land into privately operated units. It is now agreed that it was largely induced by the growing disequilibrium between the fixed institutional rent that landlords received under copyhold tenures (with lifetime contracts) and the higher economic rents expected from adoption of new technology which became more profitable as a consequence of higher grain prices and lower wages. When the land was enclosed there was a redistribution of income from farmers to landowners and the disequilibrium was reduced or eliminated.[6]

In 19th century Thailand, the opening-up of the nation for international trade and the reduction in shipping rates to Europe resulted in a sharp increase in the demand for rice. The land available for rice production, which had been abundant, became more scarce. Investment in land development for rice production became profitable. The response was a major transformation of property rights. Traditional rights in human property (corvee and slavery) were replaced by more precise private property rights in land (fee-simple titles) (Feeny, 1982).

In Japan, at the beginning of the feudal Tokugawa period (1603-1867), peasants' rights to cropland had been limited to the right to till the soil with the obligation to pay a feudal land tax in kind. As the population grew, commercialization progressed and irrigation and technology were developed to make intensive farming more profitable. Some peasants divided their holdings into smaller units and leased them out to ex-servants or extended family members. Some accumulated land through mortgaging arrangements that made other peasants de facto tenants. As a result of the accumulation of illegal leasing and mortgaging practices, peasants' property rights in land approximated those of a fee-simple title by the end of the Tokugawa period. These rights were readily converted to the modern private-property system in the succeeding Meiji period (Hayami and Kikuchi, 1982:28).

Research conducted by Yujiro Hayami and Masao Kikuchi in the Philippines during the late 1970s has enabled us to examine a contemporary example of the interrelated effects of change in resource endowments and technical change on the demand for institutional change in land tenure and labor relations (Kikuchi and Hayami, 1980; Hayami and Kikuchi, 1982). The case is particularly interesting because the institutional innovations occurred as a result of private contracting among individuals. The study is unique in that it is based on a rigorous analysis of microeconomic data in a village over a period of about 20 years.

Change in Technology and Resource Endowment

Between 1956 and 1976, rice production per hectare in the study village rose dramatically, from 2.5 to 6.7 metric tons per hectare per year. This was due to two technical innovations. In 1958, the national irrigation system was extended to the village. This permitted double-cropping to replace single-cropping, thereby substantially increasing the annual production per hectare of rice land. The second major technical change was the introduction in the late 1960s of the modern high-yielding rice varieties. The diffusion of modern varieties was accompanied by increased use of fertilizer and pesticides and by the adoption of improved cultural practices such as straight-row planting and intensive weeding.

Population growth in the village was rapid. Between 1966 and 1976 the number of households rose from 66 to 109 and the population rose from 383 to 464, while cultivated area remained virtually constant. The number of landless laborer households increased from 20 to 54. In 1976, half of the households in the village had no land to cultivate, not even land for rent. The average farm size declined from 2.3 to 2.0 hectares.

The land is farmed primarily by tenants. In 1976, only 1.7 hectares of the 108 hectares of cropland in the village were owned by village residents. In both 1956 and 1966, 70 percent of the land was farmed under share tenure arrangements. In 1963, a new agricultural land reform code was passed which was designed to break the political power of the traditional landed elite and to provide greater incentives to peasant producers of basic food crops.[7] A major feature of the new legislation was an arrangement that permitted tenants to initiate a shift from share tenure to leasehold, with rent under the leasehold set at 25 percent of the average yield for the previous three years. Implementation of the code between the mid-1960s and the mid-1970s resulted in a decline in the percentage of land farmed under share tenure to 30 percent.

Institutional Innovation

The shift from share tenure to lease tenure was not, however, the only change in tenure relationships that occurred between 1966 and 1976. There was a sharp increase in the number of plots farmed under subtenancy arrangements. The number increased from one in 1956, to sixteen in 1976. Sub-tenancy is illegal under the land reform code. The subtenancy arrangements are usually made without the formal consent of the landowner. All cases of subtenancy were on land farmed under a leasehold arrangement. The most common subtenancy arrangement was fifty-fifty sharing of costs and output.

The incentive for the emergence of the subtenancy institution was that the rent paid to landlords under the leasehold arrangement was below the equilibrium rent -- the level which would reflect both the higher yields of rice obtained with the new technology and the lower wage rates implied by the increase in population pressure against the land.

To test this hypothesis, market prices were used to compute the value of the unpaid factor inputs (family labor and capital) for different tenure arrangements during the 1976 wet season. The results indicate that the share-to-land was lowest and the operators' surplus was the highest for the land under leasehold tenancy. In contrast, the share-to-land was the highest and no surplus was left for the operator who cultivated the land under the subtenancy arrangement (Table 1; page 132). Indeed, the share-to-land when the land was farmed under subtenancy was very close to the sum of the share-to-land plus the operators' surplus under the other tenure arrangement. A substantial portion of the economic rent was captured by the leasehold tenants in the form of operators' surplus. On the land farmed under a subtenancy arrangement, the rent was shared between the leaseholder and the landlord.

A second institutional change, induced by higher yields and the increase in population pressure, has been the emergence of a new pattern of employer-labor relationship between farm operators and landless workers. According to the traditional system called hunusan, laborers who participated in the harvesting and threshing received a one-sixth share of the harvest. By 1976, most of the farmers (83 percent) adopted a system called gamma, in which participation in the harvesting operation was limited to workers who had performed the weeding operation without receiving wages.

The emergence of the gamma system can be interpreted as an institutional innovation designed to reduce the wage rate for harvesting to a level equal to the marginal productivity of labor. In the 1950s, when the rice yield per hectare was low and labor was less abundant, the one-sixth share may have approximated an equilibrium wage level. With the higher yields and the more abundant supply of labor, the one-sixth share became larger than the marginal product of labor in the harvesting operation.[8]

To test the hypothesis that the gamma system was adopted rapidly primarily because it represented an institutional innovation that permitted farm operators to equate the harvesters' share of output to the marginal productivity of labor, inputed wage costs were compared with the actual harvesters' share (Table 2; page 133). The results indicate that a substantial gap existed between the inputed wage for the harvesters' labor alone and the actual harvesters' shares. This gap was eliminated if the inputed wages for harvesting and weeding labor were added.

Those results are consistent with the hypothesis that the changes in institutional arrangements governing the use of production factors were induced when disequilibria between the marginal returns and the marginal costs of factor inputs occurred as a result of change in factor endowments and technical change. Institutional change, therefore, was directed toward the establishment of a new equilibrium in factor markets.

Efficiency and Equity Implications

It is important to recognize that subtenancy and gamma contracts were the institutional innovations to facilitate more efficient resource allocations through voluntary agreements by assigning more complete private property rights. The land reform laws gave tenants strong protection of their tenancy rights with the result that a part of land property rights, which is the right to continue tilling the soil at a rent lower than the marginal product of land, was assigned to tenant operations. But the laws prohibited tenants from renting their land to someone else who might utilize it more efficiently, when they become elderly or found more profitable off-farm employment, for example. Subtenancy was developed to reduce such inefficiency due to the institutional rigidity in the land rental market based on the land reform programs. Likewise, the gamma system was developed to counteract the institutional rigidity in the labor market based on the traditional custom in the rural community in the form of a fixed harvester's share.

It might appear that these institutional innovations increased efficiency at the expense of equity. But, if the subtenancy system had not been developed, the route would have been closed for some of the landless laborers to become farm operators and use their entrepreneurial abilities more profitably. If the implicit wage rate for harvesting work had been raised in the absence of the gamma contract, it might have encouraged mechanization in threshing and thereby reduced employment and labor earnings. It must be recognized that the institutional innovations to develop a more efficient market by assigning more complete private property rights do not necessarily impair equity, as is often argued by Marxist and populist critiques against private market institutions.

In the case reviewed here the induced innovation process leading toward the establishment of equilibrium in land and labor markets occurred very rapidly in spite of the fact that many of the transactions--between landlords, tenants and laborers--were less than fully monetized. Informal contractual arrangements or agreements were utilized. The subleasing and the gamma labor contract evolved without the mobilization of substantial political activity or bureaucratic effort. Indeed, the subleasing arrangement evolved in spite of legal prohibition. Where substantial political and bureaucratic resources must be mobilized to bring about technical or institutional change, the changes occur much more slowly, as in the cases of the English enclosure movements and the Thai and Japanese property rights cases referred to at the beginning of this section.

The Demand for Institutional Innovation--Non-market Institutions for the Supply of Public Goods

The examples of institutional change advanced in the previous section, such as the Enclosure in England and the evolution of private property rights in land in Japan and Thailand, have contributed to the development of a more efficient market system. Institutional changes of this type are profitable for society only if the costs involved in the assignment and protection of rights are smaller than the gains from better resource allocation. If those costs are very high, it may be necessary to design non-market institutions in order to achieve more efficient resource allocation.[9]

For example, in Japan, although the system of private property rights was developed on cropland during the pre-modern period, communal ownership at the village level permitted open access to large areas of wild and forest land which were utilized for the collection of firewood, leaves and wild grasses to fertilize rice fields. However, over time more detailed common property rights were stipulated for the use of communal land in order to prevent resource exhaustion.[10]

Detailed stipulations of the time and place of utilization of communal land as well as rules for mobilizing village labor to maintain communal property (such as applying fire to regenerate pasture) were often enforced with religious taboos and rituals. Those communal village institutions remained viable because it was much more costly to demarcate and partition wild and forest land than cropland among individuals and to enforce exclusive use. Any villager's use of communal land involves externality. For example, his collection of firewood reduces the availability of the firewood for other villagers. If property rights are not assigned, there may be only limited incentive for resource conservation. This is not a serious problem if the resource that is subject to open access is abundant relative to population. However, as population pressure begins to rise, a common understanding regarding appropriate use, reinforced by social sanctions, may act to limit excessive exploitation. But, as population growth continues to press against limited land resources and the market value of the resource product rises, it becomes necessary to impose more formal regulations regarding the access of individual villagers to communal land.

Group action to supply public goods, such as the maintenance of communal land, may work effectively if the size of the group involved is small, as in the case of a village community. However, if a large number of people are involved in the use of a public good, as in the case of marine fisheries, it is more difficult to regulate their resource use or to prevent free riders by means of voluntary agreements.[11] Action by a higher authority with coercive power, such as government, may be required to limit free riding.

The "socialization" of agricultural research is common not only in socialist economies but also in market economics (Hayami and Yamada, 1975: 224-49). This can be explained by the failure of the market in allocating resources efficiently for the supply of public goods for a large, unidentifiable clientele group. New information or knowledge resulting from research is typically endowed with the attributes of a public good characterized by "nonrivalness" or jointness in supply and utilization, and "nonexcludability" or external economies.[12] The first attribute implies that the good is equally available to all. The second implies that it is impossible for private producers to appropriate through market pricing the full social benefits arising directly from the production (and consumption) of the good -- it is difficult to exclude from the utilization of the good those who do not pay for it. A socially optimal level of supply of such a good cannot be expected if its supply is left to private firms. However, present institutional arrangements are such that much information resulting from basic research is nonexcludable. This is the major reason why it has been necessary to establish nonprofit institutions to advance basic scientific knowledge.[13]

A unique aspect of agricultural research, particularly that directed to advancing biological technology, is that many of the products of research--even in the applied area--are characterized by nonexcludability. Protection by patent laws is either unavailable or inadequate. The nature of agricultural production makes it difficult to restrict information about new technology or practices. Furthermore, even the largest farms are relatively small units and are unable to capture more than a small share of the gains from inventive activity. Private research activities in agriculture have been directed primarily toward developing mechanical technology for which patent protection is established.[14]

Another important attribute of the research production function is that it has a stochastic form. Research, by nature, is characterized by risk and uncertainty. Success in a research project is like hitting a "successful oil well." Any number of dry holes may be bored before the successful one is found. Richard Nelson has pointed out that this stochastic nature of the research production function, which is especially strong in the case of basic research, contributes to the failure of the market in attaining optimum resource allocation over time:

> The very large variance of the profit probability distribution from a basic research project will tend to cause a risk-avoiding firm, without the economic resources to spread the risk by running a number of basic-research projects at once, to value a basic-research project at significantly less than its expected profitability and hence, ... at less than its social value (Nelson, 1959:304).

The public-good attributes of the agricultural research project together with the stochastic nature of the research production function make public support of agricultural research socially desirable. It does not necessarily follow, however, that agricultural research should be conducted in governmental institutions financed by tax revenue. If the benefit consists primarily of producers' surplus, agricultural research may be left to the cooperative activities of agricultural producers (i.e., to the activities of such institutions as agricultural commodity organizations and cooperatives). In the United States, organized producers are funding an increasing share of agricultural research by means of a tax on production. The willingness of organized producers to share the costs of research appears to be related to the elasticity of demand in domestic and international markets for the specific commodity. Research on a number of tropical export crops grown under plantation conditions such as sugar, bananas and rubber is also often supported in this manner. The emergence of new institutional arrangements such as plant variety registration, which provides patent-like protection for new crop varieties, also acts to shift the optimum allocation of agricultural research resources in favor of the private sector.

However, most agricultural commodities are produced by a number of small producers. Under these conditions voluntary cooperation to support research would be very costly to organize. Furthermore, most agricultural commodities, except those intended for export, are characterized by low price elasticity of demand. As a result, a major share of the social benefit produced by research tends to be transmitted to consumers through lower market prices. In such a situation the cost of agricultural research should be borne by the general public.

If agricultural research were left entirely to the private sector the result would be serious bias in the allocation of research resources. Resources would flow primarily to those areas of mechanical and chemical technology that are adequately protected by patents and to those areas of biological technology where the results can be protected by trade secrets (such as the inbred lines used in the production of hybrid corn seed). Other areas, such as research on open-pollinated seed varieties, biological control of insects and pathogens, and improvements in farming practices and management, would be neglected. The socialization of agricultural research or the predominance of public institutions in agricultural research, especially in the biological sciences, can be considered a major institutional innovation designed to offset what would otherwise represent a serious distortion in the allocation of research resources.

The Supply of Institutional Innovation

We have identified the disequilibria in economic relationships associated with economic growth, such as technical change leading to the generation of new income streams and changes in relative factor endowments, as important sources of demand for institutional change. But the sources of supply of institutional innovation are less well understood. The factors that reduce the cost of institutional innovation have not been widely studied by economists or by other social scientists.

In the Philippines village case changes in tenure and labor market institutions were supplied, in response to the changes in demand generated by changing factor endowments and new income streams, through the individual and joint decisions of owner-cultivators, tenants and laborers. But even at this level it was necessary for gains to the innovators to be large enough to offset the risk of ignoring the land reform prohibitions against subleasing and the social costs involved in changing traditional harvest-sharing arrangements. While mobilization of substantial political resources was not required to introduce and extend the new land and labor market institutions, the distribution of political resources within the village did influence the initiation and diffusion of the institutional innovations.

The supply of major institutional innovations, however, necessarily involves the mobilization of substantial political resources. It is useful to think in terms of a supply schedule of institutional innovation that is determined by the marginal cost schedule facing political entrepreneurs as they attempt to design new institutions and resolve the conflicts among various interest groups (or suppression of opposition when necessary). We hypothesize that institutional innovations will be supplied if the expected return from the innovation that accrues to the political entrepreneurs exceeds the marginal cost of mobilizing the resources necessary to introduce the innovation. To the extent that the private return to the political entrepreneurs is different from the social return, the institutional innovation will not be supplied at a socially optimum level.[15]

The supply of institutional innovation depends critically on the power structure or balance among interest groups in a society. If the power balance is such that the political entrepreneurs' efforts to introduce an institutional innovation with a high rate of social return are adequately rewarded by greater prestige and stronger political support, a socially desirable institutional innovation may occur. However, if the institutional innovation is expected to result in a loss to a dominant political block, the innovation may not be forthcoming even if it is expected to produce a large net gain to society as a whole. And socially undesirable institutional innovations may occur if the returns to the entrepreneur or the interest group exceed the gains to society (Tullock, 1967; Krueger, 1974; Tollison, 1982).

