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TWO CHAPTERS

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*The two papers in this Bulletin were prepared for the forthcoming book edited by Bruce M. Koppel, Induced Innovation Theory and International Agricultural Development: A Reassessment (Baltimore : The Johns Hopkins University Press, forthcoming 1984). The book contains a series of papers which critique, assess, and extend the theory of induced technical and institutional change. In the first paper (Chapter 1) we review the evolution of ideas and the progress of our collaboration in extending and testing the theories of induced technical and institutional change. In the second paper (Chapter 10) we respond to the critics' comments or suggestions for advancing the theory and suggest some productive areas for further research.

Chapter 1

Induced Innovation Theory and Agricultural Development: A Personal Account

by

Vernon W. Ruttan and Yujiro Hayami

The collaboration that lead to our work on induced technical and institutional change began when Yujiro Hayami spent the 1967/68 and 1968/69 academic years as Visiting Professor in the Department of Agricultural and Applied Economics at the University of Minnesota.

Our initial collaboration was a paper dealing with the effect of Japanese colonial policy in Korea and Taiwan on rice production in Japan.[1] We then collaborated on two additional articles, one using a production function framework to account for agricultural productivity differences among countries[2] and a second article, in which we elaborated and tested a preliminary version of the induced technical change hypothesis against historical experience in both Japan and the United States,[3] We then began outlining a joint research program that lead to the elaboration and further testing, in our book on Agricultural Development, of the induced technical change hypothesis.[4]

We each brought to this collaboration, a substantial body of research on technical change and productivity growth in agriculture. Ruttan had published a paper in the mid-1950s challenging the pessimistic views that were prevalent at that time concerning the future of agricultural production capacity in the United States.[5] This was followed by a series of papers during the late 1950s and 1960s that attempted to refine and interpret measures of agricultural productivity growth in U.S. agriculture at both the regional and national levels.[6] In addition, Ruttan brought to the collaboration several years of research in southeast Asia where he was an economist with the Rockefeller Foundation at the International Rice Research Institute (IRRI). There he had conducted research on issues related to the design and introduction of the new seed-fertilizer technology being developed by the IRRI.[7]

Hayami also brought to the collaboration a substantial body of research on technical change in Japanese agriculture. His initial papers were on the development of the Japanese fertilizer industry and its role in enhancing agricultural productivity growth in Japan.[8] The paper drew from his contribution to a volume on agriculture of the monumental Long-Term Economic Statistics of Japan (LTES) organized and edited by Kazushi Ohkawa.[9] Before arriving at the University of Minnesota, he had embarked upon an exceedingly ambitious effort, in the spirit of earlier work by Colin Clark, to assemble a complete set of agricultural sector input, output and productivity data on a global basis and to estimate cross country "meta-production functions" which would then serve as a basis for efforts to "account" for the sources of differences in land and labor productivity among countries.[10]

We first met in Tokyo in the summer of 1966. Ruttan had been attracted by a survey article by Hayami on the role of the technical change in agriculture which he had been asked to review.[11] Ruttan arranged to stop in Tokyo, while en route to the Philippines, to talk to Hayami about his work. Our mutual work on productivity growth and our emerging sensitivity to the role of factor endowments in shaping the direction of technical change resulted in a highly stimulating exchange. This exchange was continued in the summer of 1968, at a conference in Japan on the role of technical change in the history of Japanese agriculture.[12]

Our growing sensitivity to the significance of differences and changes in relative resource endowments and relative factor prices drew on several sources. Ruttan had been very impressed by a lecture by H.J. Habakuk at Purdue in 1963 on the history of British and American technology.[13] We were both were familiar with the articles by Earl O. Heady (1954) and Amartya Sen (1959) that had employed the concept of "landesque" (land saving) and "laboresque" (labor saving) capital.[14]

We were, however, influenced even more directly by our own experience and research. Hayami had been impressed by the response of Japanese rice breeders to the long term decline in the price of fertilizer relative to land in Japan by breeding "fertilizer consuming" rice varieties. While working at the IRRI, Ruttan was impressed with the tendency for the international group of scientists at IRRI to carry with them, etched in their subconscious, the relative factor endowments of their home countries.[15]

We were also familiar with John R. Hick's 1932 pronouncement, in The Theory of Wages, to the effect that changes or differences in relative prices of factors of production could be expected to influence the relative labor saving direction of technical change[16] and with the criticism of Hick's assertion by W.E.G. Salter.[17] Salter had argued, in effect, that entrepreneurs were interested in profitability "from whatever source" and that, while changes in relative factor prices might effect the choice of technology, they could not be expected to result in a bias in the direction of inventive activity. We noted in our 1970 Journal of Political Economy article that Salter's result was based upon an excessively broad definition of technical change. We did not however become aware of the important debate in the theoretical literature beginning in the mid-1960s, centering around the issue of induced technical change, until our own formulation and initial testing of the theory was well underway.

In the mid-1960s, seminal articles by Charles Kennedy and Syed Ahmad had staked out alternative versions of the theory of induced technical change.[18] The initial drafts of the articles were written while Kennedy was teaching at the University of the West Indies (Kingston) and Ahmad was teaching at the University of Khartoum (Sudan). Ahmad submitted his article to the Economic Journal in 1963. Kennedy served as a reviewer of the Ahmad article. His article, which was published in 1964, was originally written as a comment on the Ahmad article. The Ahmad article was initially rejected. A revised version was re-submitted and published in 1966. The Kennedy version, was cast within the context of contemporary growth theory. It was presented as a contribution to the solution of the puzzle about the seeming stability of the factor shares of labor and capital in spite of rapid substitution of capital for labor. The Ahmad version was built directly on the Hicks microeconomic foundation. When we became aware of the Kennedy and Ahmad articles, and the series of exchanges that had gone on in the literature, we very rapidly assimilated the Ahmad micro-economic version into our own work. In our judgement the Kennedy growth theory approach could not serve as a productive foundation for empirical research.[19]

As we completed the first several articles referred to above, our conversations gradually turned toward writing a book on agricultural development in which the theory of induced technical change would serve as the organizing theme. As we proceeded with our writing, it became clear that the induced technical change theme could provide the structure needed to integrate a large body of theoretical and empirical research on agricultural development.

One of our objectives was to develop a single model of agricultural development that would be able to incorporate historical agricultural development experience in both the presently developed and less developed countries. This involved integrating a number of models that had been proposed to interpret the process of agricultural development during specific epochs in particular countries or regions. These earlier models were identified as the conservation, urban-industrial impact, diffusion, and high pay-off input models. We also wanted to be able to incorporate the location specific characteristics of agricultural technology in the model. Our personal experience, and our reading of the technical literature, had convinced us that, by and large, agricultural technology must be invented in the agroclimatic and socioeconomic environment in which it is to be used. These observations, combined with the induced innovation framework, turned out to be exceedingly powerful in interpreting the alternative paths of technological change which we observed, both among the presently developed and developing countries and among developing countries characterized by different resource endowments.