The failure of many developing countries to institutionalize the agricultural research capacity needed to take advantage of the large gains from relatively modest investments in technical change may be due, in part, to the divergence between social returns and the private returns to political entrepreneurs. In the mid-1920s, for example, agricultural development in Argentina appeared to be proceeding along a path roughly comparable to that of the United States. Mechanization of crop production lagged slightly behind that in the United States. Grain yields per hectare averaged slightly higher than in the United States. In contrast to the United States, however, output and yields in Argentina remained relatively stagnant between the mid-1920s and the mid-1970s. It was not until the late 1970s that Argentina began to realize significant gains in agricultural productivity. Part of this lag in Argentine agricultural development was due to the disruption of export markets in the 1930s and 1940s. Students of Argentine development have pointed to the political dominance of the landed aristocracy, to the rising tensions between urban and rural interests, and to inappropriate domestic policies toward agriculture (de Janvry, 1973; Smith, 1969, 1974; Cavallo and Mundlak, 1982). The Argentine case would seem to represent a situation where the bias in the distribution of political and economic resources imposed exceptionally costly delays in the institutional innovations needed to take advantage of the relatively inexpensive sources of growth that technical change in agriculture could have made available.

Cultural endowments, including religion and ideology, exert a strong influence on the supply of institutional innovation. They make some forms of institutional change less costly to establish and impose severe costs on others. For example, the traditional moral obligation in the Japanese village community to cooperate in joint communal infrastructure maintenance has made it less costly to implement rural development programs than in societies where such traditions do not prevail. These activities had their origin in the feudal organization of rural communities in the pre-Meiji period. But practices such as maintenance of village and agricultural roads and of irrigation and drainage ditches through joint activities in which all families contribute labor existed in well over half of the hamlets in Japan as recently as 1970 (Ishikawa, 1981). The traditional patterns of cooperation have represented an important cultural resource on which to erect modern forms of cooperative marketing and joint farming activities. Similar cultural resources are not available in South Asian villages, where, for example, the cast structure inhibits cooperation and encourages specialization.

Likewise, the aspiration of new ideology may reduce the cost to political entrepreneurs of mobilizing collective action for institutional change. For example, the Jeffersonian concept of agrarian democracy provided ideological support for the series of land ordinances culminating in the Homestead Act of 1862, which established the legal framework designed to encourage an owner-operator system of agriculture in the American West (Cochrane, 1979: 41-47, 179-88). Strong nationalist sentiment in Meiji Japan, reflected in slogans such as "A Wealthy Nation and Strong Army" (Fukoku Kyohei), helped mobilize the resources needed for the establishment of vocational schools and agricultural and industrial experiment stations (Hayami, et al., 1981). In China, communist ideology, reinforced by the lessons learned during the guerrilla period in Yenan, inspired the mobilization of communal resources to build irrigation systems and other forms of social overhead capital (Schran, 1975). Thus, ideology can be a critical resource for political entrepreneurs and an important factor affecting the supply of institutional innovations.

Advances in social sciences that improve knowledge relevant to the design of institutional innovations that are capable of generating new income streams or that reduce the cost of conflict resolution act to shift the supply of institutional change to the right. Throughout history, improvements in institutional performance have occurred primarily through the slow accumulation of successful precedent or as by-products of expertise and experience. Institutional change was generated through the process of trial and error much in the same manner that technical change was generated prior to the invention of the research university, the agricultural experiment station, or the industrial research laboratory. With the institutionalization of research in the social sciences and related professions the process of institutional innovation has begun to proceed much more efficiently; it is becoming increasingly possible to substitute social science knowledge and analytical skill for the more expensive process of learning by trial and error.

If this view is correct it suggests that a major source of demand for social science knowledge is derived from the demand for institutional innovation. But how responsive is the supply of social science knowledge to the demand for institutional change arising out of social conflict or economic growth? Is the supply of social science knowledge sufficiently elastic to reduce the cost of institutional change? Or is society typically faced with a situation where the demand for institutional innovation shifts against a relatively inelastic supply curve? The most pervasive view among economic historians is that the supply of social science knowledge is relatively inelastic (Spengler, 1968:159-205; Stigler, 1965:16-30; Stigler, 1982:63-66).

My own view, based on a recent review of the evolution of United States agricultural commodity and credit policies and institutions, is somewhat more optimistic. In the field of development the research that led to advances in our understanding of the production and consumption behavior of rural households in less developed countries represents an important example of the contribution of advances in social science knowledge to the design of more efficient institutions (Schultz, 1964; Nerlove, 1974; Binswanger, Evenson, Florencio, and White, 1981). In a number of countries this research has led to the abandonment of policies that viewed peasant households as unresponsive to economic incentives. And it has led to the design of policies and institutions to make more productive technologies available to peasant producers and to the design of more efficient price policies for factors and products.

Similarly, the diffusion of education designed to raise the intellectual level of the general public and to facilitate better understanding of the private and social costs of institutional change may reduce the cost to political entrepreneurs of introducing socially desirable institutions and raise the cost of biasing institutional change in a manner that is costly to society.

Toward a More Complete Model of Induced Innovation

This review of the state of our knowledge with respect to the forces and process of institutional innovation leave us with two general perspectives. The first is that it is possible to use the tools of modern analytical economics to advance our understanding of the process of institutional change. The second is that the state of our knowledge remains highly unsatisfactory. But how do we continue the tentative advances that have been made? Instead of attempting to provide a direct response to this question let me map out where we have been and where I think we are in this quest.

I illustrate, in Figure 1, the elements of a model that maps the general equilibrium relationships among resource endowments, cultural endowments, technologies and institutions.[16] The model goes beyond the conventional general equilibrium model in which resource endowments, technologies, institutions, and culture (conventionally designated as tastes) are given.[17] In the study of long-term social and economic change the relationships among the several variables must be treated as recursive. The formal microeconomic models that are employed to analyze the supply and demand for technical and institutional change can be thought of as "nested" within the general equilibrium framework of Figure 1.

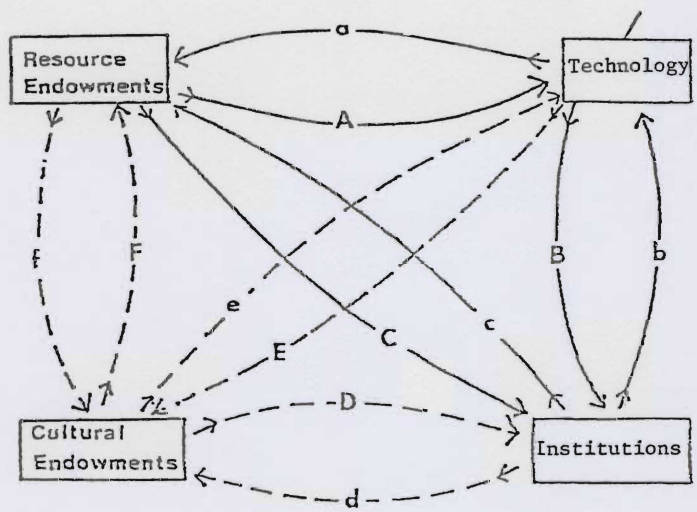


Figure 1 Interrelationships between changes in resource endowments, cultural endowments, technology, and institutions.

One advantage of the "pattern model" outlined in Figure 1 is that it helps to identify areas of ignorance. Our capacity to model and test the relationships between resource endowments and technical change is relatively strong. Our capacity to model and test the relationships between cultural endowments and either technical or institutional change is relatively weak. A second advantage of the model is that it is useful in identifying the model components that enter into other attempts to account for secular economic and social change.

For example, historians working within the Marxist tradition often tend to view technical change as dominating both institutional and cultural change. In his book, Oriental Despotism, Karl Wittfogel views the irrigation technology used in wet rice cultivation in East Asia as determining political organization (Wittfogel, 1957). In terms of Figure 1 his primary emphasis was on the impact of resource endowments on institutions (C) and (B).

A serious misunderstanding can be observed in contemporary neo-Marxian critiques of the "green revolution." These criticisms have focused attention almost entirely on the impact of technical change on labor and land tenure relations. Both the radical and populist critics have emphasized relation (B). But they have tended to ignore relationships (A) and (C).[18] This has led to repeated failure to identify effectively the separate effects of population growth and technical change on the growth and distribution of income. The analytical power of the more complete induced innovation model was illustrated in the work by Hayami and Kikuchi, discussed earlier in this paper, on the impact of both technical change and population growth on changes in land tenure and labor market relationships in the Philippines.

Armen Alchian and Harold Demsetz identify a primary function of property rights as guiding incentives to achieve greater internalization of externalities. They consider that the clear specification of property rights reduces transaction costs in the fact of growing competition for the use of scarce resources as a result of population growth and/or growth in product demand (Demsetz, 1967; Alchian and Demsetz, 1973).

North and Thomas, (building on the Alchian-Demsetz paradigm), attempted to explain the economic growth of Western Europe between 900 and 1700 primarily in terms of changes in property institutions.[19] During the 11th and 13th centuries the pressure of population against increasingly scarce land resources induced innovations in property rights that in turn created profitable opportunities for the generation and adoption of labor-intensive technical changes in agriculture. The population decline in the 14th and 15th centuries was viewed as a primary factor leading to the demise of feudalism and the rise of the national state (line C). These institutional changes in turn opened up new possibilities for economies of scale in nonagricultural production and in trade (line b).

In a more recent work Mancur Olson has emphasized the proliferation of institutions as a source of economic decline.[20] He also regards broad-based encompassing organizations as having incentives to generate growth and redistribute income to their members with little excess burden. For example, a broadly based coalition that encompasses the majority of agricultural producers is more likely to exert political pressure for growth-oriented policies that will enable its members to obtain a larger share of a larger national product than a smaller organization that represents the interests of the producers of a single commodity. Small organizations representing narrow interest groups are more likely to pursue the interests of their members at the expense of the welfare of other producers and the general public. In contrast, an even more broadly based farmer-labor coalition would be more concerned with promoting economic growth than an organization representing a single sector. But large groups, in Olson's view, are inherently unstable because rational individuals will not incur the costs of contributing to the realization of the large group program--they have strong incentives to act as free riders. As a result, organizational "space" in a stable society will be increasingly occupied by special interest "distributional coalitions." These distributional coalitions make political life more devisive. They slow down the adoption of new technologies (line b) and limit the capacity to reallocate resources (line c). The effect is to slow down economic growth or in some cases initiate a period of economic decline.

What are the implications of the theory of institutional innovation outlined in this paper for the research agenda on the economics of institutional change? In our research on the direction and rate of technical change we were able to advance significantly our knowledge by treating technical change as endogenous--as induced primarily by changes in relative resource endowments and the growth of demand. We have also attempted to develop a theory of induced institutional innovation in which we treat institutional innovation as endogenous. There is now a significant body of evidence that suggests that substantial new insights on institutional innovation and diffusion can be obtained by treating institutional change as an economic response to changes in resource endowments and technical change.

We also insist on the potential significance of cultural endowments, including the factors that economists typically conceal under the rubric of tastes and that political scientists include under ideology. But our capacity to develop rigorous empirical tests capable of identifying the relative significance of the relationships between cultural endowments and the other elements of the model outlined in Figure 1 is quite unsatisfactory. Until our colleagues in the other social sciences provide us with more helpful analytical tools, we are forced to adhere to a strategy that focuses primarily on the interactions between resource endowments, technical change and institutional change. The strategy suggested here does have the clear advantage of allowing us to explore how far a strategy based on the rather straightforward extension of standard microeconomic theory will take us in the analysis of both technical and institutional change.

A P P E N D I X 5

Table 1 Factor Shares of Rice Output per Hectare, 1976 Wet Season

	Number of Plots	Area (ha)	Rice Output	Factor shares[a]						
				Current Inputs	Land-owner	Sub-tenancy	Total	Labor	Capital[b]	Operators' Surplus
			- - - - - - - - kg/ha - - - - - - - -							
Leasehold land	44	67.7	2,889	657	567	0	567	918	337	410
			(100.0)	(22.7)	(19.6)	(0)	(19.6)	(31.8)	(11.7)	(14.2)
Share tenancy land	30	29.7	2,749	697	698	0	698	850	288	216
			(100.0)	(25.3)	(25.4)	(0)	(25.4)	(30.9)	(10.5)	(7.9)
Sub-tenancy land	16	9.1	3,447	801	504	801[c]	1,305	1,008	346	-13
			(100.0)	(23.2)	(14.6)	(23.2)	(37.8)	(29.3)	(10.1)	(-0.4)

[a] Percentage shares are shown in parentheses.

[b] Sum of irrigation fee and paid and/or imputed rentals of carabao, tractor and other machines.

[c] Rents to sub-leasors in the case of pledged plots are imputed by applying the interest rate of 40 percent crop season (a mode in the interest rate distribution in the village).

Source: Yujiro Hayami and Masao Kikuchi, Asian Village Economy at the Crossroads: An Economic Approach to Institutional Change (Tokyo: University of Tokyo Press, 1981, and Minneapolis: University of Minnesota Press, 1982), pp. 111-13.

Table 2 Comparison between the imputed value of harvesters' share and the imputed cost of _gamma_ labor.

	Based on employers' data	Based on employees' data
No. of working days of _Gamma_ labor (days/ha)[a]		
Weeding	20.9	18.3
Harvesting/threshing	33.6	33.6
Imputed cost of _Gamma_ labor (P/ha)[b]		
Weeding	167.2	146.4
Harvesting/threshing	369.6	369.6
(1) Total	536.8	516.0
Actual share of harvesters:		
In kind (kg/ha)[c]	504.0	549.0
(2) Imputed value (P/ha)[d]	504.0	549.0
(2) - (1)	-32.8	33.0

[a] Includes labor of family members who worked as _Gamma_ laborers.

[b] Imputation using market wage rates (daily wage = P8.0 for weeding, P11.0 for harvesting).

[c] One-sixth of output per hectare.

[d] Imputation using market prices (1 kg = P1).

Source: Yujiro Hayami and Masao Kikuchi, _Asian Village Economy at the Crossroads: An Economic Approach to Institutional Change_ (Tokyo: University of Tokyo Press, 1981, and Minneapolis: University of Minnesota Press, 1982), p. 121.

NOTES

1. There is considerable disagreement regarding the meaning of the term institution. A distinction is often made between the concepts of institution and organization. We find the broad view which includes both concepts most useful for our purpose. This is consistent with the view expressed by both Commons (1950:24) and Knight (1952:51). Our definition also encompasses the classification employed by Davis and North (1971:8-9). We employ the more inclusive definition in order to be able to consider changes in the rules or conventions that govern behavior (a) within economic units such as families, firms and bureaucracies, (b) among economic units as in the cases of the rules that govern market relationships, and (c) between economic units and their environment, as in the case of the relationship between a firm and a regulatory agency.

2. See Runge (1981b:xv). Formal analysis of the role of institutions in providing assurance of stability in economic relationships emerged from dissatisfaction with the implications of the assumption of strict dominance of individual strategy in modern welfare economics. See Sen (1967) and Runge (1981a). In a less formal treatment, North argues, in a chapter on "Ideology and the Free Rider Problem," that shared ideological and ethical perspectives provide assurance that is lacking in models built on the dominance of individual strategies (1981:45-58).

3. The role of special interest "distributional coalitions" in slowing society's capacity to adopt new technology and reallocate resources in response to changing conditions is the central theme in Olson (1982:74).

4. "At a certain stage of their development, the material forces of production in society come in conflict with the existing relations of production, or--what is but a legal expression for the same thing--with the property relations within which they had been at work before. From forms of development of the forces of production these relations turn into their fetters. Then comes the period of social revolution. With the change of the economic foundation the entire immense superstructure is more or less rapidly transformed" (Marx, 1913:11012). For a discussion of the role of technology in Marxian thought see Rosenberg (1982:34-54).

5. The orthodox view of a generation ago was expressed by Samuelson (1948:221-22), "The auxiliary (institutional) constraints imposed upon the variables are not themselves the proper subject of welfare economics but must be taken as given." Contrast this with the more recent statement by Schotter (1981:6), "We view welfare economics as a study ...that ranks the system of rules which dictate social behavior." There are now five fairly well defined "political economy" traditions that have attempted to break out of the constraints imposed by traditional welfare economics and treat institutional change as endogenous. These include (a) the theory of property rights, (b) the theory of economic regulation, (c) the theory of interest group rent seeking, (d) the liberal-pluralist theories of government, and (e) the neo-Marxian theories of the state. In the property rights theories the government plays a relatively passive role; the economic theory of regulation focuses on the electoral process; the rent seeking and liberal-pluralist theories concentrate on both electoral and bureaucratic choice processes; and the theory of the state attempts to incorporate electoral, legislative choice, and bureaucratic choice processes. For a review and criticism see Rausser, Lichtenberg, and Lattimore (1982).

6. There has been a continuing debate among students of English agricultural history about whether the higher rents that landowners received after enclosure was (a) because enclosed farming was more efficient than open field farming, or (b) because enclosures redistributed income from farmers to landowners. See Chambers and Mingay (1966), Dahlman (1980), and Allen (1982).

7. Although the passage and implementation of the Land Reform Code of 1986 was exogenous to the economy of the village, the land reform of the 1960s has been interpreted as the result of efforts by an emerging industrial elite to break simultaneously the political power of the more conservative land-owning elite and to provide incentive to peasant producers to respond to the rapid growth in demand for marketable surpluses of wage goods, primarily rice and maize, needed to sustain rapid urban industrial development. Thus, the Land Reform Code can be viewed as an institutional innovation designed to facilitate realization of the opportunities for economic growth that could be realized through rapid urban industrial development. See Ruttan (1969).

8. Real wages for agricultural labor declined significantly between the mid-1950s and the mid-1960s in the Philippines. See Khan (1977). Thus, while we cannot be certain that the labor market was in equilibrium in the 1950s, it is clear that the degree of disequilibrium widened, as a result of both higher yields and lower wage rates, prior to the introduction and diffusion of the gamma system.

9. Harold Demsetz has pointed out that the relative costs of using market and political institutions is rarely given explicit consideration in the literature on market failure. An appropriate way of interpreting the "public goods" vs. "private goods" issue is to ask whether the costs of providing a market are too high relative to the cost of non-market alternatives (1964). A similar point is made by Leonid Hurwicz (1972).

10. For the distinction between open access and common property, see Ciriacy-Wantrup and Bishop (1975). In the case of open access use rights have not been fully established. In the case of common property rules have been established that govern joint use. Common property is, therefore, a form of land use that lies between the extremes of open access and fully exclusive private rights. The problem of resource exhaustion in open access properties was elaborated in Demsetz (1967) and Alchian and Demsetz (1973).

11. See Olson (1968). Several students of institutional change have emphasized that coordinated or common expectations resulting from the assurance provided by traditional institutions or common assumptions about equity or ideology have permitted much larger groups to engage in either implicit or explicit voluntary cooperation than implied by Olson's model. See Runge (1981b:189-99) and North (1981:54). North notes that "the premium necessary to induce people to become free riders is positively correlated with the perceived legitimacy of the existing institution."

12. For a characterization of the nonrivalness and nonexcludability attributes of public goods see Samuelson (1954; 1955; 1958) and Musgrave (1959).

13. Nonrivalness is an essential attribute of information. The use of information about a new farming practice (contour ploughing, for example) by a farmer is not hindered by the adoption of the same practice by other farmers. There is no capacity limit for its utilization. Nonexcludability, in contrast, is not a natural attribute of information but rather is determined by institutional arrangements. In fact, patent laws are an institutional arrangement that make a certain kind of information (called an "invention") excludable, thereby creating profit incentives for private creative activities. Retention of trade secrets is another legally sanctioned method of retaining control over inventions or other forms of new technical knowledge. These arrangements are the ones designed to promote more efficient resource allocation through market arrangements as discussed in the previous section.

14. In a number of countries "breeders' rights" and "petty patent" legislation has induced rapid growth in private sector R&D related to agriculture. See Ruttan (1982) and Evenson and Evenson (1983).

15. See, for example, Frohlich, Oppenheimer, and Young (1971). For a review and extension of concepts of political entrepreneurship see Guttman (1982).

16. Fusfeld (1980:330 uses the terms "pattern" or "Gestalt" model to describe a form of analysis that links the elements of a general pattern together by logical connections. The recursive multi-causal relationships of the pattern model imply that the model is always "open"--"it can never include all of the relevant variables and relationships necessary for a full understanding of the phenomenon under investigation."

17. In economics the concept of cultural endowments is usually subsumed under the concept of "tastes" which are regarded as "given"--that is, not subject to economic analysis. Our use of the term culture is consistent with the definition suggested by Leslie A. White, "When things and events are considered in the context of their relation to the human organism, they constitute behavior; when they are considered ... in their relationship to one another, they become culture" (White, 1974:1158). We use the term cultural endowments to capture those dimensions of culture that have been transmitted from the past. Contemporary changes in resource endowments, technology, and institutions can be expected to result in changes in cultural endowments.

18. A major limitation of the Marxian model is the emphatic rejection of a causal link between demographic change and technical and institutional change (North, 1981:60, 61). This blindness to the role of demographic factors, and to the impact of relative resource endowments, originated in the debates between Marx and Malthus. An attempt to correct this deficiency represents the major innovation of the "cultural materialism" school of anthropology. See Harris (1979).

19. See North and Thomas (1970:1-17a; 1973). For a critical perspective on the North-Thomas model see Field (1981). Field is critical of the attempt by North and Thomas to treat institutional change as endogenous.

20. See Olson (1982). For a review of the Olson work see North (1983:162-64).

REFERENCES

Alchian, Armen and Demsetz, Harold, (1973), "The property right paradigm," The Journal of Economic History, 33, 16-27.

Allen, Robert C., (1982), "The efficiency and distributional consequences of eighteenth century enclosures," The Economic Journal, 92, 937-53.

Binswanger, Hans P., Evenson, Robert E., Florencio, Cecilia A., and White, Benjamin N.W., eds., (1981), Rural Household Studies in Asia. Singapore: University of Singapore Press.

Cain, Louis P. and Paterson, Donald G., (1981), "Factor bias and technical change in manufacturing: the American system: 1850-1919," The Journal of Economic History, 41, 341-60.

Cavallo, Domingo and Mundlak, Yair, (1982), Agricultural and Economic Growth In an Open Economy: The Case of Argentina. International Food Policy Research Institute, Research Report No. 36, Washington, D.C.

Chambers, J.D. and Mingay, G.E., (1966), The Agricultural Revolution 1750-1880. London: B. T. Batsford.

Ciriacy-Wantrup, S.V. and Bishop, R.C., (1975), "Common property as a concept in natural resources policy," Natural Resources Journal, 15, 713-27.

Cochrane, Willard W., (1979), The Development of American Agriculture: A Historical Analysis. Minneapolis: University of Minnesota Press, 41-47, 179-88.

Commons, John R., (1950), The Economics of Collecting Action. New York: Macmillan.

Dahlman, Carl J., (1980), The Open Field System and Beyond: A Property Rights Analysis of an Economic Institution. Cambridge: Cambridge University Press.

Davis, Lance E. and North, Douglass C., (1971), Institutional Change and American Economic Growth. Cambridge: Cambridge University Press.

de Janvry, Alain, (1973), "A socioeconomic model of induced innovations for Argentine agricultural development." Quarterly Journal of Economics, 87, 410-35.

Demsetz, Harold, (1964), "The exchange and enforcement of property rights." The Journal of Law and Economics, 7, 11-26.

____________, (1967), "Toward a theory of property rights," American Economic Review, 57, 347-59.

Evenson, D.D. and Evenson, R.E., (1983), "Legal systems and private sector incentives for the invention of agricultural technology in Latin America." in Technical Change and Social Conflict in Agriculture: Latin American Perspectives. ed. Martin E. Pineiro and Eduardo J. Trigo, Boulder, Colo.: Westview Press.

Feeny, David, (1982), The Political Economy of Productivity: Thai Agricultural Development 1880-1975. Vancouver: University of British Columbia Press.

Field, Alexander J., (1981), "The problem with neoclassical institutional economics: a critique with a special reference to the North/Thomas model of pre-1500 Europe," Explorations in Economics History, 18, 174-98.

Frolich, Norman, Oppenheimer, Joe A., and Young, Oran R., (1971), Political Leadership and Collective Goods. Princeton, N.J.: Princeton University Press.

Fusfeld, Daniel R., (1980), "The conceptual framework of modern economics," Journal of Economic Issues, 14, 1-52.

Guttman, Joel M., (1982), "Can political entrepreneurs solve the free-rider problem?" Journal of Economic Behavior and Organization, 3, 1-10.

Harris, Marvin, (1979), Cultural Materialism: The Struggle for a Science of Culture. New York: Random House.

Hayami, Yujiro, in association with Akino, Masakatsu; Shintani, Masahiko, and Yamada, Saburo, (1975), A Century of Agricultural Growth in Japan. Minneapolis: University of Minnesota Press.

Hayami, Yujiro and Kikuchi, Masao, (1981), Asian Village Economy at the Crossroads: An Economic Approach to Institutional Change. Tokyo: University of Tokyo Press; and Baltimore: The Johns Hopkins University Press.

Hayami, Yujiro and Ruttan, Vernon W., (1971), Agricultural Development: An International Perspective. Baltimore: The Johns Hopkins University Press.

Hayami, Yujiro and Yamada, Saburo, (1975), "Agricultural research organization in economic development: a review of the Japanese experience," in Agriculture in Development Theory. ed. Lloyd G. Reynolds, New Haven, Conn.: Yale University Press, 224-49.

Hurwicz, Leonid, (1972), "Organizational structures for joint decision making: a designer's point of view," in Interorganizational Decision Making. ed. Matthew Tuite, Roger Chisholm, and Michael Radnor, Chicago: Aldine, 37-44.

Ishikawa, Shigeru, (1981), Essays on Technology, Employment and Institutions in Economic Development. Tokyo: Kinokuniya, 325-47.

Khan, Azizur Rahman, (1977), "Growth and inequality in the rural Philippines," in Poverty and Landlessness in Rural Asia. Geneva: International Labour Office, 243-49.

Kikuchi, Masao and Hayami, Yujiro, (1980), "Inducements to institutional innovations in an agrarian community," Economic Development and Cultural Change, 29, 21-36.

Knight, Frank H., (1952), "Institutionalism and empiricism in economics," American Economic Reivew, 42.

Krueger, Anne O., (1974), "The political economy of the rent-seeking society," American Economic Review, 64, 291-303.

Marx, Karl, (1913), A Contribution to the Critique of Political Economy. Chicago: Kerr, 11-12.

Musgrave, Richard A., (1959), The Theory of Public Finance. New York: McGraw-Hill.

Nelson, R.R., (1959), "The simple economics of basic scientific research," Journal of Political Economy, 67.

Nerlove, Marc, (1974), "Household and economy: toward a new theory of population and economic growth," Journal of Political Economy, 82, Part II, S200-S218.

North, Douglass C., (1981), Structure and Change in Economic History. New York: Norton.

____________, (1983), "A theory of economic change," Science, 219, 163-64.

North, Douglass C. and Thomas, Robert Paul, (1970), "An economic theory of the growth of the Western World," The Economic History Review, 22, 1-17a.

____________, (1973), The Rise of the Western World. London: Cambridge University Press.

Olson, Mancur, (1968), The Logic of Collective Action: Public Goods and the Theory of Groups. New York: Schocken Books.

_____________, (1982), The Rise and Decline of Nations: Economic Growth, Stagflation, and Social Rigidities. New Haven: Yale University Press.

Phillips, William H., (1982), "Induced innovation and economic performance in late Victorian British industry," The Journal of Economic History, 42, 97-104.

Rausser, Gordon C., Lichtenberg, Erik, and Lattimore, Ralph, (1982), "Developments in the theory and empirical application of endogenous government behavior," in New Directions in Econometric Modeling and Forecasting in U.S. Agriculture. ed. Gordon C. Rausser, New York: Elsevier, 547-614.

Rosenberg, Nathan, (1982), "Marx as a student of technology," Inside the Black Box: Technology and Economics. Cambridge: Cambridge University Press, 34-54.

Runge, Carlisle Ford, (1981a), "Common property externalities: isolation, assurance, and resource depletion in a traditional grazing context," American Journal of Agricultural Economics, 63, 595-606.

_____________, (1981b), "Institutions and common property externalities: the assurance problem in economic development," Ph.D. dissertation, University of Wisconsin-Madison.

Ruttan, Vernon W., (1982), "Changing role of public and private sectors in agricultural research," Science, 216, 23-29.

_____________, (1969), "Equity and productivity issues in modern agrarian reform legislation," in Economic Problems of Agriculture in Industrial Societies. ed. Ugo Papi and Charles Nunn, London: MacMillan; New York: St. Martin's Press, 581-600.

Sameulson, Paul A., (1959), "Aspects of public expenditure theories," Review of Economics and Statistics, 40, 332-38.

_____________, (1955), "Diagrammatic exposition of a theory of public expenditure," Review of Economics and Statistics, 37, 350-56.

_____________, (1948), Foundations of Economic Analysis. Harvard Economic Studies, vol. 80, Cambridge, Mass.: Harvard University Press.

_____________, (1954), "The pure theory of public expenditure," Review of Economics and Statistics, 36, 387-89.

Schotter, Andrew, (1981), The Economic Theory of Social Institutions. Cambridge: Cambridge University Press.

Schran, Peter, (1975), "On the Yenan origins of current economic policies," in China's Modern Economy in Historical Perspective. ed. Dwight H. Perkins, Stanford, Calif.: Stanford University Press, 279-302.

Schultz, Theodore W., (1964), Transforming Traditional Agriculture. New Haven: Yale University Press.

_____________, (1975), "The value of the ability to deal with disequilibria," Journal of Economic Literature, 13, 822-46.

Seckler, David, (1975), Thorstein Veblen and the Institutionalists. London: Macmillan.

Sen, A,K., (1967), "Isolation and the social rates of discount," Quarterly Journal of Economics, 81, 112-24.

Smith, Peter H., (1974), Argentina and the Failure of Democracy: Conflict Among Elites, 1880-1955. Madison: University of Wisconsin Press.

_____________, (1969), Politics and Beef in Argentina: Patterns of Conflict and Change. New York: Columbia University Press.

Spengler, Joseph J., (1968), "Exogenous and endogenous influences in the formation of post-1970 economic thought: a sociology of knowledge approach," Events, Ideology and Economic Theory. ed. Robert V. Eagly, Detroit: Wayne State University Press.

Stigler, George J., (1965), Essays in the History of Economics. Chicago: University of Chicago Press.

Stigler, George J., (1982), The Economist as Preacher and Other Essays. Chicago: University of Chicago Press.

Tollison, Robert D., (1982), "Rent seeking: a survey," Kyklos, 35 (fasc. 4), 575-602.

Tullock, Gordon, (1967), "The welfare costs of tariffs, monopolies and theft," Western Economic Journal, 5, 224-32.

Wade, William W., (1981), Institutional Determinants of Technical Change and Productivity Growth: Denmark, France and Great Britian, 1870-1965. New York: Arno Press.

White, Leslie A., (1974), "Human culture," Encyclopedia Britannica, vol. 8, 15th ed., Chicago: Benton, 1152.