Our book on Agricultural Development was published in 1971. It was generally well received. We were, however, surprised that some reviewers interpreted our findings as implying that technical change in agriculture could be left primarily to the private sector -- guided by the invisible hand of the market. The inference was apparently drawn from our demonstration that the path of technical change in both Japan and the United States had been induced by relative resource endowments interpreted through changes or differences in relative factor prices (Figure 1 and Figure 2). A careful reading of our book should have made it clear, however, that our purpose in attempting to understand the role of resource endowments and market forces in directing technical change was to be able to design the policies and institutions that would lead to more efficient paths of technical change.

We were also somewhat surprised at the strong negative reaction to our research by a number of scholars writing in the "political economy" or neo-Marxian tradition. We expected that our analysis, particularly of the relationship between resource endowments and the direction of technical change and our analysis of the relationships between technical and institutional change would find a more sympathetic hearing from the political economy school.[20]

It became clear to us fairly soon, however, that we should not remain too satisfied with the adequacy of the induced technical change model to interpret the process of technical change in agriculture. Much of agricultural research, particularly the research leading to advances in biological technology, was produced by public sector institutions -- research institutes, experiment stations and universities. The induced technical change model represented a modest extension of the neoclassical theory of the firm. We were using the theory of the firm to explain the innovative behavior of public sector bureaucratic organizations! But there was no available theory of bureaucratic productivity. Indeed the prevailing orthodoxy denied even the possibility of innovative behavior in the public sector.[21] We had, in the book, suggested the elements of a theory of induced institutional change. But it represented primarily a suggestion for future research.[22]

In the early 1970s, Ruttan began a collaboration with Hans P. Binswanger that lead to the development more rigorous tests of the induced technical change hypothesis and to a more intensive effort to interpret institutional change within the induced innovation framework. In 1970, while a student at North Carolina State University Binswanger attended a seminar in which Ruttan presented the Hayami-Ruttan tests of the induced technical change hypothesis. He later wrote a term paper in which he argued that while the Hayami-Ruttan results appeared plausible their tests were not able to distinguish between price induced factor substitution and induced technical change. While searching for a thesis topic he discovered an article by Ryuzo Sato, written in 1970, that presented a rigorous two factor (labor and capital) test.[23] Binswanger hypothesized that if induced technical change could be distinguished from factor substitution for the two factor case it should also, in principle, be possible to design a multi-factor test. He proceeded to develop a generalized multi-factor test which later, using a translog production function, he operationalized as a four factor test (land, labor, fertilizer, and power). The test was first applied against United States and Japanese experience and reported in his 1973 Ph.D. thesis.[24]

The method employed by Hayami and Ruttan was, in retrospect, more of a plausibility test, relying on the consistency between microeconomic observations of experimental results and sectoral level statistical associations, than a fully integrated rigorous test of the hypothesis. The method developed by Binswanger partitioned the historical changes in factor shares into two components. One component reflected the change due to pure substitution effects -- the result of choice of technology in response to changing relative prices along a given production function. The second component represented the change in the factor share resulting from shifts in the production function itself. This enabled him to determine whether this second component of the factor share shift was consistent or inconsistent with induced technical change.

Following the completion of his thesis at North Carolina State University, Binswanger spent the 1972/73 academic year at the University of Minnesota. While at Minnesota Binswanger published a series of exceedingly important papers drawing on his thesis research.[25] Binswanger and Ruttan also began discussing the possibility of a book that would include tests of the induced technical change hypothesis against Western European and Latin American experiences. The book would be a thorough review and evaluation of the burgeoning theoretical literature on induced technical change, and on application of the more rigorous tests of the model developed by Binswanger plus an attempt to extend the elements of a model of induced institutional innovation.

As their discussions were getting underway, Ruttan left the University of Minnesota to become President of a small private foundation, the Agricultural Development Council (ADC). The program of the Council focused on strengthening rural social science research and graduate education capacity in Asia. Binswanger accepted an appointment as ADC associate in India and was located at the International

Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Hyderabad (India). At ICRISAT he initiated, in collaboration with several colleagues, a series of large village level studies. These changes in institutional affiliations and responsibilities slowed work on the proposed book, which was finally completed and published in 1978.[26]

During the early and mid-1970s, Yujiro Hayami and several collaborators were also engaged in a series of studies designed to advance the theory of induced institutional innovation and test it against Southeast Asian experience. Hayami spent 1974-1976 as economist at the International Rice Research Institute in the Philippines. While at IRRI he initiated, with Masao Kikuchi a series of studies of village level changes in land tenure and labor relations.[27] The studies provided both a more fully elaborated theory of induced institutional innovation and carefully constructed microeconomic tests of the hypothesis.[28] The Hayami and Kikuchi analysis also drew on the work of the public choice theorists for inspiration, including the work of Harold Demsets on property rights, of Mancur Olson on collective action, of Gary Becker on social interactions, and of Ronald Coase, Oliver Williamson, Steven Cheung and others on the role of risk and transaction costs in shaping economic organization.[29] We were also deeply influenced by the broad historical work of Douglas North and his associates.[30] Our work went beyond the earlier literature, however, in explicitly distinguishing between the sources of demand and supply of institutional change. The sources of demand for institutional change included changes in resource endowments and changes in technology. Ruttan, in the book with Binswanger, had identified advances in social science knowledge as an important source of the supply of institutional change and had elaborated this perspective in a series of articles.[31]

As our work with other collaborators was maturing, we began in the late 1970s to discuss writing a second edition of our book on Agricultural Development that would incorporate the new research on induced technical and institutional change and the experience of agricultural development between the mid-1960s and the early 1980s.

By this time Hayami had returned from IRRI to Tokyo Metropolitan University and Ruttan had returned to the University of Minnesota. In the early 1980s, we prepared a revised outline and started to exchange chapters of the revision. The Rockefeller Foundation awarded us a joint fellowship that enabled us to spend a month at the Foundation's Bellagio Center in Italy to argue out our differences and coordinate our revisions. In preparing the new edition, we were able to draw upon longer time series data for Japan and the United States (1880-1980), a broader set of country studies, and on the advances in methodology that had occurred since the mid-1960s.

The new edition contained separate a chapter on induced technical and institutional innovation.[32] The model of induced institutional change maps the general equilibrium relationships among resource endowments, cultural endowments, technology and institutions (Figure 3). The empirical testing of the model remained incomplete. The recursive relationship among the several elements of the model do not lend themselves to econometric testing as readily as the earlier induced technical change hypothesis. Historical and case studies have been the primary methodological approach. The revised edition of our book was published in 1985.[33]

While preparing the second edition Hayami was also engaged in collaboration with Kym Anderson in an effort to utilize the induced institutional change perspective to interpret the emergence of protectionist import substitutions policy in Japan and the other rapidly developing economies of East Asia.[34] Ruttan was applying the induced technical and institutional change perspective in an analysis of agricultural research organization and to the reform of agricultural research policy.[35]

By the mid 1980s the induced technical change model had been successfully tested against the experience of a large number of developed market economies.[36] Ruttan, in cooperation with several students had initiated a program to test the induced technical change model in the centrally planned economies.[37] In a review of the literature on agricultural development, C. Peter Timmer used the induced technical model as the universal paradigm for the interpretation of the role of technical change in agricultural development.[38]

In retrospect several things stand out during our collaboration that now extends back almost twenty five years. One is how difficult it now is to identify which of us has been responsible for particular contributions. As we were working on the second edition, we found that we were frequently attributing the same contributions in the first edition to the other person.