Whitehead, Alfred North, (1925), Science and the Modern World. New York: Macmillan.

Wittfogel, Karl A., (1957), Oriental Despotism: A Comparative Study of Total Power. New Haven: Yale University Press.

Zingler, Ervin K., (1974), "Veblen vs. Commons: a comparative evaluation," Kyklos, 17, 322-44.

CHAPTER SEVEN

Technical Change, Human Capital, and the World Food Problem

by
D. Gale Johnson

TECHNICAL CHANGE, HUMAN CAPITAL, AND THE WORLD FOOD PROBLEM

D. Gale Johnson*

My role--at least as I interpret it--is to highlight the main points of the six papers presented today and then to relate what we have heard to the changing nature of the world food problem and the prospects for the improvement in the food situation of the world's poorest people.

Let me start by describing the sense in which I use the term "the world food problem." Obviously, there are numerous world food problems, but my reference is to the adequacy of food availability for the lower income segments of the population of the developing countries. I do not believe it necessary to be very precise about the definition of low income or whether, in developing countries such as India, the low income population constitute a half, a third or a quarter of the population. The basic concern is with the population groups that spend a large percentage of their income on food, perhaps 65 percent or more. For these people the effects of productivity improvement upon the price or cost of food is a critical variable in their welfare as is, of course, anything that affects their incomes. Technological change and increased investment in human capital, along with other critical elements required for productivity change, are powerful tools for simultaneously lowering the real cost of producing food and for increasing the real income of farm people. Since the majority of the world's poor people live in rural areas, farm productivity increases work to benefit the rural poor both as consumers and resource owners.

I shall comment, at least briefly, on the issue of the distribution of benefits to resource owners. But let us never forget that consumers qua consumers will always benefit from productivity improvement in agriculture, though these benefits may be widely dispersed throughout the world or at least to individuals in those countries whose consumers are permitted access to food at prices that approximate international market prices or move in a way more or less proportional to international market prices.

Each of the talks that we have heard today has something of relevance to the improvement of the nutritional status of the world's poor people. Robert Evenson discussed recent developments in the international agricultural research system. This system represents one of the most significant institutional innovations of the past half century affecting world food. Perhaps one should drop the qualifier "one of the most significant" institutional developments in the efforts of the high income countries to assist the low income countries to improve agricultural productivity and to increase food production at a pace approximately equal to the population growth rate. It is not that there has been no support by the industrial countries for research on the crops important to the low income countries. Evenson has documented such support in the case of sugar, but the support was primarily for export crops with the supporting country expecting to reap some significant part of the benefits from yield increases. But the international research centers, growing out of the innovation and productivity efforts of the Rockefeller Foundation in Mexico, were the first cooperative effort by private foundations, governments of industrial countries, and international organizations, to support research to improve the food supply of developing countries.

Evenson emphasized the growth of national agricultural research efforts and the role of international organizations and aid in influencing the development of agricultural research in the developing countries. He noted that there was a great expansion in research between 1959 and 1980--real spending increased by almost 7 times in Asian developing countries, and by 4 to 5 times in Africa and Latin America. Expenditures on extension increased by 2.5 to 6 times.

He discussed the roles of foreign aid. During the 1950s the major emphasis was upon institutional building; in the 1960s the effort shifted to the international research centers. His research indicated that national governments increased their investment in research without a very direct relationship to the availability of aid. He noted the small country problem, namely that such countries spend more on research per unit of farm output; that spending on traded goods is higher than on domestic crops, and that national systems do not free ride on other national research centers. The latter represents a new result.

---

*Professor of Economics, University of Chicago.

Evenson noted a number of important and interesting results from his research. To mention a few: there appears to be a fair degree of rationality in institutional development and the public sector seems to respond reasonably well; the aid pattern is much less rational than the response by national governments; there has been a significant move toward a genuine research support base in the developing countries, and the small country problem is a real one and perhaps more emphasis should be put upon borrowing. He raised questions concerning the long run comparative advantage of the international research centers. He was particularly critical of the neglect of basic research.

Hans Binswanger began his remarks by referring to the work of Esther Boserup, noting that her work has been neglected by agricultural economists. More attention should be given to the endogeneity of technical change. His major emphasis was upon the interrelationships between natural conditions and farming techniques. He noted the systematic relationship between intensification of agriculture and soil types. For example, high, light soils are easy to farm but are risky; low, heavy soils are difficult to farm, but less risky. In low population density areas, labor is a limiting factor and in these areas it is likely that the light soils will be farmed first.

The research in his paper (written with P.L. Pingali) emphasized the rationality of the farming systems in Africa. In much of Africa, land is plentiful and labor is scarce. Thus the question: Why do the farmers still rely primarily upon hand tools and not machinery? The answer is that labor requirements increase when there is a shift to animal draft power. When population density increases, there is a shift in farming systems and not a simple choice of techniques for the same set of functions.

Their research made it clear that market access was a major factor in influencing farming intensity. He then turned to the issue of land rights, noting the complexity of land rights in sub-Saharan Africa. Such rights, when land has become relatively scarce, appear to be more rational than is obvious to the causal observer. In most areas land can be passed on to descendents. The existence of land rights that can be enforced is essential to investment in land.

In his remarks Pineiro noted the near absence of technological change in agriculture in Latin America, especially in Argentina, until the 1960s. Governments turned their attention to agriculture mainly due to the increase in demand brought about by the industrialization of the 1950s. After 1960 the growth in farm output was as great as in the U.S., approximately three percent annually. Mechanization took place in the Southern Cone where it was profitable due to the low man-land ratio.

He attributed the failure to jointly develop improved seeds and fertilizer, as well as other chemical inputs, to the relatively high prices of the chemicals and the need to wait for the development of new varieties that were responsive to fertilizer. Product prices were often not conducive to the use of fertilizer. He was critical of the lack of research on livestock, which is of such great importance in Latin America. Livestock has been neglected in both research and in price policies. There has been little productivity change in Argentina and Uruguay, as evidenced by such things as calving rates and the limited extent of improved pastures.

T.W. Schultz noted the strong survival capacity of the family and its strong comparative advantage in raising children. In Israel some kibbutzes undertook to displace the family in raising children but the idea did not spread. In China during the early period of the communes an effort was made to restrict the role of the family with the institution of communal feeding, but this experiment soon was abandoned. He noted the great significance of the increase in the life span. He emphasized the decline in the cost of increasing the life span, after noting the 60 percent increase in life expectancy that occurred in India between 1951 and 1981.

He referred to some of the implications of the relative price of wheat and rice. Rice eaters generally spend 50 percent or more of their income on food (in the developing countries) while wheat eaters spend much less on the average. Rice prices today are approximately double wheat prices; a century ago the two prices were similar. Wheat production has become a man's job while rice production has become increasingly women's work with striking implications to their respective roles in rural communities.

The decline in the real cost of food has contributed to reducing the inequality in the distribution of income, a point that has generally gone unrecognized. In the developing countries in the

18th and 19th centuries 40 to 45 percent of income came from property; now it is about 20 to 25 percent. The reduced scarcity of food has been the major contributing factor to the reduction in the relative importance of property income.

T. Paul Schultz contributed to the discussion of the responsiveness of public institutions to changing conditions in his study of investment in schooling in the developing countries. He found a near explosion in schools. Over the past two decades, the expected years of schooling for a child doubled and the school age population doubled as well. The expenditures on schools increased 4-fold in 22 years in 32 low income countries.

Profitability and Technical Change

Technical change and increases in human capital have made and will continue to make important contributions to the improvement of the nutrition of the world's poor people. Increased productivity from research, innovation and improved human skills resulting in greater human capital are not sufficient, however, to assure improvement in real resource returns and the available per capita food supply. This is a lesson that has not yet been learned everywhere. Even though the original and innovative work of several of the participants in today's conference have made it quite clear that profitabiity is a necessary condition for change in production methods and productivity improvement, too many low income countries still refuse to provide farmers the opportunity to make personal and socially efficient use of their resources and talents.

The evidence on the role of profitability as a major factor in productivity change is overwhelming--Zvi Griliches' analysis of the adoption of hybrid corn and, later, of grain sorghum in the United States; T.W. Schultz's analysis and empirical evidence in Transforming Traditional Agriculture; and Vernon Ruttan's work on induced innovation. But it has taken a very long time for the role of profitability to achieve appropriate recognition as one of the major engines for improving real incomes and food supply in low income countries. The studies of the World Bank provide shocking documentation of the willingness of governments, especially in Africa, to exploit their farmers through low prices with little or no willingness to face up to the long run negative consequences of such exploitation.

But recent years have seen significant progress and change. Perhaps the most important changes have occurred in the People's Republic of China. In fact it is hard to believe that a more radical change affecting such a large percentage of the world's population has ever occurred. In six short years there has been a transformation of the incentive structure. There has been a transformation from an arcane commune system that rewarded indolence as much as productive effort, that imposed large and unnecessary work burdens upon its members, and that restricted efforts to use one's own labor in private activities on plots, and had nearly destroyed most market activities. This transformation includes improved product prices, reductions in and then elimination of required deliveries, permission to sell and trade any output not contracted for delivery to the state in markets that are reasonably free with respect to prices, and the elimination of much of the control of bureaucrats over the productive efforts of farm people through the institution of the household responsibility system. The reform assigned nearly all cropland to individual households, first for three years and now for fifteen years.

According to official data the effects of these and other changes, such as reducing taxes on farm people, on agricultural production and the real incomes of farm people have been dramatic. Not only has aggregate farm production increased at an annual rate of seven percent between 1978 and 1984, but the mix of that output with the relaxation of the emphasis upon regional grain self sufficiency has resulted in a more efficient use of Chinese agricultural resources. One can perhaps be pardoned for asking "what took so long" for China to adopt more rational and effective agricultural policies, but there remain too many examples of equally negative farm policies in other countries for one to be other than thankful that positive change finally emerged in China.

One outcome of the assignment of communal lands in China to individual households in China has been the reemergence of scattered plots. This is true even though the average amount of land assigned to a household is little more than an acre; five or six scattered plots are not unusual. Planners are almost always opposed to scattered plots and even some academic economists. In my opinion we should always start from the assumption that people, including farm people, are rational. Apparently the return to the scattered plot occurred for two reasons. One was a concern that if one received but one plot, it might be of significantly lower productivity than the average. The other represented a response to risk aversion--output from several plots is less variable than from one plot.

China has not overcome all of the negative legacies of the past. Rice prices, as in several other Asian economies, are below international prices by a significant percentage and below wheat prices absolutely. Urban food consumption is heavily subsidized and rural to urban migration is strictly controlled and held to a mere trickle. Government investment in job creating activities still favors the cities; on a per capita basis productive capital investments in urban areas are at least ten times as great as in rural areas.

Binswanger called to our attention the role of rice price policy in Thailand in delaying the introduction of the new high yielding varieties of rice in the Central Plain. In recent years there has been a rapid increase in productive investment and rice yields in the area. This represents a shift away from the upland areas in the North. But the shift has been a recent phenomena and probably came later than it should have due to the Thai rice price policy. For nearly three decades, the Thai Government imposed export taxes on rice, at times equal to a third or more of the export price.

In its 1983 World Development Report the World Bank developed measures of price distortion for 31 developing countries and compared its measure of distortion to growth in GDP for 1970-80. The difference in GDP growth rates for the third of the countries with the least distortions and the third with the most was four percentage points. The average for all 31 countries was 5 percent per year. The regression between the degree of distortions and GDP growth rates indicated a degree of association of about one third. A striking result was that there was no correlation between the distortions and equity in the distribution of income as measured by the proportion of income going to the bottom two-fifths of the population. It is interesting that large distortions did not increase the equality of income distributions. It is not obvious why any one should expect that distortions that favor the urban population, which has much higher incomes than the farm population, should make income distributions more equal.

Let me conclude with some additional comments about the relationships between what we have heard today and the world food problem. During the morning, Ruttan accused me of always looking for optimistic material (such as the UNICEF report on The State of the Child). I readily accept his chiding comment because I think that he has provided the basis for an optimistic view of the world food situation, as have the other papers presented here. Basically, what we have heard is that institutions--public, private or social--do generally function reasonably well. Ruttan's own development of the concept of induced innovation is a basis for an optimistic conclusion about mankind and improvements in nutrition and well-being. Similarly, Binswanger's analysis of the adaptability of farming systems, Evenson's analysis of factors affecting institution development and allocation of research resources, including the enormous increase in effort in the developing countries, Paul Schultz's demonstration of the remarkable expansion of education in developing countries represent hopeful signs of great significance.

In the 1970s the proposition that productivity growth in agriculture had slowed down received some credence. It is not obvious that this was the case, but more importantly if there were any basis then for believing that the productivity of research was declining because applied research had utilized most of the available basic knowledge, this position now seems unreasonable with the explosion of effort on bio-technology and related areas, such as growth hormones for cattle.

In my view there are two strong indicators that there is a basis for an optimistic viewpoint, both in terms of the past several decades and for the future. Both were noted by T.W. Schultz. One is the unprecedented increase in life expectancy in the low income countries since 1950. The increase of 60 percent achieved in India is approximately what was achieved in all developing countries. The low income countries now have the same life expectancy as the U.S. had at the turn of this century, Italy and the USSR in the 1930s, and Japan in the 1940s. The second is the declining price of cereals since World War I. Related to this last point, my colleague Robert Fogel attributes about 40 percent of the increase in life expectancy in Europe and the Caribbean to improved nutrition. The other trend has been the declining real prices for cereals, the primary source of calories for the majority of the world's poor. I have seen no convincing evidence that this long term trend will be reversed in the foreseeable future.

I am confident that we will observe further increases in life expectancy and further declines in the real prices of cereal. One important reason for their doing so well is the continuing improvement and enhancement of human capital, continuing increases in knowledge (both basic and applied research), and in the translation of knowledge into technology and production.

A P P E N D I X 7

VERNON W. RUTTAN

Home: 2381 Commonwealth Avenue
St. Paul, MN 55108
Telephone: 612/644-9570

Office: Department of Agricultural and Applied Economics
University of Minnesota
St. Paul, MN 55108
Telephone: 612/376-3560

Department of Economics
University of Minnesota
Minneapolis, MN 55455
Telephone: 612/373-4383

PERSONAL

Born August 16, 1924; RFD #1, Alden, Michigan USA

EDUCATION

Michigan State University, 1942-43
Yale University, BA - 1948
University of Chicago, MA - 1950, Ph.D. - 1952

EMPLOYMENT

(1) Tennessee Valley Authority, Economist, Division of Regional Studies, 1951-1953; Office of the General Manager, 1954-1954.

(2) Purdue University, Department of Agricultural Economics, Assistant Professor, 1955-57; Associate Professor, 1957-60; Professor, 1960-63.

(3) University of California (Berkeley), Associate Agricultural Economist. Giannini Foundation of Agricultural Economics, 1958-59, (on leave from Purdue).

(4) Council of Economic Advisors, Executive Office of the President, Staff Economist, November 1961-January 1963, (on leave from Purdue).

(5) Rockefeller Foundation (at the International Rice Research Institute, Philippines), Agricultural Economist, May 1963-August 1965.

(6) Agricultural Development Council, Inc. -- trustee, 1967-1973; President, May 1973-December 1977.

(7) University of Minnesota -- Professor and Head, Department of Agricultural Economics, September 1965 to July 1970.

Professor and Director of Economic Development Center, July 1970 to May 1973.

Professor (A) Department of Agricultural and Applied Economics, (b) Department of Economics, (c) Hubert H. Humphrey Institute of Public Affairs, 1978 to present.

PROFESSIONAL

(1) American Agricultural Economics Association

(a) Committee on New Orientations in Agricultural Economics Research, 1959-63.
(b) Editorial Council, 1965-67.
(c) Vice-President, 1967-68.
(d) Committee on Professional Problems in International Research, 1967-69, (Chairman, 1968-69).
(e) President, 1971-72.

(2) Awards and Honors

(a) Publication Award, American Agricultural Economics Association, 1956, 1957, 1962, 1966, 1967, 1971, 1979, 1985.
(b) Fellow, American Agricultural Economics Association, elected 1974.
(c) Fellow, American Academy of Arts and Sciences, elected 1976.
(d) Honorary Degree, Rutgers University: Doctor of Laws (LLD), 1978.
(e) U.S. Department of Agriculture, B.Y. Morrison Memorial Lectureship, 1983.
(f) Alexander von Humboldt Award, 1984 (for outstanding contribution to agriculture over previous five years).

(3) Professional and Public Service

International

(a) Agricultural Development Council, Inc., Board of Trustees, 1967-73, President, 1973-78.
(b) Economics Institute, Policy and Advisory Board, 1968-1970.
(c) International Association of Agricultural Economists, U.S. Council Member, 1969-1972.
(d) Consultative Group on International Agricultural Research, Technical Advisory Committee (TAC), 1973-1977.
(e) Asian Vegetable Research and Development Center, Board of Directors, 1975-1977.
(f) Asian Development Bank, Co-chairman (with Kazushi Ohkawa), Consultative Committee on Updating the Asian Agricultural Survey, 1975-77.
(g) International Service for National Agricultural Research (ISNAR) Board of Directors, 1979 - present.
(h) Director, UM-ISNAR Agricultural Research Policy Seminar, (Annual 1982, 1983, 1984, 1985, 1986).

National

(i) Agency for International Development, Research Advisory Committee (RAC), 1967-1975, 1983-
(j) Asian Society-Southeast Asia Development Advisory Group (SEADAG): Chairman, Rural Development Seminar, 1968-1969, Executive Committee, 1969-1971.
(k) National Research Council, (a) Committee on Problems of Pest Control, 1971-1975; (b) Agricultural Board, 1983-
(l) National Planning Association, Committee on Agriculture, 1981-
(m) Sierra Club, Economics Committee, 1983-

Minnesota

(n) Governor's Council of Economic Advisors (Minnesota), 1971-1973.
(o) Chairman, Committee to Review State Funded Research, Governor's Office of Science and Technology, St. Paul, 1984.

(4) Member

(a) American Academy of Arts and Sciences
(b) American Agricultural Economics Association
(c) American Economics Association
(d) Council on Foreign Relations
(e) Economic History Association
(f) Indian Society of Agricultural Economists
(g) International Association of Agricultural Economists
(h) Philippine Economic Society
(i) Society for the History of Technology

(5) Listings

(a) Who's Who in America, 1972-1973, 37th edition (Chicago: Merquis, 1972). (Also in subsequent editions.)

(Listings continued)

(b) American Men and Women of Science: The Social and Behavioral Sciences, 11th edition (New York: R.R. Bowker, 1968). (Also in subsequent editions.)

(c) Who's Who in Economics: A Biographical Dictionary of Major Economists: 1970-1981 Eds. Mark Blaug and Paul Sturgis (Cambridge: The MIT Press, 1983).

PUBLICATIONS

1. Books - author

The Economic Demand for Irrigated Acreage: New Methodology and Some Preliminary Projections, 1954-1980, Baltimore: The Johns Hopkins Press, (for Resources for the Future, Inc.), 1965.

Plant Science: An Introduction to World Crops, San Francisco: W.H. Freeman and Company, 1st edition, 1969; 2nd edition, 1974; 3rd edition, 1981 (with J. Janick, R.W. Schery and F.W. Woods).

Agricultural Development: An International Perspective, Baltimore: Johns Hopkins Press, first ed., 1981; second ed., 1985 (with Yujiro Hayami). (First edition received American Agricultural Economics Association Publication of Enduring Quality Award, 1985).

Induced Innovation: Technology, Institutions and Development, Baltimore: The Johns Hopkins University Press, 1978 (with Hans P. Binswanger and others). (American Agricultural Economics Association Publication Award, 1979.)

Agricultural Research Policy, Minneapolis: University of Minnesota Press, 1982. (Italian translation, Politica per la Riceria in Agricoltara, Venezia: Giunta Regionale del Veneto, 1985.)

Books - editor

Agricultural Policy and an Affluent Society, New York: W.W. Norton and Company, 1969 (edited with A.D. Waldo and J.P. Houck).

Plant Agriculture: Readings from Scientific American, San Francisco: W.H. Freeman and Company, 1970 (edited with J. Janick, R.W. Schery, and F.W. Woods).

Agricultural Revolution in Southeast Asia: Impact on Grain Production and Trade, New York: The Asia Society, 1970.

Resource Allocation and Productivity in National and International Agricultural Research, Minneapolis: University of Minnesota Press, 1977 (edited with Thomas M. Arndt and Dana G. Dalrymple).

Agricultural Growth in Japan, Taiwan, Korea and the Philippines, Honolulu: The University Press of Hawaii, 1979 (edited with Yujiro Hayami and Herman Southworth).

2. Journal Articles

"The Changing Industrial Molasses Market," Journal of Agricultural and Food Chemistry, July 22, 1953, pp. 602-608 (with T.N. Hubbuch).

"The Relationship Between the BAE Level-of-Living Index and the Average Incomes of Farm Operators," Journal of Farm Economics, Vol. 36, February, 1954, pp. 41-51.

"The Impact of Urban-Industrial Development on Agriculture in the Tennessee Valley and the Southeast," Journal of Farm Economics, Vol. 37, February, 1955, pp. 38-56. Reprinted in Karl A. Fox and D. Gale Johnson (eds.) Readings in the Economics of Agriculture (Homewood: Richard D. Irwin, 1969), pp. 339-358). (American Farm Economics Association Award, 1956).

(Journal Articles continued)

"Industrial Progress and Agricultural Stagnation in the New South," Social Forces, Vol. 34, December, 1955, pp. 114-118.

"The Contribution of Technological Progress to Farm Output: 1950-75," Review of Economics and Statistics, Vol. 38, February, 1956, pp. 61-69 (American Farm Economics Association Award, 1957).

"Agricultural and Non-Agricultural Growth in Output Per Unit of Input," Journal of Farm Economics, Vol. 39, December, 1957, pp. 1566-1576.

"Regional patterns of Technological Change in American Agriculture," Journal of Farm Economics, Vol. 40, May, 1958, pp. 196-207 (with T.T. Stout).

"Technological Change and Resource Requirements in American Agriculture," Journal of Agricultural and Food Chemistry, September, 1958, pp. 652-656.

"Farm and Non-Farm Employment Opportunities for Low Income Farm Families," Phylon (The Atlanta University Review of Race and Culture), Fall Quarter, 1959, pp. 248-255.

"Usher and Schumpeter on Invention, Innovation and Technological Change," Quarterly Journal of Economics, Vol. 73, November, 1959, pp. 596-606. (See also P.R. Schweitzer "Comment," and V.W. Ruttan, "Reply," Quarterly Journal of Economics, Vol. 73, February, 1961, pp. 152-156.

"Regional Differences in Factor Shares in American Agriculture," Journal of Farm Economics, Vol. 41, February, 1960, pp. 52-68 (with T.T. Stout).

"Research on the Economics of Technological Change in American Agriculture," Journal of Farm Economics, Vol. 42, No. 4, November, 1960, pp. 735-754.

"Impact of Local Population Pressure on Farm Real Estate Values in California," Land Economics, Vol. 38, No. 2, May, 1961, pp. 125-131.

"Resource Inputs and Output Growth: Comparisons between Agriculture and Forestry," Forest-Science, Vol. 8, No. 1, March, 1962, pp. 68-82 (with J.C. Callahan).

"The Effectiveness of Location Incentives on Local Economic Development," Journal of Farm Economics, Vol. 44, No. 4, November, 1962, pp. 968-978 (with L.T. Wallace).

"Evaluation of Area Redevelopment Loans to Agricultural Firms," Journal of Farm Economics, Vol. 45, No. 5, December, 1963, pp. 1022-1026 (with E.M. Babb and L.T. Wallace).

"Equity and Productivity Objectives in Agrarian Reform Legislation: Perspectives on the New Philippine Land Reform Code," Indian Journal of Agricultural Economics, Vol. 19, Nos. 3 and 4, July-Decemer 1964, pp. 114-130. Reprinted as "Land Reform and National Economic Development" in G.R. Sicat, The Philippine Economy in the 1960's, Institute of Economic Development and Research, University of the Philippines, Quezon City, 1964, pp. 92-119.

"Productivity Models of Economic Growth," The Philippine Statistician, Vol. 13, No. 3, September, 1964, pp. 132-147. Reprinted in Productivity, Indian National Productivity Council, New Delhi, Vol. 7, No. 4, Winter, 1966-1967, pp. 530-539.

"Partial Budgeting of Costs and Returns Using Experimental Data from Herbicide and Fertilizer Experiments," The Philippine Agriculturist, Vol. 48, Nos. 6-7, November-December, 1964, pp. 249-268 (with H.C. Moomaw).

"On Schumpeter and Development," Philippine Economic Journal, Vol. 4, No. 1, (First Semester, 1965), pp. 57-63.

"Growth Stage Theories and Agricultural Development Policy," Australian Journal of Agricultural Economics, Vol. 9, No. 1, 1965, pp. 17-32. (Abstracted in Mercurio, Vol. 8, No. 10, Rome, October, 1965, pp. 59-64; The Economic Weekly, Bombay, August 7, 1965, pp. 1231-1234.)

(Journal Articles continued)

"Tenure and Productivity of Philippine Rice Producing Farms," The Philippine Economic Journal, Vol. 5, No. 1, First Semester, 1966, pp. 42-63.

"Technological and Environmental Factors in the Growth of Rice Production in the Philippines and Thailand," Rural Economic Problems, Vol. 3, No. 1, May, 1966, pp. 63-107. (Japanese translation in Agricultural Development Bulletin 265, Agricultural Policy Research Committee, Tokyo) (with A. Soothipan and E.C. Venegas.) For preliminary reports covering the same material see World Crops, March, 1966, pp. 16-33; Economic Research Journal, December, 1964, pp. 159-179; September, 1965, pp. 116-133; December, 1965, pp. 181-201; Bangkok Bank Monthly Review, May, 1966, pp. 182-191.

"Price and Market Relationships for Rice and Corn in the Philippines," Journal of Farm Economics, Vol. 48, No. 3, August, 1966, pp. 685-703 (with A.E. Rectoand Mahar Mangahas). Also in Philippine Economic Journal, Vol. 5, (First Semester, 1966), pp. 1-27.

"Equity and Productivity Issues in Modern Agrarian Reform Legislation," Philippine Studies, Vol. 14, No. 1, January, 1966, pp. 52-64.

"Agricultural Policy in an Affluent Society," Journal of Farm Economics, Vol. 48, No. 5, December, 1966, pp. 1100-1120. (American Agricultural Economics Association Award, 1967.)

"Issues in the Evolution of Production Economics," Journal of Farm Economics, Vol. 49, No. 5, December, 1967, pp. 1490-1498.

"Environmental, Technological and Institutional Factors in the Growth of Rice Production: Philippines, Thailand, and Taiwan," Food Research Institute Studies, Vol. 7, No. 3, 1967, pp. 307-341 (with S.C. Hsieh). Reprinted in M.L. Dantwala, Agricultural Development in Developing Countries: Comparative Experience, Indian Society of Agricultural Economics, Bombay, 1972, pp. 59-72.

"Production Economics for Agricultural Development," Indian Journal of Agricultural Economics, Vol. 23, No. 2, April-June, 1968, pp. 1-14.

"Agricultural Product and Factor Markets in Southeast Asia," Economic Development and Cultural Change, Vol. 17, No. 4, 1969, pp. 501-519. Reprinted in (a) K.R. Anchel, R.H. Brannan and Eldon D. Smith, Agricultural Cooperatives and Markets in Developing Countries, Praeger, 1969, pp. 79-106; and in (b) Boedino and Peter McCawley, Bunga Rampai Ekonomi Mikro (Jogjakarta: Gadjah Mada University Press, 1976), pp. 170-187.

"Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880-1960," The Journal of Political Economy, Vol. 78, No. 5, September-October, 1970, pp. 1115-1141 (with Yujiro Hayami) (American Agricultural Economics Association Award, 1971).

"Korean Rice, Taiwan Rice and Japanese Agricultural Stagnation: An Economic Consequence of Colonialism," The Quarterly Journal of Economics, Vol. 84, No. 4, November, 1970, pp. 562-589 (with Yujiro Hayami).

"Agricultural Productivity Differences Among Countries," The American Economic Review, Vol. 60, No. 5, December, 1970, pp. 895-911 (with Yujiro Hayami). Reprinted in M.L. Dantwala, Agricultural Development in Developing Countries: Comparative Experience, Indian Society for Agricultural Economics, Bombay, 1972, pp. 73-88. Abstract also in Journal of Northeastern Agricultural Economics Council, Vol. 1, No. 1, Summer, 1972, pp. 1-18.

"Technology and the Environment," American Journal of Agricultural Economics, Vol. 53, No. 5, December, 1971, pp. 707-717. Reprinted in Lloyd F. Seatz, Symposium on Ecology and Agricultural Production (Knoxville: University of Tennessee Institute of Agriculture, 1977).

"Technology Transfer and Agricultural Development," Technology and Culture, Vol. 14, No. 2, April, 1973, pp. 1-52. Also in Shigeru Ishikawa (ed.), Agriculture and Economic Development--Structural Readjustment in Asian Perspective, Japan Economic Research Center, Tokyo, May, 1972, pp. 505-583 (with Yujiro Hayami).

(Journal Articles continued)

"Strategies for Agricultural Development," Food Research Institute Studies, Vol. 11, No. 2, 1972, pp. 129-148 (with Yujiro Hayami). Reprinted in Carl K. Eicher and John M. Staatz, Agricultural Development in the Third World (Baltimore: The Johns Hopkins University Press, 1984), pp. 59-74.

"Technology Transfer and Agricultural Development," Technology and Culture 14, April, 1973, pp. 119-151 (with Yujiro Hayami).

"Technical and Institutional Transfer in Agricultural Development," Research Policy, Vol. 4, 1975, pp. 350-378. Also published in J.D. Drilon (ed.), Institutionalizing Research Management in Asia, Los Banos: Southeast Asian Regional Center for Graduate Study and Research in Agriculture, 1974, pp. 74-92.

"Integrated Rural Development Programs: A Skeptical Perspective," International Development Review, Vol. 17, No. 4, December, 1975, pp. 9-16. Reprinted in Productivity 19, Jan-Mar, 1979, pp. 481-495.

"Induced Innovation and Agricultural Development," Food Policy, Vol. 2, No. 3, August, 1977, pp. 196-216. Reprinted in Gordon K. Douglass, Agricultural Sustainability in a Changing World Order (Boulder, Colorado: Westview Press, 1984), pp. 107-134.

"Reviewing Agricultural Research Programs," Agricultural Administration, Vol. 5, No. 1, January, 1978, pp. 1-19. (Also in Revista Latino-americana de ciencias Agricolas, Vol. 13, No. 1, 1977, pp. 20-32.)

"The Green Revolution: Seven Generalizations," International Development Review, Vol. 19, No. 4, December, 1977, pp. 16-23.

"Structural Retardation and the Modernization of French Agriculture," Journal of Economic History, Vol. 37, No. 3, September, 1978, pp. 714-728.

"The International Agricultural Research Institute as a Source of Agricultural Development," Agricultural Administration, Vol. 5, No. 4, November, 1978, pp. 293-310.

"Induced Institutional Innovation," Agricultural Economics Research, Vol. 31, No. 3, July, 1979, pp. 32-35.

"Economic Benefits from Research: An Example from Agriculture," Science, Vol. 205, September 14, 1979, pp. 1101-1107 (with Robert E. Evenson and Paul E. Waggoner). Reprinted in Ciecia y Desarrollo (Mexico), Vol. 6, Septiembre-Octubre, 1980, pp. 127-144.