By the time the second edition of the book was in print, our work was also coming under increased scrutiny. Some of the more critical evaluations are included in this volume. We will return, at the end of this book, to an evaluation of the comments and criticisms, and we will also outline some of our own concerns and suggest some priorities for the induced innovation research agenda.

Among the concerns that we will deal with are the following:

* The lack of a theory of action. The inducements that lead individuals - farmers, mechanics, research scientists, planners - to respond to changes in their external environment - to changes in resource and cultural endowments to bring about changes in technology and institutions remains largely a black box.

* We have been fairly successful in explaining the rate and direction of technical and institutional change when it occurs. But we have very little to say about those societies where progressive technical and institutional change is not occurring or, in some cases, is regressing.

* We, and our colleagues, have not yet developed and tested a well integrated model of (a) the theory of "factor induced" technical change, which explains the direction of technical change and (b) of the theory of "demand induced" technical change which explains the rate of technical change. Nor have we yet effectively integrated the theory of induced innovation with the theory of trade. This is a serious incompleteness since relative resource endowments play such a dominant role in both the trade theory and the theory of technical change.

ENDNOTES

[1]Vernon W. Ruttan and Yujiro Hayami, "Korean Rice, Taiwan Rice and Japanese Agricultural Stagnation: An Economic Consequence of Colonialism," The Quarterly Journal of Economics 84 (November 1970), pp. 562-589.

[2]Yujiro Hayami and Vernon W. Ruttan, Agricultural Productivity Differences Among Countries", The American Economic Review 60 (December 1970), pp. 895-911. It was at this time that we introduced the term "meta-production function" in referring to the frontier production function.

[3]Yujiro Hayami and Vernon W. Ruttan, "Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880-1960," The Journal of Political Economy 78 (September-October, 1970) pp. 1115-1141.

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

[5]Vernon W. Ruttan, "The Contribution of Technological Progress to Farm Output: 1950-75," Review of Economics and Statistics 38 (February 1956), pp. 61-69.

[6]Vernon W. Ruttan, "Agricultural and Non-Agricultural Growth in the Output Per Unit of Input," Journal of Farm Economics 40 (May 1958), pp. 196-207; Thomas T. Stout and Vernon W. Ruttan, "Regional Differences in Factor Shares in American Agriculture," Journal of Farm Economics, 41 (February 1960), pp. 52-68; Vernon W. Ruttan, "Research on the Economics of Technical Change in American Agriculture," Journal of Farm Economics, 42 (November 1960), pp. 735-754.

[7]See for example, Vernon W. Ruttan and James E. Moomow, "Partial Budgeting of Costs and Returns Using Experimental Data From Herbicides and Fertilizer Experiments," The Philippine Agriculturalist, 48 (November-December 1964); Vernon W. Ruttan, "Tenure and Productivity of Philippine Rice Producing Farms," The Philippine Economic Journal, 5 (First Semester, 1966), pp. 42-63; Vernon W. Ruttan, Aida E. Recto and Mahar Mangahas, "Price and Market Relationships for Rice and Corn in the Philippines, " Journal of Farm Economics, 48 (August 1966), pp. 685-703.

[8]Yujiro Hayami, "Demand for Fertilizer in the Course of Japanese Agricultural Development," Journal of Farm Economics 46 (November 1964), pp. 776-79; "Innovations in the Fertilizer Industry and Agricultural Development: The Japanese Experience," Journal of Farm Economics 49 (May 1967), pp. 403-12.

[9]Kazashi Ohkawa, Miyohei Shinohara and Mataji Umemora (eds.) Estimates of Long-Term Economic Statistics of Japan Since 1868, Vol. 9 (Tokyo: Toyo Keizai Shimposha, 1966).

[10]Yujiro Hayami, "Industrialization and Agricultural Productivity: An International Comparative Study," Developing Economies (March 1969), pp. 3-21; Yujiro Hayami and Kinuyo Inagi, "International Comparison of Agricultural Productivities," Farm Economist, 11 (1969), pp. 407-19.

[11]The article had been commissioned by John Dillon for a survey volume on agricultural economics literature. The Dillon project was never brought to completion. however, the manuscript was later revised and published in collaboration with Willis Peterson. See Willis Peterson and Yujiro Hayami, "Technical Change in Agriculture" in Lee R. Martin (ed.) A Survey of Agricultural Economics Literature vol. 1 (Minneapolis: University of Minnesota Press, 1977), pp. 497-540.

[12] See Kazushi Ohkawa, Bruce F. Johnston and Hiromitsu Kaneda (eds.), Agriculture and Economic Growth: Japan's Experience (Tokyo: University of Tokyo Press, 1969).

[13]H. J. Habakuk, American and British Technology in the Nineteenth Century: The Search for Labor Saving Inventions (Cambridge: Cambridge University Press, 1962).

[14]Earl O. Heady, "Basic Economical Welfare Aspects of Farm Technological Advance," Journal of Farm Economics 31 (May 1949), pp. 293-316. Hayami had studied with Heady at Iowa State University. Ruttan had written a critique of the Heady article which was not accepted for publication by the Journal of Farm Economics; Amartya K. Sen, "The Choice of Agricultural Techniques in Underdeveloped Countries," Economic Development and Cultural Exchange 7 (April 1959), pp. 279-85. Also Choice of Techniques: An Aspect of the Theory of Planned Economic Development (Oxford: Basil Blackwell, 1960).

[15]It may be useful to cite a somewhat amusing example. At an IRRI semi annual internal research review in 1964, the Japanese plant physiologist (Akira Tanaka) and the American agronomist (James Moomow) reported sharply different results from the same experiment carried out in the same environment. Tanaka reported a classic "S" shaped yield response to fertilizer. Moomow reported a rather flat inverted "U" shaped response. After considerable discussion, the agricultural engineer, Lloyd Johnson, and Ruttan suggested that Tanaka and Moomow were controlling for the independent variables that interested them, in this case fertilizer, and doing "whatever else it took to make a good experiment." Tanaka came from a traditionally low-wage, labor surplus economy. He employed a very labor intensive system of weed control. Moomaw, accustomed to working in a labor scarce high-wage economy, waited until the weed infestation had become competitive with the rice and then applied herbicide -- and killed some rice plants as well as the weeds. There were also differences in views regarding the relative emphasis that should be given to green manure as a source of soil fertility that reflected the relative land resource endowments of their home countries.

[16]John R. Hicks, The Theory of Wages (London-Macmillan, 1932), p. 125.

[17]W.E.G. Salter, Productivity and Technical Change (Cambridge: Cambridge University Press), p. 43. Ruttan had reviewed the Salter book in the Journal of Farm Economics 43 (February, 1961), pp. 160-162.

[18]The key articles in the "growth theory" and "microeconomic" approaches were: Charles Kennedy, "Introduced Bias in Innovation and the Theory of Distribution," Economic Journal, 74 (September 1964), pp. 541-47; Syed Ahmad, "On the Theory of Induced Innovation," Economic Journal, 76 (June 1966), pp. 344-57. The best review and evaluation of this controversy, which extended from the mid-1960s to the mid-1970s is by Hans P. Binswanger in Hans P. Binswanger and Vernon W. Ruttan, (and others), Induced Innovation: Technology, Institutions and Development (Baltimore: Johns Hopkins University Press, 1978), pp.13-43. In our judgement the Ahmad contribution received less attention than it deserved in part because of his unlikely location, the University of Khartoum, at the time his article was published.

[19]The Kennedy version incorporated a fixed innovation possibility trade off. It is of some interest that neither Ahmad or Kennedy had thought of their work as even potentially productive of empirical research. They were both primarily concerned with the factor share stability puzzle -- a puzzle that disappeared shortly after the Kennedy and Ahmed articles were published.

[20]See Edmund K. Oasa and Bruce H. Jennings, "La naturaleza de la Investigacion Social en la Agricultura Internacional: Le Experiencia Norte Americana, el IRRI el CIMMYT (The Nature of Social Inquiry in International Agricultural Research: A Reproduction of the American experience at IRRI and CIMMYT), El Trimestre econômico 49 (October-December, 1982), pp. 975-1002. For a more sympathetic perspective, also written from a "political economy" perspective see Paolo Palladino, "Science for Whom? Agricultural Development and the Theory of Induced Innovation", Agriculture and Human Values 4 (Spring/Summer 1987), pp. 53-64.

[21]Orthodox economic doctrine had held that institutional innovation was not the appropriate concern of economics. According to Paul Samuelson: "The auxiliary constraints imposed upon the variables are not themselves the proper subject of welfare economies, but must be taken as given." Paul A. Samuelson, Foundations of Economic Analyses (Cambridge, MA: Harvard University Press, 1948), pp. 221-222.

[22]For an initial attempt to apply the induced institutional change framework outside of agriculture, see Vernon W. Ruttan, "Technology and the Environment," American Journal of Agricultural Economics, 53 (December 1971), pp. 707-717.

[23]Ryuzo Sato, "The Estimation of Biased Technical Progress and the Production Function," International Economic Review 11 (1970), pp. 179-208.

[24]Hans P. Binswanger, "The Measurement of Biased Efficiency Gains of U.S. and Japanese Agriculture to Test the Induced Innovation Hypothesis," Ph.D. Dissertation, North Carolina University Press, Raleigh, 1973.

[25]Hans P. Binswanger, "A Cost Function Approach to the Measurement of Elasticities of Factor Demand and Elasticities of Substitution," American Journal of Agricultural Economics 56 (1874), pp. 377-386; "A Microeconomic Approach to Induced Innovation," Economic Journal 84 (1884), pp. 940-958); "The Measurement of Technical Change Biases With Many Factors of Production," American Economic Review, 64 (1974), pp. 969-976.

[26]Hans P. Binswanger, Vernon W. Ruttan (and others), Induced Innovation: Technology, Institutions and Development (Baltimore: Johns Hopkins University Press, 1978). For the test of the model against Western European historical experience see Vernon W. Ruttan, Hans P. Binswanger, Yujiro Hayami, William Wade and Adolf Weber, "Factor Productivity and Growth: A Historical Interpretation," Ibid, pp. 44-72; for the Latin American tests see Alain de Janvry, "Social Structure and Biased Technical Change in Argentine Agriculture," Ibid, pp. 297-323; John Sanders and Vernon W. Ruttan, "Biased Choice of Technology in Brazilian Agriculture" Ibid, pp. 276-296.

[27]Masao K. Kikuchi and Yujiro Hayami, "Inducements to Institutional Innovation in an Agrarian Community," Economic Development and Cultural Change, 29 (October 1980), pp. 21-36; Yujiro Hayami and Masao Kikuchi, Asian Village at the Crossroads: An Economic Approach to Institutional Change, (Tokyo: University of Tokyo Press, 1981, and Baltimore, Johns Hopkins University Press, 1982).

[28]The plausibility of the hypothesis was reinforced by study of long-run institutional change in Thai agriculture by David H. Feeny, Technical and Institutional Change in Thai Agriculture, 1880-1940 (Ph.D. Dissertation, University of Wisconsin, 1976).

[29]Harald Demsets, Toward A Theory of Property Rights, American Economic Review 42 (Way 1967), pp. 347-359; Mancur Olson, The Logic of Collective Action (Cambridge, Mass.: Harvard University Press, 1965); Ronald H. Coase, "The Nature of the Firm," Economica y (1937), pp. 386-405; Oliver E. Williamson, Markets and Hierarchies (New York: Free Press, 1975); Steven N.S. Cheung, The Theory of Share Tenancy (Chicago: University of Chicago Press, 1969); Gary S. Becker, "A Theory of Social Interactions" Journal of Political Economy 82 (1974), pp. 1063-1093.

[30]Douglas C. North and Robert Paul Thomas, "An Economic Theory to the Growth of the Western World" The Economic History Review 22 (1970), pp. 1-17. Also The Rise of the Western World (London: Cambridge University Press, 1973).

[31]Vernon W. Ruttan, "Institutional Innovation," in Theodore W. Schultz (ed.), Distortions of Agricultural Incentives, Bloomington, IN: Indiana University Press, 1978, pp. 290-306; Vernon W. Ruttan, "Three Cases of Induced Institutional Innovation" in Clifford S.

Chapter 10

INDUCED INNOVATION THEORY AND AGRICULTURAL DEVELOPMENT: A REASSESSMENT*

Yujiro Hayami and Vernon W. Ruttan**

In this chapter we first respond to the several criticisms that have been made in our work on induced innovation. We then comment on the suggested new directions for research advanced in the several papers in part three of the volume. Finally we suggest several suggestions for further development of the induced innovation research agenda.

The reader is asked to keep in mind that the theory of induced innovation - of induced technical and institutional change - is part of a broader research agenda in economics and the social sciences to develop a fully endogenous theory of economic development.

The Critical Applications: Some Comments

In his chapter on "Induced Innovation and Agricultural Research in South Korea: A Reassessment" Larry L. Burmeister suggests that a "directed innovation" model is more effective in interpreting the rate and direction of technical change in Korean rice production than the induced innovation model. He distinguishes two variants of the

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induced innovation model - "pure" induced innovation occurs when economic and political markets function efficiently - when they provide accurate signals about demand for technical and institutional change. In contrast "imperfect" induced innovation can be expected to occur when economic markets and political markets are excessively biased due to the maldistribution of economic and political resources.[1] Rent seeking interventions by interest groups to achieve political objects introduces inefficient biases in the direction of technical and institutional change. Burmeister then goes on to argue that the "directed innovation" process cannot be adequately interpreted by either induced innovation variant. In the ideal directed innovation case, the programmatic direction of state sponsored R & D activities is determined within an autonomous state apparatus. Programs are calculated attempts by state agents to mobilize the private sector in support of national projects relating to effective competition within the world political economy.