"Inflation and Productivity," American Journal of Agricultural Economics, Vol. 60, December, 1979, pp. 896-902. Reprinted in Developing Agriculture 580, November, 1980, pp. 5-17 (in Japanese).

"Behavior and Productivity Implications of Institutional and Project Funding of Research," American Journal of Agricultural Economics, Vol. 62, No. 3, August, 1980 (with Maury E. Bredahl and W. Keith Bryant), pp. 371-383; "Comment" (by William E. Becker, Jr.) AJAE, Vol. 64, No. 3, August, 1982, pp. 596-598; "Reply (by Maury E. Bredahl, W. Keith Bryant and Vernon W. Ruttan) AJAE, Vol. 64, No. 3, August, 1982, pp. 599-602.

"Bureaucratic Productivity: The Case of Agricultural Research," Public Choice, Vol. 35, No. 5, 1980, pp. 529-547; "Bureaucratic Productivity: The Case of Agricultural Research Revisited," (by E.C. Pasour, Jr. and Marc A. Johnson), Public Choice, Vol. 39, No. 2, 1982, pp. 301-317; "A Rejoiner," (by Vernon W. Ruttan), Public Choice, Vol. 39, No. 2, 1982, pp. 319-329.

"Changing Role of Public and Private Sectors in Agricultural Research," Science, Vol. 216, April 2, 1982, pp. 23-29.

"Agricultural Scientists as Reluctant Revolutionaries," Interdisciplinary Science Reviews, Vol. 7, No. 3, September, 1982, pp. 170-177.

(Journal Articles continued)

"Perspectives on Agrarian Reform and Rural Development," Quarterly Journal of International Agriculture, Vol. 21, No. 3, July-September, 1982, pp. 240-249.

"Moral Responsibility in Agricultural Research," Southern Journal of Agricultural Economics, Vol. , July, 1983, pp. 73-80. Also in Hartwig de Haen, Glenn L. Johnson and Stefan Tangerman (eds.), Agri-culture and International Relations (London: Macmillan Press, 1985), pp. 66-83.

"Agricultural Research Policy Issues," HortScience, Vol. 18, No. 6, December, 1983, pp. 809-818 (B.Y. Morrison Memorial Lecture).

"Integrated Rural Development Programs: A Historical Perspective," World Development, Vol. 12, No. 4, 1984, pp. 393-401.

"A Guide to LDC Food Balance Projections," European Review of Agricultural Economics 10, July, 1983, pp. 325-356 (with Glenn Fox). Reprinted in Ray A. Goldberg (ed.), Research in Domestic and International Agribusiness Management, Vol. 5 (Greenwich, Conn.: JAI Press, Inc., 1984), pp. 165-201.

"Toward a Theory of Induced Institutional Innovation," Journal of Development Studies, Vol. 20, July, 1984, pp. 203-223 (with Yujiro Hayami).

"The Green Revolution: Inducement and Distribution," The Pakistan Development Review, Vol. 23, Spring, 1984, pp. 37-63 (with Yujiro Hayami).

"Perspective on Population and Development," Indian Journal of Agricultural Economics 39, October, 1984, pp. 630-638.

"The Intercountry Agricultural Production Function and Productivity Differences Among Countries," Journal of Development Economics 19, 1985, pp. 113-132.

"Social Science Knowledge and Institutional Change," American Journal of Agricultural Economics, Vol. 66, No. 5, December, 1984, pp. 549-559 (American Agricultural Economics Association Fellows Lecture, 1984).

3. Chapters in Books and Conference Proceedings

"The Potential in Rural Industrialization and Local Economic Development," in E.O. Heady, et al, Agricultural Adjustment Problems in a Growing Economy (Iowa State College Press, 1938), pp. 183-197.

"Measuring Productivity Changes in Marketing," in R.M. Hill (ed.), Marketing Concepts in Changing Times (Procedings of the 42nd National Conference of the American Marketing Association), American Marketing Association, Chicago, February, 1960.

"Projections of Irrigated Acreage and Water Requirements for Western Water Resource Regions," in Harold L. Amos (ed.), Water: Measuring and Meeting Future Requirements, (Western Resources Conference Papers, 1960), University of Colorado Press, Boulder, 1961, pp. 63-86.

"The Role of the Community as a Factor in Industrial Location," Papers and Proceedings of the Regional Science Association, Vol. 7, 1961, pp. 133-142 (with T. Wallace).

"Area Development and Industrial Decentralization," Conference on Area Development, Agricultural Policy Institute, North Carolina State College and the Institute of Community and Area Development, University of Georgia, May, 1962, pp. 185-203 (with L.T. Wallace). Abstract appears in Agricultural Policy Review, North Carolina State College, Vol. 2, No. 3, Summer, 1962, p. 8-9.

"The Human Resource Problem in American Agriculture," in K.A. Fox, V.W. Ruttan and L.W. Witt, Farming, Farmers, and Markets for Farm Goods, Supplementary Paper No. 15, Committee for Economic Development, New York, 1962, pp. 75-116.

(Chapters in Books and Conference Proceedings continued)

"Regional Differences in the Impact of Irrigation on Farm Output," in S.C. Smith and E.N. Castle (eds.), Economics and Public Policy in Water Resource Development, Iowa State University Press, Ames, 1964, pp. 127-149. Reprinted from Committee on the Economics of Water Resources Development, Water Resources and Economic Development of the West, Report No. 8, Western Agricultural Economics Research Council, San Francisco, January, 1960, pp. 107-134 (with J.C. Headley).

"Determining Factor Shares," in L.B. Fletcher, Farmers in the Market Economy, Iowa State University Press, Ames, 1964, pp. 190-213 (with G.A. MacEachern).

"Output and Productivity Growth in South East Asian Agriculture," Productivity, (Indian National Productivity Council, New Delhi), Vol. 6, Nos. 2 and 3, 1965, pp. 220-225.

"Technological Change, Productivity, and Economic Growth," in G.P. Sicat (ed.), Economics and Development: An Introduction, University of the Philppines Press, Quezon City, 1965.

"Industrialization and Agricultural Development," in H.W. Singer, et al (eds.), International Development, 1966, Society for International Development, 1967, pp. 219-231.

"Two Sector Models and Development Policy," in Clifton R. Wharton, Jr., (ed.), Subsistence Agriculture and Economic Development, Chicago, Aldine, 1969, pp. 353-360.

"The Philippines," in R.T. Shand(ed.), Agricultural Development in Asia, Canberra: Australian National University Press, 1969 (with Richard Hooley).

"The International Institute Approach," in Guy Benveniste and Warren F. Ilchman (eds.), Agents of Change: Professionals in Developing Countries, New York, Praeger, 1969, pp. 220-228.

"Technical Change and Agricultural Trade: Three Examples - Sugarcane, Bananas and Rice," in Raymond Vernon (ed.), The Technology Factor in International Trade, New York and London: Columbia University Press, 1970, pp. 415-480 (with R.E. Evenson and J.P. Houck, Jr.).

"Agricultural Economics," in Nancy D. Ruggles (ed.), Economics, Englewood Cliffs: Prentice Hall, 1970, pp. 144-151. Reprinted as "Zukunftige Aufgaben der agrarokonomischen Forshung," Agrarwirtchaft, Jahrgang 20,
Heft 11, November, 1971, pp. 362-367.

"Research Institutions: Questions of Organizations," in Melvin G. Blase (ed.), Institutions in Agricultural Development, The Iowa State University Press, Ames, 1971, pp. 129-138.

"Problems and Issues in Resource Allocation for Agricultural Research," in Walter L. Fishel (ed.), Resource Allocation in Agricultural Research, University of Minnesota Press, 1971, pp. 3-22 (with Philip J. Tichenor).

"Transformation of Tranditional Agriculture: Induced Technical and Institutional Innovation," in M.L. Dantwala (ed.), Agricultural Development in Developing Countries: Comparative Experience, Indian Society of Agricultural Economics, Bombay, 1972, pp. 371-380.

"Planning Technological Advance in Agriculture: The Case of Rice Production in Taiwan, Thailand and the Philippines," in Robert A. Solo and Everett M. Rogers, Inducing Technological change for Economic Growth and Development, Michigan State University Press, East Lansing, 1972, pp. 52-77.

"Induced Innovation in Agricultural Development," in Eliezor B. Ayal (ed.), Micro-Aspects of Development, Praeger, New York, 1973, pp. 181308 (with Yujiro Hayami).

"Induced Technical and Institutional Change and the Future of Agriculture," Fifteenth International Conference of Agricultural Economists: Theme Papers, International Association of Agricultural Economists, Institute of Agricultural Economics, University of Oxford, AUgust, 1973,pp. 16-33.

(Chapters in Books and Conference Proceedings continued)

"Priorities in Agricultural Economics Research: An International Perspective," in H. Albrecht and G. Schmitt (eds.), Forschung und Ausbildung im Bereich der Wirtschafts - und Sozialwissenschaften des Landbaues, Muchen: BLV Verlagsgesellschaft, 1975, pp. 13-21.

"Technological Transfer, Institutional Transfer, and Induced Technical and Institutional Change in Agricultural Development," in Lloyd G. Reynolds (ed.), Agriculture in Development Theory, New Haven: Yale University Press, 1975, pp. 165-191.

"The Prospect for Agricultural Growth," in Economic and Demographic Change: Issues for the 1980's, Liege, Belgium: International Union for the Scientific Study of Population, 1978, pp. I.1: 1-29.

"Institutional Innovation," in Theodore W. Schultz (ed.), Distortions of Agricultural Incentives, Bloomington: Indiana University Press, 1978, pp. 290-306.

"New Rice Technology and Agricultural Development Policy," in R. Barker and Y. Hamayi (eds.), Economic Consequences of the New Rice Technology, Los Banos: International Rice Research Institute, 1978, pp. 367-381.

"Some Empirical Evidence on Induced Technical Change in Agriculture," in Herbert Giersch (ed.), International Economic Development and Resource Transfer, Tubingen, J.C.B. Morh (Paul SIebeck), 1979, pp. 193-226.

"International Comparisons of Productivity in Agriculture," in John W. Kendricka dn Beatrice N. Vaccara (eds.), New Developments in Productivity Measurement and Analysis, Chicago: University of Chicago Press, 1980, pp. 509-585 (with Saboro Yamada).

"Induced Innovation in Agriculture," in Christopher Bliss and M. Boserup, (eds.), Economic Growth and Resources: National Resources (Vol. 3). Proceedings of the Fifth World Congress of the International Economic Association, Tokyo, Japan. Blonden: Macmillan, 1980, pp. 162-189 (with Hans P. Binswanger and Yujiro Hayami).

"The Social Sciences in Agricultural Research," Canadian Journal of Agricultural Economics, Proceedings of the 1980 Annual Meeting, August, 1980, pp. 1-13.

"Agricultural Research and the Future of American Agriculture," in Sandra S. Batie and Robert G. Healy, (eds.), The Future of American Agriculture as a Strategic Resource, Washington, D.C.: The Conservation Foundation, 1980, pp. 117-155.

"The Private Sector in Agricultural Research," Proceedings and Minutes of the Twenty-Ninth Annual Meeting of the Agricultural Research Institute, Washington, D.C.: Agricultural Research Institute, 1980, pp. 80-97.

"Three Cases of Induced Institutional Innovation," in Clifford S. Russell and Norman K. Nicholson, (eds.), Public Choice and Rural Development, Baltimore: Johns Hopkins University Press for Resources for the Future, 1981, pp. 239-270. Reprinted in Economia 9, June, 1982, pp. 83-104.

"TVA Programs and the Development of the Tennessee Valley Region: An Introduction," in Vernon W. Ruttan, (ed.), The Role of TVA Programs in Regional Development: The 1979 Summer Policy Study, Knoxville: Tennessee Valley Authority, March, 1981, pp. 1-8.

"Agricultural Research as an Investment: Past Experience and Future Opportunities," Report of the 1982 Plant Breeding Research Forum, Des Moines, Iowa: Pioneer Hi-Bred International, 1983 (with Burt Sundquist).

"La Innovacion Inducida Como Interpretacion Del Cambio Technologico en el Desarrollo Agricola de los Paises in Desarrollo," Memorios del primer Seminario Sobre Investigacion y Desarrollo Technologico en el Sector Agropecuaria Colombiano, Bogota: Ministerio de Agricultura and Departamento Nacional de Planeacion, 1982, pp. 81-122.

(Chapters in Books and Conference Proceedings continued)

"Los Institutos Internacionales de Investigation Agricola Como Fuente del Desarrollo Agricola," in Manuel Elqueta G. and Eduardo Venezian L., (eds.), Economia y Organizacion de la Investigacion Agropecuaria, Santiago: Instituto de Investigaciones Agropecuarias, Diciembre, 1982, pp. 191-208.

"Reforming the Global Agricultural Research Support System," in Kenneth C. Nobe and Rajan K. Sampath, (eds.), Issues in Third World Development, Boulder, Colorado: Westview Press, 1983, pp. 405-418.

"Accountability in Research: Examples from Agriculture," in Kenneth E. Boulding and Lawrence Senesh, The Optimum Utilization of Knowledge, Boulder, Colorado: Westview Press, 1983, pp. 239-253.

"The TVA and Regional Development," in Erwin C. Hargrove and Paul K. Conklin, (eds.), TVA: Fifty Years of Grass-roots Bureaucracy, Urbana, Illinois: University of Illinois Press, 1983, pp. 150-166.

"An Induced Innovation Interpretation of Technical Change in Agriculture in Developed Countries," in Martin Pineiro and Eduardo Trigo, (eds.), Technical Change and Social Conflict in Agriculture, Boulder, Colorado: Westview Press, 1983, pp. 1-24. Also published as "La teoria de la innovacion inducida del cambio technica en el agro de los paises dessarrollados," in Martin Pineiro and Eduardo Trigo, (eds.), Cambio Tecnico en al Agro Latinoamericano, San Jose, Costa Rice: Instituto Interamericano de Cooperacion Para La Agricultura, 1983, pp. 13-57.

4. Monographs and Bulletins

Comparative Data on Farm Income and Employment, 1928-51, Report No. 1 of the Project on Research in Agricultural and Industrial Development in the Tennessee Valley Region. (TVA, Division of Regional Studies, May, 1985).

Differentials in Farm Income and Employment in the Tennessee Valley Region Counties, Report No. 2 of the Project on Research in Agricultural and Industrial Development in the Tennessee Valley Region. (TVA, Division of Regional Studies, July, 1953).

Technological Progress in the Meatpacking Industry, United States Department of Agriculture, Marketing Research Report No. 59, January, 1985.

The Pricing of Indians Eggs at Country and Terminal Markets, Purdue Agricultural Experiment Station Bulletin No. 648, 1957 (with W.F. Laird).

The-Marketing of Indiana Canned Tomatoes and Tomato Products, Purdue Agricultural Experiment Station Mimeo ID-24, April, 1958 (with J.F. Ritchey).

Cost and Efficiency in Indiana Tomato Canning Plants, Purdue Agricultural Experiment Station Mimeo ID-25, June, 1958 (with W.L. Fishel).

"The Impact of Irrigation on Farm Output in California," Hilgardia, (Journal of the California Agricultural Experiment Station), Vol. 31, No. 4, July, 1961, pp. 69-111 (American Farm Economic Association Award, 1962).

Job Mobility and Migration in a Low Income Rural Community, Purdue Agricultural Experiment Station Research Bulletin 730, September, 1961 (with R.D. Geschwind).

Growth Stage Theories, Dual Economy Models, and Agricultural Development Policy, Department of Agricultural Economics, University of Guelph, Ontario, 1968.

Resource Allocation in Agricultural Research: The Minnesota Symposium, University of Minnesota Agricultural Experiment Station, 1969 (with Philip Tichenor).