The Burmeister chapter opens up an important methodological issue. The evidence that he draws on to support the hypothesis of "directed" rather than "induced" technical change was political pressure to introduce and diffuse the Tongil variety without adequate testing into areas where it was not ecologically adapted. In research completed just a year later than Burmeister's initial study, however, Jung Keun Park finds that the pattern of technical change in Korean is agriculture fully consistent with the induced technical change model.[2] Park goes on to argue that "directed innovation" can be viewed as an institutional innovation induced by the same changes in resource endowments that induced the technical changes. In effect he is arguing that in advancing the "directed innovation" model Burmeister is focusing on relation (B) in our pattern model (Figure 1, Chapter 1) to the neglect of relations (A) and (C). He argues that the decline in fertilizer prices, rather than inducing the development of higher yielding rice varieties as implied by the induced technical change hypothesis, was a result of intervention by the Korean state to speed the rate of technology diffusion.

Contrary to Burmeister's assertion that the experience with the Tongil rice variety introduction can only be interpreted through his "directed innovation" model our own perspective is that the Korean experience is an example with what might be termed an "ultra" induced innovation model. The authoritarian character of the Korean state enabled the political authorities to force the process of development and diffusion of a fully appropriate technology more rapidly than could have occurred with efficient feedback from the research and extension system through the market. The constraints on the working of the induced innovation mechanism, resulting from underdeveloped market institutions and limited private entrepreneurship, was overcome by political and bureaucratic entrepreneurship. This Korean experience is similar to the experience of Japan during the Meiji period. The success of this model depends on enlightened political and bureaucratic leadership reinforced by a strong development oriented national ideology that limits rent seeking behavior.[3] In our view, "directed" and "induced" innovations represent a false dichotomy. The real issue is to identify the cultural endowments that induce or fail to induce political and bureaucratic entrepreneurs to direct public resources toward the development and diffusion of appropriate technology, especially when confronted with mission or inefficient factor and product markets.

The central thesis of the chapter by Bruce Koppel, "Induced Innovation Theory Agricultural Research and Asia's Green Revolution: A Reappraisal" is that the explanation of innovation offered by induced innovation theory has had important but unrecognized influence, as an ideology of neutrality, on agricultural research policy.

It is worth noting that the concept of "neutrality" adopted by Koppel is not congruent with the use of the term in the Hayami-Ruttan work. We have used the term neutrality in two contexts - both defined in terms of the production function. The first is with respect to change in relative factor use. The term neutrality (and bias) is used analytically to indicate the effect of a technical change on the relative marginal productivities among inputs. If a technical change increases the marginal productivity of one factor relative to another and hence leads, at constant factor prices, to the substitution of one factor for another, of capital for labor for example, we indicate that the direction of technical change is non-neutral - it is biased in a labor-saving direction.[4] The induced technical change hypothesis specifies that a change in relative factor prices, for example, a decline in the price of fertilizer relative to land can be expected to lead to a bias in the direction of technical change - to the invention of land-saving and fertilizer-using technical change - "to facilitate the substitution of relatively scarce (hence cheap) factors for relatively abundant (hence expensive) factors in the economy" (Hayami-Ruttan, 1971, p. 43; 1985, p. 73).

A second context in which the term neutrality is used in our work is to define neutrality with respect to economies of scale or to determine whether technical change has favored large rather than small farmers. Has, for example, technical change in agriculture, particularly the new seed-fertilizer technology, been neutral with respect to scale? Our general conclusion is that the seed fertilizer technology has been "scale neutral" - that the modern variety or green revolution technology has not been a source of inequity in rural areas (Hayami-Ruttan, 1985, pp. 329-366).

But Koppel has something else in mind in his use of the term "neutrality." Hayami and Ruttan define neutrality in terms of shifts in the production function. Koppel defines neutrality in terms of the socio-political stance of research administrators and scientists. He is concerned that the social and political pressures on research administrators might bias technical change in a direction that would worsen income distribution among farmers. In his view, the induced innovation theory theory imposes a presumed "optimality" in the direction of technical change corresponding to certain changes in factor prices. His argument is that since this "optimality" seems to be confirmed by the theory of induced innovation it has become a theoretical and ideological tool used by research scientists and administrators to resist pressure to bias research resource allocation to achieve distributional objectives. In this sense agricultural research is, in his view, neutral if the bias in technical change is optimum for the given meta-production function and relative prices. Thus in his terminology what Burmeister refers to as "pure" induced innovation is neutral since it relieves research mangers from any requirement that they consider the distributional implications of the technical changes that their research generates. Ruttan has argued that scientists, engineers and agronomists cannot evade responsibility for the economic and social consequences of their investigations. He also argues that it is in the interest of society to let the burden of responsibility rest lightly on the shoulders of individual researchers and research managers - unless society wishes to forego the gains from productivity enhancing technical change.[5] Therefore we would be very complemented if, in fact, induced innovation theory had been effective in inducing research managers and scientists to pursue a neutral, in the Koppel sense, research agenda.

We would like to be able to accept the credit which Koppel attributes to us - with providing an ideology for the CGIAR sponsored system of international agricultural research institutes. But we cannot accept his generosity. In our judgment a careful adherence to the principles of research resource allocation that we have articulated in Agricultural Development, and in our related writing, would have resulted in even larger social returns to the resources allocated to the international system - and to national systems. Our thinking has been more influenced by the research of the CGIAR institutes, particularly the International Rice Research Institute (IRRI), than influential (see Chapter 1). We would like to insist, however, that Koppel has not distorted our intent. The primary purpose of our historical analysis of the sources of technical and institutional change has not been to advance theory - although that has been one result. Our concern has been to utilized the knowledge derived from our historical analysis to design technologies and institutions, including research organization, that perform in a manner consistent with the resource and cultural endowments of a nation or region - that result in a more economically and socially efficient path of technical and institutional change.

Richard Grabowski has examined critically, and sought to clarify, some of the issues that we have confronted in elaborating and testing the theory of induced technical and institutional change in a series of papers beginning in the late 1970's. In the paper in this volume he raises three important issues. The first issues concerns the distribution of political and economic resources (also discussed by Burmeister) on the process of induced technical change. He draws on the article by Alain de Janvry, which was included in the volume on Induced Innovation edited by Binswanger and Ruttan, to argue that inequities in the distribution of economic and political resource can act to bias the rate and direction of technical change in agriculture. This is an issue on which we are in essential agreement. We have discussed this issue in the second edition of our book (Hayami and Ruttan, 1985, pp. 345-352; 432-444) and elsewhere. The fact that the induced innovation process resulted in inappropriate bias in the path of technical change in the presence of inefficient economic and political markets calls, however, for an extension rather than a rejection of the theory of induced innovation.