(Monographs and Bulletins continued)

Production and Market Relationships for Rice and Corn in the Philippines, International Rice Research Institute Technical Bulletin 9, Los Banos, Laguna, Philippines, 1970 (with Mahar Mangahas and Aida Recto).

Resource Allocation and Productivity in National and International Agricultural Research, The Agricultural Development Council, Inc., New York, September, 1975 (with Thomas T. Arndt).

Thinking About Agricultural Development, University Lecture Series, Texas A&M University, College Station, Texas, October 30, 1975.

Impact of Government regulations on Development of Chemicals Used in Animal Production, Task Force on Impact of Government Regulations on the Development of Agricultural Chemicals, Council of Agricultural Science and Technology, Ames, Iowa, October, 1980.

Impact of Government Regulations on the Development of Chemical Pesticides for Agriculture and Forestry, Task Force on Impact of Regulations on the Development of Agricultural Chemicals, Council for Agricultural Science and Technology, Ames, Iowa, January, 1981.

Toward a Global Agricultural Research System, Douglas-Coldwell Foundation Lecture, Department of Agricultural Economics, University of Saskatchewan, Saskatoon, Canada, March 8, 1985.

5. Notes, Comments and Reviews

"Regional Economics and Economic Development," Abstract in Econometrica, July, 1953, pp. 466-467 (with S.H. Robock).

"Economic Development and Adjustments of Southern Low-Income Agriculture: Comment," Journal of Farm Economics, December, 1954, pp. 1158-1160.

"Review of the Pricing of Cigarette Tobaccos," by Elmo Jackson (University of Florida Press: 1959), Journal of Farm Economics, Vol. 38, February, 1956, pp. 217-219.

"Review of Regional Income," (National Bureau of Economic Research, Conference on Research in Income and Wealth, Vol. 21, Princeton University Press, 1957), Journal of Farm Economics, Vol. 39, November, 1957, pp. 1036-1038.

"Agriculture: A Growth Industry-Decision," Marketing's Role in Scientific Management, American Marketing Association, Chicago, 1957, pp. 591-594.

"The Location of Economic Activity: Discussion," Journal of Farm Economics, Vol. 41, December, 1959, pp. 952-954.

"Review of The Fertilizer Industry," by Jessee W. Markham, (Vanderbilt University Press, Nashville, 1958), Journal of Business, Vol. 33, January, 1960, pp. 64-65.

"Positive Policy in the Fertilizer Industry," Journal of Political Economy, Vol. 63, December, 1960, p. 634.

"Factor Substitution and the Composition of Input: Comment," in Output, Input and Productivity Measurement, National Bureau of Economic Research Studies in Income and Wealth, Vol. 25, Princeton University Press, 1961, pp. 475-480.

"Review of Productivity and Technological Change," by W.E.G. Salter, (Cambridge University Press, Cambridge, 1960), Journal of Farm Economics, Vol. 43, No. 1, February, 1961, pp. 160-162.

"Review of Mechanization in Agriculture," Journal of Political Economy, Vol. 69, No. 4, August, 1961, pp. 416-417.

(Notes, Comments and Reviews continued)

"Rural Development Policies: Comment," Second Annual Farm Policy Review Conference, Agricultural Policy Institute, North Carolina State College and Center for Agricultural and Economic Adjustment, Iowa State University, November, 1961, pp. 126-133.

"Review of Natural Resources and Economic Growth," by J.J. Spengler (ed.), Resources for the Future, Washington, 1961, Journal of Political Economy, Vol. 70, No. 4, August, 1962, pp. 405-406.

"Tomorrow's Critical Manpower Demands: Comments," in Educational Needs for Economic Development of the South, Agricultural Policy Institute, North Carolina State College and Southern Regional Educatoin Board, Agricultural Policy Institute Series, No. 7, October, 1962, pp. 39-44.

"Discussion: Farm and Non-Farm Income Comparisons," Journal of Farm Economics, Vol. 45, No. 2, May, 1963, pp. 381-384.

"Demand," in J. Gould and W.L. Kolb, A Dictionary of the Social Sciences, Free Press of Gelncoe, New York, 1964, pp. 185-197.

"Supply," Ibid., pp. 705-707.

"Introduction," (to Seminar on Savings and Capital Accumulation in Philippine Agriculture), The Philippine Economic Journal, Vol. 3, No. 2, Second Semester, 1964, pp. 110-113 (with E.U. Quintana and A.M. Weisblat).

"Some Issues in the Training of Asia Agricultural Economics Graduate Students in the United States," Journal of Farm Economics, Vol. 47, No. 4, November, 1965, pp. 1024-1026 (with A.M. Weisblat).

"Agriculture--Midway in the 1960's: A Comment," Agricultural Policy Review, Raleigh, Vol. 6, No. 1, January-March, 1966, pp. 8-9. Also in Policies Affecting Rural People, API Series 20, Raleigh, April, 1966, pp. 13-17.

"Economic and Cultural Impact of Advancing Technology: Comment," in Symposium on Research in Agriculture, Symposium sponsored by the U.S. Department of Agriculture and the National Academy of Sciences, USDA, ARS, Washington, August, 1966, p. 85.

"Review of The Economics of Agricultural Development," by John W. Mellor, Ithaca, Cornell University Press, 1966, American Economic Review, Vol. 57, No. 3, June, 1967, pp. 680-681.

"The Distribution of Benefits from Cotton Price Supports: Comment," in Samuel B. Chase, Jr. (ed.), Problems in Public Expenditure Analysis, Brookings Institution, Washington, 1968, pp. 251-254.

"Review of Supply Response in Underdeveloped Agriculture, A Case Study of Four Major Annual Crops in Thailand, 1937-63, by Jere R. Behrman, (North Holland, Amsterdam, 1968), World Crops, December, 1968.

"Review of Campaigns Against Hunger," by E.C. Stakman, Richard Bradfield and Paul C. Mangelsdorf (Cambridge, the Belknap Press of Harvard University Press, 1967), Journal of Economic History, Vol. 28, No. 4, 1968, pp. 738-739.

"The Food-Supply Question," in Science, Vol. 168, May, 1970, pp. 690-691.

"Introduction," in Agricultural Revolution in Southeast Asia, Vol. 1, Impact on Grain Production and Trade, New York: The Asia Society, 1970, pp. 11-12.

"Impact of New Cereal Varieties on Southeast Asia's Pattern of International Relations: Discussion," in Agricultural Revolution in Southeast Asia, Vol. II, Consequences for Development, New York: The Asia Soceity, 1970, pp. 81-82.

(Notes, Comments and Reviews continued)

"Rice Production in Thailand: Comment," World Crops, November-December, 1970, p. 309.

"Review of Arid Lands in Transition," by Harold E. Dregne (ed.), (Washington: American Association for the Advancement of Science, 1970), Science, Vol. 172, May, 1971.

"Review of Land and Peasants in Central Luzon," by Akira Takahashi, (Honolulu, East-West Center Press, 1970), The Asian Student, Spring, 1971, p. 8.

"Review of The Role of Agriculture in Economic Development," by Erik Thorbecke, (ed.), (New York: Columbia University Press, 1969), Economic Development and Cultural Change, Vol. 20, NO. 3, April, 1972, pp. 590-594.

"Review of From Peasant to Farmer: A Revolutionary Strategy for Development," by Raanan Weitz (New York: Columbia University Press, 1972), Monthly Labor-Reveiw, Vol. 95, No. 9, September, 1972, pp. 85-86.

"Review of Agricultural Development in India's Districts," by Dorris D. Brown (Cambridge: Harvard University Press, 1971) and of Agricultural Development Strategies in Asia: Case Studies of the Philippines and Thailand, by Shigeru Ishikawa (Tokyo: The University of Tokyo Press, 1970), Agricultural History, Vol. 46, No. 3, July, 1972, pp. 438-440.

"Professor Rosenberg and the Direction of Technological Change: A Comment," Economic Development and Cultural Change, Vol. 21, No. 2, January, 1973, pp. 352-355 (with Yujiro Hayami).

"Review of Institution Building: A Model for Applied Social Change," by D. Woods Thomas, et al, (eds.), (Cambridge: Schenkman, 1972), International Development Review/Focus, Vol. 15, No. 1, 1973, pp. 15-16.

"Review of Differential Structure and Agriculture: Essays on Dualistic Growth," by Kazushi Ohkawa, (Tokyo: Kinokuniya Bookstore Co., Ltd., 1972), Journal of Economic Literature, Vol. 11, No. 3, September, 1973, pp. 912-914.

"The Role of Marketing and Market Institutions," in T.H. Shen (ed.), Agriculture's Place in the Strategy of Development: The Taiwan Experience, (Taipei: Joint Commission on Rural Reconstruction, July, 1974), pp. 107-113.

"Food production and the Energy Crisis: A Comment," Science, Vol. 187, February 14, 1975, pp. 560-561.

"Money in the Production Function: An Interpretation of Empirical Results," The Review of Economics and Statistics, Vol. 67, May, 1975, pp. 246-247.

"Introduction," to Impact of Fertilizer Shortage: Focus on Asia, (Tokyo: Asian Productivity Organization, 1975), pp. vii-viii.

"Review of Agricultural Policy in Development Countries," by Nurul Islam, (London: MacMillan Press, 1974), Journal of Economic Literature, Vol. 13, No. 3, 1975, pp. 940-941.

"Preface," to Sudhin K. Mukhopadhyay, Sources of Variation in Agricultural Productivity: A Cross Section and Time Series Study in India, (Delhi: MacMillan India, 1976), pp. xi-xii.

"Review of Agriculture in a World Context: Policies and Approaches for the Next Decade," by D. Gale Johnson and John A. Schnittker, (eds.), (New York and London: Praeger, 1974), Economic Development Cultural Change, Vol. 25, No. 1, October, 1976, pp. 194-196.

"Comment," on "The Organization of Research to Improve Crops and Animals in Low Income Countries," by Robert E. Evenson in Theodore W. Schultz (ed.), Distortions in Agricultural Incentives, (Bloomington: Indiana University Press, 1978), pp. 246-253.

"Centralizing and Limiting Information," Society, Vol. 16, November/December, 1978, pp. 13-14.

(Notes, Comments and Reviews continued)

"Review of Hired Hands: Seasonal Farm Workers in the United States," by Stephen H. Sosnick, (Santa Barbara, California: McNally and Loftin, West, 1978), Monthly Labor-Review, Vol. 102, July, 1979, pp. 48-49.

"Review of Agricultural Development of India: Policy and Problems," by C.H. Shad (ed.), (Bombay: Orient Longman Ltd., 1979), Indian Journal of Agricultural Economics, Vol. 35, No. 1, April-June, 1980), pp. 153-156.

"Review of The Open Field System and Beyond: A Property Rights Analysis of an Economic Institution," by Carl J. Bahlman, (New York: Cambridge University Press, 1980), Land Economics 57, August, 1981, pp. 481-482.

"Review of A Plough in Field Arable: Western Agribusiness in Third World Agriculture," by Sarah Potts Voll, (Hanover, New Hampshire: University Press of New England, 1980), The Journal of Economic History 49, December, 1981, pp. 921-922.

"USDA Economics in Disarray," AAEA Newsletter 3, September, 1981, pp. 8-9.

"Review of Population and Technological Change: A Study of Long-Term Trends," by Ester Boserup, (Chicago: University of Chicago Press, 1981), Population and Development Review, Vol. 8, No. 1, March, 1982, pp. 181-183.

"Review of Essays on Technology, Employment and Institutions in Development: Comparative Asian Experience," by Shigeru Ishikawa, (Tokyo: Kinokuniya, 1980), Journal of Development Studies, Vol. 18, July, 1982, pp. 356-357.

"The Adequacy of Agricultural Land-Discussion," in Pierre R. Crosson (ed.), The Cropland Crisis: Myth or Reality," (Baltimore: The Johns Hopkins University Press, 1982), pp. 57-61.

"Comment," in William F. Hyde (ed.), Economic Evaluation of Investments in Forestry Research, (Durham, North Carolina: The Acorn Press, 1983), pp. 91-100.

"The Global Agricultural Support System," Science, Vol. 222, October 7, 1983, p. 11.

"Research on Rural Households with Farm and Non-Farm Sources of Income: A Comment," in Danilo Agostini and Allen Maunder (eds.), Mixed Income Farming, (Padova: Instituto di Estimo Rurale dell'Universito-degli Studi di Padova, 1984), pp. 227-228.

"Government Reseach Policy," Science, Vol. 225, July 20, 1984, pp. 266-268.

"Review of The Ultimate Resource," by Julian Simon, (Princeton, NJ: Princeton University Press, 1981), Economic Development and Cultural Change, Vol. 32, July, 1984, pp. 886-889.

"Review of Understanding Green Revolutions: Agrarian Change and Development Planning in South Asia," Tim P. Bayliss-Smith and Sudhir Wanmali (eds.), (Cambridge: Carmbridge University Press, 1984), pp. 466-467.

6. Public Testimony Documents, and Committee Reports

"Implications of Proposed Rate Changes in the Economy of the Southeast," in Southeastern Association of Railroad and Utility Commissioners et al vs. the Atchison-Topeka and Santa Fe Railway Company et al, ICCI. Docket No. 131874, pp. 3383-3409, November 1, 1956.

"The Potential Contribution of the Rural Development and Social Security Programs to Commercial Agriculture," in Policy for Commercial Agriculture papers submitted by panelists, Joint Economic Committee Print. 85th Congress, 1st Session, U.S. Government Printing Office, Washington,D.C., November 22, 1957, pp. 377-388; Hearings, December 16-20, 1957, U.S. Government Printing Office, Washington, D.C., 1958, pp. 161-165.

(Public Testimony Documents, and Committee Reports continued)

"Statement on Area Re-development," Area Re-development Hearings, Subcommittee on Banking and Currency, United States Senate, 85th Congress, 2nd Session, Part 2, Washington, D.C., February, 1958, pp. 967-973.

"The Economics of Resources," in Research and Development on Natural Resources, Committee on Natural Resources, Federal Council for Science and Technology, Washington, D.C., May, 1963, pp. 108-172 (with Michael Brewer and Subcommittee on Economics of Resources).

"Agricultural and Industrial Extension Services to Diffuse Technical Knowledge," Science, Technology and Development, Vol. IX, Scientific and Technological Policy, Planning and Organization, United States papers prepared for the United Nations Conference on the Application of Science and Technology for Development (Washington, D.C.: U.S. Government Printing Office, 1963), pp. 51-60 (with John C. Green).

"Production Incentives for Farmers," in The World Food Problem, Vol. 2, (A Report of the President's Science Advisory Committee, Panel on the World Food Supply), USGPO, Washington, D.C., May, 1967, pp. 501-535 (with other members of the Subpanel).

"Statement on Bargaining Power for Farmers," Farm Program and Farm Bargaining, Hearings before the Committee on Agriculture and Forestry, United States Senate, 90th Congress, 2nd Session, USGPO, Washington, D.C., 1968, pp. 465-486.

"Production Incentives and the Use of Technical Inputs," in Workshop on Food, (Lonbago Ilmu Pengetahuan, Indonesia, and National Academy of Sciences, USA), National Academy of Sciences, Washington, D.C., November, 1968, pp. 115-130 (with Sjarifuddin Baharsjah).

"Program Analysis and Public Policy," in The Analysis and Evaluation of Public Expenditures: The PPB System, (Joint Economic Committee, Congress of the United States), U.S. Government Printing Office, Washington, D.C., 1969, pp. 1128-1150.

"Statement," on International Development and Food Assistance Act of 1975: Hearings and Markup, Committee on International Relations, House of Representatives, 94th Congress, First Session, (USGPO, Washington, 1975), pp. 394-398.

"Statement," in Presentations Before Regents' Committee on Educational Policy in Regard to Farm Mechanization Research in the University of California, (University of California Board of Regents, 1978), pp. 5-11.