Grabowski's second criticism raises once more what has been referred to as the "Lipton mystery." "After almost thirty years of developing and applying high yield varieties, there does not seem to be a significant or dramatic reduction in the extent of poverty" (p. 11). The Lipton mystery reflects a continuing confusion by "green revolution" critics about the sources of poverty and inequality. Explosive population growth in the third world since World War II has been translated, with a time lag, into explosive growth in the labor force. Meanwhile labor absorption by the non-farm sectors has been slow due largely to the capital-using bias of imported industrial technology. The result has been a rise in the number of workers forced to eke out a living in agriculture. As the possibility of opening new land for cultivation has largely disappeared, especially since the 1950's, the application of labor per unit of farm land has increased. When technology is constant, labor's marginal productivity decreases and land's marginal productivity increases as the man-land ratio rises. This implies that the income position of tenants and agricultural laborers deteriorates relative to that of landlords and owner farmers. The MV innovation has been a major counteracting force against this tendency by shifting the production function in a land-saving direction. Yet it has not always been sufficiently rapid to outpace the shift in labor demand relative to the shift in labor supply. As a result it is common to observe that, side by side with the dramatic development and diffusion of MVs, poverty has continued to prevail. Even in some areas like the Indian Punjab, for which the employment and income generation effects of MVs are so large as to outpace growths in population and labor force within their localities, the wage increases have been largely counteracted by labor immigration from other areas that have not experienced the green revolution. It must be clearly recognized that the MV innovation has, at least partially, counteracted the immeserizing effect of population pressure on land, even though it can hardly be a panacea for the poverty problem in the third world. As Hayami has shown elsewhere the "Lipton mystery" is no mystery.[6]

Grabowski's third criticism is that not enough attention has been given to the uncertain response of institutional innovation to changes in resource endowments or relative factor prices. He suggests, in addition to cultural endowments, such factors as transaction costs and non-cooperative strategies. One might also add rent seeking and missing markets. It is quite clear that the tests that we have been able to make of the induced institutional innovation hypothesis thus far represent case-study "plausibility tests" rather than the more rigorous econometric tests that we have been able to make of the induced technical change hypothesis. A more rigorous approach to understanding the process of institutional innovation should rank high on the economic development research agenda. In the cases that we have investigated, however, we have been impressed that even public institutions have been more responsive to changes in resource endowments than much of the writing in the public choice literature suggests. We do not, for example, see nearly as much "institutional constipation" as Mancur Olson has suggested.[7] This suggests a research agenda that would seek to identify the cultural endowments that prevent moral hazard and rent seeking from imposing excessive costs on society.

In their chapter, "Induced Innovations and Farm Mechanization" Kislev and Peterson argue that "an incomplete conceptualization of the induced innovation idea has led to invalid empirical tests and to inappropriate implications of the causes of American farm mechanization"[8](p. 1). Furthermore, the "aggregate economy-wide framework of the induced innovation hypothesis does not account for the intersectoral transfer of technology because the whole economy is taken as one sector. However, when applying the induced innovation idea to a single sector such as agriculture, it may be necessary to separate the sector where the technology is developed from the sector where it is used. Otherwise market phenomena reflecting farmers' responses to relative factor prices may be mistakenly identified as technical change internal to agriculture" (p. 2). They go on to argue that the induced innovation hypothesis as applied to agriculture should be interpreted as an assertion that relative price changes induce innovations through two separate channels, external and internal, to the agricultural sector.

The Kislev-Peterson critique may appropriately be directed to conventional growth accounting methodology but it hardly seems a criticism of our theory of induced technical change mechanisms.[9] In our model information about changes in the demand for factor-embodied technical change, induced by changes in the relative prices of factors, is conveyed to the private and public sector suppliers of agricultural technology and infrastructure through the signals generated in both political and economic markets. The impact of technical changes in the input supply sectors is, in turn, conveyed to agricultural producers through changes in the relative prices of factors which, in turn, induces technical change within agriculture.

We must remember that "innovation" includes both invention and adoption processes. For example, the cotton picker was invented and made available by machine manufacturers. It was a "product innovation" in the machine industry. On the other hand, the adoption of the cotton picker by farmers to reduce the cost of cotton production was a "process innovation" in agriculture. This process innovation in agriculture was induced by both the increase in wage rates due to labor absorption by non-agriculture and the decrease in capital cost (in efficiency units) due to product innovation in the machinery industry. Furthermore, the "product innovation" in the machinery industry was induced by the inventors perception of the rising costs of hand picking of cotton.

We would like to emphasize here a point that we have made from the beginning, but which critics often choose to ignore, "We do not argue...that technical change is wholly of an induced character. There is a supply (an exogenous) dimension to the process as well as a demand (an endogenous) dimension."[10] Thus the invention of the cotton harvester benefitted from other advances in the farm equipment and related industries that were not induced by changes in relative factor prices in cotton production.

Some Generic Concerns

In addition to the criticisms raised in Chapters 3-6 there have been a number of other critical evaluations of the theory of induced technical and institutional innovation. In this section we comment on several of the more pervasive criticisms.[11]

Structural Duality

An early and continuing criticism of the induced technical change hypothesis is that structural duality biases the direction of technical change in a direction that is not consistent with relative resource endowments. This criticism was first raised by George L. Beckford shortly after the publication of the first edition of Agricultural Development.[12] Beckford noted that "in plantation economies, labor may be relatively cheap to peasants but considerably more expensive to plantations while land may be relatively cheap to plantations but relatively expensive to peasants. In such a situation there is no uniquely efficient path of technical change for the society as a whole unless...some exogenous institutional reform to eliminate duality occurs."[13] We agree with Beckford that structural duality can be expected to "bias the bias" due to differences or changes in relative resource endowments. Ruttan has suggested that this may have been an important factor accounting for the lag in public agricultural research investment in the U.S. south relative to the midwest. Except for the studies of the effect of structural bias on the adoption of biological technology in Argentina by de Janvry and on the adoption of mechanical technology in Brazil by Sanders and Ruttan empirical research on the effects of structural duality on bias in the rate or direction of technical change has been neglected.[14]

The theory of induced institutional innovation was developed, in part, in an attempt to understand the forces which lead to the erosion of structural rigidity. Mancur Olson has emphasized the impact of institutional constipation, resulting from the growth of distributional coalitions, in dampening economic growth.[15] We are impressed, however, with the tendency of both dynamic changes in technology and relative factor prices to erode the power of distributional coalitions.

Neoclassical Institutional Economics

The extension of the induced technical innovation framework, particularly the effect of changing resource endowments and of technical change, on the process of institutional innovation has been the subject of more vigorous criticism than the theory of induced technical change. We have frequently been confronted with the assertion that an extension of the neo-classical theory of the firm to interpret the process of institutional change is simply not legitimate.

Daniel W. Bromley has argued this point with particular vigor. "The Ruttan-Hayami model of induced institutional innovation is driven by differential economic returns emanating from changes in resource endowments and technical change; it is a response to exogenous disequilibrium in market processes. The potential flaw in this model is that it is institutional arrangements that define income and cost streams; one has a model of change driven by something (economic rent) that only gets its meaning and magnitude from that which one is trying to understand and model."[16]

Our interpretation of the Bromley criticism is that we have ignored what economists refer to as the "identification problem" - what are the independent and dependent variables. In part this is an argument with the way the world is constructed rather than with Hayami and Ruttan. The identification issue is a particular plague in the case of partial equilibrium analyses. In Figure 1 (Chapter 1) we have sketched out the elements of a general equilibrium "pattern model." But our analysis of institutional innovation, such as the change in land-tenure labor relations in Laguna province, employs a partial equilibrium approach. We argue that we have been aided in resolving this problem, at least to our own satisfaction, by the fact that the forces operating in the model are not all changing at the same rate.

New Directions

A limitation of the induced innovation model developed so far has been the "black box" nature of the internal working mechanism. Induced technical and institutional changes were modelled as a response to changes in economic opportunities with relatively little analysis of the mechanism and process with which changes in incentives are translated into actions by private and public agents to result in technical and institutional change. This is especially the case in our work on institutional innovation. All three papers in Part III represent attempts to fill this void, drawing on the development of new institutional economics that include the theories of information and transaction costs, principal-agent relations, public choice, and collective action.

In Chapter 8, Hans Binswanger brings together the findings of a series of previous papers with his colleagues, in which they have explored the emergence of major institutions governing the production and exchange of factors and products in rural areas.[17] His analysis is focused on how environmental and technological characteristics of agricultural production determine risk and transaction costs and how certain forms of production organization and contract for the transactions of land, labor, and credit are chosen as the devices for coping with risk and transaction costs. His analysis is limited to the private choice of organization and contract corresponding to the unique production characteristics of agriculture. Within this limitation, the Binswanger paper presents a highly comprehensive list of testable hypotheses that should become a very fruitful research agenda for advancement of the induced institutional innovation theory. His analysis of contract choice, which has so far been limited to its relation with the characteristics of agricultural production technology and environment, will be enriched further if it incorporates the community mechanism of contract enforcement in agrarian societies, as attempted by Hayami and Kikuchi.[18]

In chapter 8, James Roumasset advocates the incorporation not only the theory of private choice in terms of risk and transaction costs but also the theory of public choice involving collective action. He begins with identification of the area of agrarian structure and institutions that can be adequately analyzed with the standard neoclassical theory (first-best theory with the assumption of perfect markets). He then tries to identify the area that requires the use of transaction cost economics in the spirit of Oliver Williamson (second-best theory).[19] This area coincides with the area analyzed by Binswanger in the previous chapter. In addition he discusses the area for which the theories of public choice, especially of rent-seeking (third-best theory), must be applied.

Roumasset goes on to argue that efficiency is the fuel of economic growth and rent seeking provides the incentives for interest groups to pursue institutional change. The traditional definition of rent seeking is applied to the cases in which rent seekers try to advance (or maintain) certain rules or regulations for the sake of biasing the distribution of income in their favor while adding little (or negatively) to the total income stream. If the concept of rent seeking is expanded to cover the cases in which a significant addition to the total income stream is produced from the institution of new rules then all institutional innovations can be considered the results of rent-seeking activities. If this is what Roumasset implies, the relevant issue must be, as we have emphasized earlier, to identify what cultural and institutional environments may induce the rent seekers to allocate their resources for advancing the institutions that generate income streams rather than those that distort income distributions.

In Chapter 9, Alain de Janvry, Marcel Fafchamps, and Elizabeth Sadoulet explore analytically and empirically the effects of farm size distribution, transactions costs and state objectives on the process of induced technical change. They assume (as do Burnmeister and Koppel) that the state has objectives of its own, and that public resource allocation for agricultural research and development are " a compromise between the states own objectives and the demands of organized lobbies The most counter-intuitive result from their exercise is that a larger research budget decreases the bias against land saving technical change. It "makes the actual technological bias more land saving and leaves greater benefits for the small farmers. A larger research budget is thus an instrument to enhance equity in the distribution of income in the farm sector" (p. 13).

An important perspective that emerges from the three papers in this section is the importance of exploring, both analytically and empirically, the implications of what Burmeister has termed impure induced innovation. The gains from incorporating the objectives of the state are less obvious. There are basically two methods of aggregating preferences - through economic markets and through political markets. Once one has taken into account the imperfections in these two markets, including missing markets, there is very little content left in the concept of the states own objectives. But where markets are missing, or under-developed, as noted in our discussion of the Burmeister paper, the state may have greater autonomy.

We also share with the authors in this section the view that the interesting questions center on cases in which it appears that the processes of technical and institutional innovation produce results that are not consistent with the "pure" (efficiency) theory of induced innovation. This has been a focus of some of our own recent research.[20]

More New Directions

In addition to the new directions discussed in the preceding section areas we discuss in this section three unresolved issues that should represent fruitful areas for further research.

Integration of Factor Supply and Product Demand Induced Technical Change Models

The induced technical change models discussed in this volume are appropriately referred to as "factor endowment" or "factor supply" induced innovation models. They represent extensions of the micro-economic theory of the firm initially suggested by Hicks and extended by Ahmed, Hayami, Ruttan and Binswanger. There is also a second tradition of "product demand" induced innovation theory that was initially advanced by Griliches and Schmookler.[21] In this version of induced innovation theory the rate of technical change is induced by the rate of growth in product demand.

If we are to achieve a more adequate understanding of why private firms and governments expand their research budgets and how they allocate their research resources we will need a fully integrated model of induced technical change that incorporates the insights of both the factor supply and the product demand induced innovation models. Binswanger has sketched the outlines of how a more general model of induced innovation might be constructed.[22] If one assumes decreasing marginal productivity of research resources in applied research and technology development and, in addition, incorporates the effect of change in product demand then growth (decline) in product demand would increase (reduce) the marginal value product of resources devoted to research and hence increase (decrease) the optimum level of research expenditure. The larger research budget, as a result of growth in product demand increases demands for the factors of production. As a consequence the differential elasticities of factor supply result in changes in relative factor prices and direct research effort to save increasingly more expensive factor supplies. The result is a non-neutral shift in the neo-classical production function along the meta-production function. This suggests how an integrated "factor supply" and "product demand" induced model of technical change might be constructed. As yet such a model has neither been constructed nor estimated.

Induced Technical Change and Trade Theory

Relative factor endowments play an important role in both the Hecksher-Ohlin approach to trade theory and the theory of induced technical change. Under the Hecksher-Ohlin assumptions each country exports its abundant factor-intensive commodity. Induced technical change acts to make the scarce factor (or its substitutes) more abundant. Except for an early article by Chipman and a more recent article by Hamilton and Soderstrom, the relationship between the theory of induced technical change and international trade theory remains almost completely unexplored.[23] To the extent that trade can release the constraints of factor endowments on growth the theory of induced technical change loses part of its power to explain the direction of bias in productivity growth. Conversely, to the extent that technical change can release the constraints on growth resulted from inelastic factor supplies, the power of the differential factor endowments explanation for trade is weakened.