(editor) The Role of TVA Programs in Regional Development, (The 1979 Summer Policy Study), Knoxville: Tennessee Valley Authority, Office of Planning and Budget, March, 1981.

"Statement on Some Lessons from Agricultural Research," Industrial Policy Hearings, Subcommittee on Economic Stabilization, Committee on Banking, Finance and Urban Affairs, United States House of Representatives, Serial No. 98-45, (Washington, D.C.: U.S. Government Printing Office, 1983), pp. 415-455.

"Statement on Some Agricultural Research Policy Issues," Agricultural Research Hearings, Subcommittee on Department Operations, Research and Foreign Agriculture, United States House of Representatives, Serial No. 98-30, (Washington, D.C.: U.S. Government Printing Office, 1984), pp. 316-318, 314-432.

7. Semi-popular, Extension and Trade

"TVA Fertilizer Research Aids Farmer," Economic and Marketing Information for Indiana Farmers, (Purdue University, Agricultural Extension Service, Lafayette, Indiana), May 24, 1955.

"Our Long Run Farm Production Potential," Economic and Marketing Information for Indiana Farmers, June 22, 1956.

(Semi-popular, Extension and Trade continued)

"How to Get Higher Prices for Your Eggs," Economic and Marketing Information for Indiana Farmers, August 27, 1956.

"Should Farmers Change Application Levels as Prices Change?", Commercial Fertilizer, February, 1957 (with Calvin R. Berry).

"Are There Cycles in Canned Tomato Prices?", Canning-Trade, April 22, 1957, pp. 6-7.

"Three Reasons Listed for Accounting Records," Canners Wail, Purdue University Department of Horticulture, 1957.

Vertical Integration in Agriculture, Purdue Agricultural Extension Service Mimeo EC-154, October, 1957 (with Committee on Integration, Purdue Department of Agricultural Economics).

"The Fertilizer Industry in 1965," Indiana Agriculture in 1965, C.B. Cox and J.S. Day (eds.), Indiana Farm Bureau Coop Association, Indianapolis, September, 1957.

"Rural Industry and Economic Development," Farm Policy Forum, Winter, 1958, pp. 29-31.

"Getting the Most for Your Fertilizer Dollar," Economic and Marketing Information for Indiana Farmers, May 29, 1958.

"How Effective is the Rural Development Program?", Farm Policy Forum, Summer, 1958, pp. 25-31 (with J.K. McDermott).

"Cambiamenti tecnici nell'economia degli Stati Uniti," Mercurio, Anno II, N. 6, 15 Guigno, 1959, pp. 7-11.

"Role of Fertilizer in Changing the Agricultural Economy," Agricultural Chemicals, 1960 (with Calvin R. Berry).

"Our growing Output Potential," Economic and Marketing Information for Indiana Farmers, January 29, 1960.

"The Community's Role in Industrial Location," The Arkansas Economist, Vol. 3, No. 3, Spring, 1961, pp. 8-12 (with L.T. Wallace).

"Developments in Plant Location Theory," Industrial Development, Vol. 13, No. 7, June, 1961, pp. 57-59) with L.T. Wallace).

"Bringing Industry to the Depressed Area," Business Horizons, (University of Indiana), Vol. 4, No. 3, Fall, 1961, pp. 82-92 (with L.T. Wallace).

Intermediate and Longer-run Outlook for Farming in Indiana, Purdue University Agricultural Extension Service, Mimeo EC-235, October, 1961 (with Long-run Outlook Committee).

"Concepts and Tools for Analyzing Area Economic Development Opportunities and Activities," in Educational Problems of an Economic Development Program, Federal Extension Service and Agricultural Policy Institute, School of Agriculture, North Carolina State College, Raleigh, January, 1962.

"Technological Change and Resource Utilization in American Agriculture," Proceedings of the-Indiana Academy of Science, 1961, Vol. 7, 1961, pp. 353-360.

"Agriculture in the National Economy," in A Place to Live, the Yearbook of Agriculture, 1963, USGPO, Washington, D.C., 1963, pp. 135-138.

"Agricultural and Industrial Extension Services to Diffuse Technological Knowledge," in Scientific and Technological Policy, Planning, and Organization, Vol. 9 of Science, Technology, and Development. (U.S. papers prepared for the United Nations Conference on The Application of Science and Technology for the Benefit of the Less Developed Areas), USGPO, Washington, D.C., 1963, pp. 51-60 (with J.C. Green).

(Semi-popular, Extension and Trade continued)

"The Economic Analysis of Technological Innovations Using Experimental Data," The Research and Guidance, Vol. 6, No. 1, 1965, Spring Issue, pp. 60-64 (in Korean).

"Agriculture: Puzzles in Plenty and Poverty," in J.R. Coleman (ed.), The Changing American Economy, Basic Books, New York, 1967, pp. 77-89.

"The Contribution of Social Science Research in the Land Grant Agricultural Experiment Stations to International Agricultural Development," Proceedings of Social Science Session of the Kansas Agricultural Experiment Station Conference, Manhattan, January 31, February 1 and 2, 1967, pp. 4-18.

"Are Grain Surpluses a Thing of the Past?", Proceedings of the 15th Regional Extension Grain Marketing Conference, Agricultural Extension Service, Institute of Agriculture, University of Minnesota and United States, Department of Agriculture, Minneapolis, May 17, 18 and 19, 1967, pp. 61-82.

"Agriculture and National Economic Development," Proceedings of the Resource Development Workshop for State Leaders, Agricultural Extension Service, University of Minnesota, Minneapolis, May, 1967, pp. 15-28.

Bargaining Power for Farmers, Staff Paper P68-1, Department of Agricultural Economics, University of Minnesota, St. Paul, May, 1968.

Surplus Capacity in American Agriculture, Minnesota Agricultural Extension Service, Special Report 28, 1968.

"Farm Policy for an Affluent Society: Implications for Minnesota," Commercial West, (Minneapolis), September 21, 1968, pp. 31-34.

"Another Look at the World Food Problem," Minnesota Agricultural Economist, University of Minnesota Agricultural Extension Service, February, 1969, pp. 1-3 (with J.H. Sanders).

"Peasants Respond to Price Incentives," Minnesota Science, Vol. 25, No. 3, Spring, 1969, pp. 4-7.

Agriculture in our Affluent Society, Great Plains Agricultural Council Publication No. 40, (published by the University of Nebraska), 1970 (with Arley Waldo).

"Agricultural Policy Choices in the 1970's: A Historical Perspective," on Policy Choices and the Impact of Agricultural Industry (Proceedings of the Twelfth Annual Agricultural Industries Forum), Urbana-Champaign: University of Illinois, AE4247, November, 1970, pp. 1-10.

"The Green Revolution - among others," Minnesota Daily, May 3, 1971.

"Resource Allocation in Agricultural Research," in Relevant Agricultural Research for the Seventies, (Proceedings, Twentieth Annual Meeting of the Agricultural Research Institute, October, 1971), Washington,D.C.: National Academy of Sciences, 1972, pp. 37-44. (See also Workshop on Research Resource Allocation, CSRS-USDA, Beltsville, January, 1971, pp. 8-20.)

"Rice Policies in the 1970's: A Perspective on the IRRI Conference," in Randolph Barker 9ed.), Viewpoints on Rice Policy in Asia, International Rice Research Institute, College, Laguna, Philippines, 1971. (Reprinted in Congressional Record, November 15, 1971; The Washington Agricultural Record, April 24, 1972, pp. 378-390.)

"Programm und Politik des Amerikanischen Agricultural Development Council," Zeitschrift Fur Auslondische Landwirtschaft, Jahrgang 14, Heft 1, 1975, pp. 87-92.

"Priorities in Agricultural Economics as a Result of the World Food Challenge," National Association of Colleges and Teachers of Agriculture (NACTA) Journal, Vol. 19, June, 1975, pp. 15-17.

(Semi-popular, Extension and Trade continued)

"The Role of Economic Research in Agricultural Development," Minnesota Agricultural Economist, University of Minnesota Agricultural Extension Service, July, 1978, pp. 3-6.

"Who Will Feed Tomorrow's Hungry," Agenda, Washington, Agency for International Development, September, 1978, pp. 7-11.

"International Rural Development: A Skeptical Perspective," in Patrick Moncrioff (ed.), Managing Rural Development (Pointe Claire, Quebec: MacDonald Steward Institute of Agriculture, June, 1978), pp. 15-29.

"Thinking About Agricultural Development," in Luther Pickrel (ed.), Food and Agricultural Policy Issues, St. Paul, University of Minnesota Agricultural Extension Service, 1978, pp. 116-126.

"Bureaucratic Productivity: The Case of Agricultural Research," Ag World 5, March/April, 1979, pp. 1-7.

"How the World Feeds Itself," in Luther Pickrel (ed.), Critical Issues for Agriculture in the 1980's; Domestic Policy, Trade and Transportation, St. Paul, University of Minnesota Agricultural Extension Service, Special Report 79, 1979, pp. 194-200.

"The Returns to Research," The Minnesota Seed Grower, 53, April, 1980, pp. 1-4.

"Food Strategies for Grain Deficit Countries," Agribusiness Worldwide, February/March, 1980, p. 1-4. Also in E.W. Turchniewicz (ed.), The New Era in World Agricultural Trade: Perspectives for the Prairies and Great Plains, Department of Agricultural Economics and Farm Management, University of Manitoba, Winnipeg, September, 1980, pp. 41-50.

"Can Productivity Growth in Agriculture Be Continued?", Minnesota Agricultural Economist, University of Minnesota Agricultural Extension Service, July, 1980, pp. 2-3.

"Soybean Yield Trends in Minnesota," Minnesota Agricultural Economist, University of Minnesota Agricultural Extension Service, July, 1980, pp. 4-7.

"How the World Feeds Itself," Society 17, September/Octover, 1980, pp. 62-67. (Reprinted in Carl K. Eicher and John M Staatz, Agricultural Development in the Third World (Baltimore: Johns Hopkins University Press, 1984), pp. 38-45.

"Are We Blighting the Land that Feeds Us," Corporate Report: Minnesota, Vol. 13, No. 6, June, 1982, pp. 44-46, 162 (with Harlan Cleveland, Willard W. Cochrane, William E. Larson, Philip M. Raup).

"Some Concerns About Agricultural Research Policy," Information from NISARC Meeting (Clemson, South Carolina: National Industry-State Agricultural Research Council, November, 1982), pp. 28-42.

"Planting the Seeds of Farm Progress," Minneapolis Star and Tribune, May 4, 1983, p. 19A.

"The Role of Agricultural Research in Economic Development," PIDE Tidings (Pakistan Institute of Development Economics), 4, January-February, 1984, pp. 3-6.

"Our Egalitarian Hierarchs," The Wall Street Journal, November 26, 1984, p. 33.

8. Thesis Chairman For:

Master's Thesis

Laird, Wallace Franklin, "An Analysis of Factors Affecting Egg Prices in Three Regions of Indiana," Master of Science, Department of Agricultural Economics, Purdue University, June, 1956.

(Thesis Chairman For: Master's Thesis continued)

Ritchey, James Frederick, "The Marketing of Indiana Tomatoes and Tomato Products," Master of Science, Department of Agricultural Economics, Purdue University, January, 1958.

Fishel, Walter Lee, "Efficiency, Size, and Costs in Indiana Tomato Canning Factories," Master of Science, Department of Agricultural Economics, Purdue University, January, 1958.

Sisler, Daniel Gene, "The Effect of Urbanization on Farm and Non-Farm Income in the United States," Master of Science, Department of Agricultural Economics, Purdue University, January, 1959.

Geschwind, Richard Dale, "Adjustment of Labor Resources in Indiana Agriculture, Master of Science, Department of Agricultural Economics, Purdue University, June, 1961.

Mangahas, Mahar, "The Response of Philippine Rice farmers to Price," Department of Economics, University of the Philippines, 1965.

Recto, Aida M., "Price and Market Surplus Relationships for Corn in the Philippines," Department of Economics, University of the Philippines, 1965.

Traxler, Gregory, J., "The Contribution of World Bank Assistance to Agricultural and Rural Development in Pakistan," Department of Agricultural and Applied Economics, University of Minnesota, 1985.

Doctor's Thesis

Berry, Calvin B., "An Economic Analysis of Fertilizer Marketing and Pricing with Particular Reference to Indiana," Doctor of Philosophy, Department of Agricultural Economics, Purdue University, January, 1958.

Olson, Phil, "Socio-economic Factors Affecting Labor Mobility in an Indiana Rural Community," Doctor of Philosophy, Department of Agricultural Economics, Purdue University, June, 1959.

Koch, Robert, "Interregional Competition in the Tomato Processing Industry," Doctor of Philosophy, Department of Agricultural Economics, Purdue University, January, 1959.

Wallace, L.T., "Factors Affecting Industrial Location in Southern Indiana," Doctor of Philosophy, Department of Agricultural Economics, Purdue University, August, 1960.

Headley, Joseph Charles, "The Contribution of Supplemental Irrigation to Agricultural Output in the Eastern United States," Doctor of Philosophy, Department of Agricultural Economics, Purdue University, January, 1960.

Hussey, Gorham W., "The Competitive Potential of the Indiana Watermelon Industry," Doctor of Philosophy, Department of Agricultural Economics, Purdue University, January, 1963.

Arromdee, Virach, "Economics of Rice Trade Among Countries of Southeast Asia," Department of Agricultural Economics, University of Minnesota, July, 1968.

Ban, Sung Hwan, "Long-run Productivity Growth in Korean Agriculture," Department of Agricultural Economics, University of Minnesota, July, 1971.

Sanders, John H., "Mechanization and Employment in Brazilian Agriculture, 1950-71," Department of Economics, University of Minnesota, 1973.

Yamaguchi, Mitoshi, "Technical Change and Population Growth in the Economic Development of Japan," Department of Agricultural Economics, University of Minnesota, 1973.

Yamashita, Sachiko, "An Exploration of the Economics of Taste and Demand for Food," Department of Agricultural and Applied Economics, University of Minnesota, 1973.

(Thesis Chairman For: Doctor's Thesis continued)

Wade, William W., "Institutional Determinants of Technical Change and Agricultural Productivity Growth: Denmark, France and Great Britain," Department of Agricultural and Applied Economics, University of Minnesota, 1973.

Pudasaini, Som P., "The Contribution of Education to Agricultural Productivity, Efficiency, and Development in Nepal," Department of Agricultural and Applied Economics, University of Minnesota, 1981.

Miner, Alan G., "The Contribution of Weather and Technology to U.S. Soybean Yields," Department of Agricultural and Applied Economics, University of Minnesota, 1982.

Hatch, Luther U., "The Effect of Environmental Protection Agency Regulation on Research and Development in the Pesticide Industry," Department of Agricultural and Applied Economics, University of Minnesota, 1982.

Nagy, Joseph G., "The Pakistan Agricultural Development Model: An Economic Evaluation of Agricultural Research and Extension Expenditures," Department of Agricultural and Applied Economics, University of Minnesota, 1984.

Ranola, Roberto de la Ruente, "Cropping System Determinants: Factors Influencing Cropping Patterns, Fertilizer-Use and Resource-Use Efficiency," Department of Agricultural and Applied Economics, University of Minnesota, 1984.

Salmon, David C., "An Evaluation of Investment in Agricultural Research in Indonesia: 1965-1977," Department of Agricultural and Applied Economics, University of Minnesota, 1984.

Wong, Lung Fai, "A Comparative Analysis of Agricultural Productivity Growth Among Socialist Countries," Department of Agricultural and Applied Economics, University of Minnesota, 1985.

Fox, Flenn, "Optimal Public Investment in U.S. Agricultural Research: A Study in the Management of Technical Change," Department of Agricultural and Applied Economics, University of Minnesota, 1985.