An attempt to integrate induced innovation and trade theory has been made by Donna Roberts in a paper at the University of Minnesota.[24] Roberts also discussed some of the implications of the "neofactor trade theory," which attempts to incorporate "different endowments of knowledge capital," and "neotechnology trade theory" which attempts to incorporate the "technology factor" as an important explanation for trade. She argues that the location specific nature of much of agricultural technology suggests that the neotechnology models would represent a more powerful explanation of international transfer of industrial than of agricultural technology. The induced technical change model might be expected to have more power in explaining the difference in the path of technological change in agriculture and in other natural research intensive sectors than in less resource intensive sectors.

Path Dependence and Induced Technical Change

Several students of technical change, stimulated by the work of Paul A. David, have argued that technical change tends to develop a path dependence or inertia that results in continuation in the same direction even though other factors, such as changes in relative factor prices, suggest that a change in the factor saving direction of technical change would be more efficient. David has pointed, for example, to the persistent failure to replace the inefficient QWERTY layout of the typewriter and computer keyboards with the more efficient DSK keyboard.[25] Gavin Wright has suggested that the historical resource intensity of American industry, based on domestic resource abundance, has been an important factor in weakening the capacity of American industry to adapt to a world in which lower transportation costs and more open trading systems have reduced the traditional advantage of United States based firms.[26] If this perspective is correct Japan's industrial success may be attributed to its historical resource scarcity.

The difference in perspective seems to hinge on how the elasticity of substitution changes over time in response to changes in resource endowments or relative factor prices. From a historical perspective the issue seems to be how dependent the path of technical change is on the initial conditions under which a "gateway technology" emerges. While it is always true that today's technical changes draw on the advances in knowledge and technology from the past it is hard to believe that in a competitive environment technological competition would not result in a "bending" of the path of technical change in the direction implied by changing factor endowments. At least that is what our work on technical change in agriculture suggests.

In our perspective the path dependence and the induced innovation models should be considered as complementary rather than as alternative interpretations of the forces that influence the direction of technical change. An important issue on the technical change research agenda should be the historical analysis of the conditions under which path dependence or induced technical change prevails.

Technology and the Environment

We are being confronted in the late 20th century with both the impact on the environment from the externalities generated by agricultural and industrial intensification and by growth in consumer demand for environmental amenities arising out of rapid growth in per capita income and high income elasticity of demand for environmental services such as freedom from pollution and congestion. The competition between the demand for disposal of residuals and the demand for resource amenities is producing a dramatic rise in the economic value of common property resources formerly regarded as free goods.[27]

Redirection of scientific and technical effort along a path induced by environmental stress is an essential element in any effort to achieve consistency between the conflicting demands for environmental services. But the institutions needed to internalize the externalities and to provide the incentives to induce an appropriate direction of scientific and technical effort, at the local, national and international level, have not yet been designed. It seems apparent, for example, that the continued "path dependent" energy and material intensity of the American economy reflects a failure to design the "incentive compatible" institutional innovations that will be needed to induce a path of technical development and infrastructure involvement consistent with the rising value of the environmental resources.

In spite of missing economic markets the rising demand for environmental amenities has induced a response in the political market place. National and international agricultural research systems have in the past focused their efforts primarily on enhancing the production of the major agricultural commodities primarily in the more favored resource areas. Efforts are now being redirected to removing the resources and environmental constraints on sustainable growth in agricultural production. One implication of the rising demand for "open access" and "common property" environmental resources is the need for a more complete integration of the theory of induced innovation with the theory of incentive compatible institutional design. Incentive compatible institutional design - the design of institutions capable of achieving compatibility among individual, organizational and social objectives - remains at this point an imperfect art. The incentive compatibility problem has not yet been solved even at the most abstract theoretical level.[28]

Induced Technical Change and Endogenous Growth Models

Since the late 1980s, students of economic growth have been engaged in a re-evaluation of neoclassical growth models. The re-examination has been stimulated by concern that the neoclassical growth models are inconsistent with the evidence of lack of convergence of growth rates between rich and poor countries.[29] One result of this re-examination has been the emergence of a new generation of endogenous growth models.

The major focus of the new "macro-endogenous" growth models is to attribute differences in growth performance among countries to endogenous factors such as investment in human capital, learning by doing, scale economies and technical change.[30] (Romer, 1986 and 1990; Lucas, 1988). In the Romer-Lucas framework the accumulation of "human capital adds to the productivity of the person in whom it is embodied, and that is why individuals invest in it. But there is also an additional external effect. The general level of productivity rises by more than can be accounted for or captured by the person or firm that makes each particular investment."[31] Gains in scale economies are enhanced by the integration into multinational trading systems of economies that are human capital intensive. Market power is introduced in order to make technical knowledge a partially excludable factor.[32] In the induced innovation model, as employed by Hayami and Ruttan, agricultural technologies are treated as local rather than global public goods because of their location-specific nature. The macro-endogenous growth models have also been criticized for the somewhat unbalanced treatment of labor and capital - the accumulation of human capital generates external returns to scale while the accumulation of physical capital exhibits decreasing returns to scale.[33]

A major challenge for the future is to integrate the insights about endogenous growth gained from the theoretical and empirical research conducted within the micro-endogenous induced technical change framework, with new insights into the relationship between human capital, scale and trade opened up by the macro-endogenous growth models.

ENDNOTES

1. A distinction between "pure theory" and the "impure" or imperfect theory of induced technical change has also been made by James K. Boyce, Agrarian Impasse in Bengal: Institutional Constraints to Technical Change (Oxford: Oxford University Press, 1987), pp. 23-95.

2. Jung Keun Park, Technological Change in The Korean Rice Economy: Sources of Direction and Impact (Ph.D. thesis, University of Minnesota, 1986). See also "Induced Innovation in the Korean Rice Economy, 1963-1984," The Korean Journal of Agricultural Economics 27 (December 1986), pp. 13-28.

3. Alice H. Amsden, Asia's Next Giant: South Korea and Late Industrialization (Oxford: Oxford University Press, 1980), pp. 11-23.

4. This definition is in the tradition of John R. Hicks, The Theory of Wages (London: Macmillan, 1932). For a technical discussion see Hans P. Binswanger, "Induced Technical Change: Evolution of Thought," in Hans P. Binswanger and Vernon W. Ruttan (eds.) Induced Innovation: Technology Institutions and Development (Baltimore: Johns Hopkins University Press, 1978), pp. 18-22; Colin G. Thirtle and Vernon W. Ruttan, The Role of Demand and Supply in the Generation and Diffusion of Technical Change London Harwood Academic Publishers, 1987) pp. 12-19.

5. Vernon W. Ruttan, Agricultural Research Policy (Minneapolis: University of Minnesota Press, 1982), pp. 331-354; "Moral Responsibility in Agricultural Research," Southern Journal of Agricultural Economics (July 1983), 73-80.

6. For the Lipton thesis see Michael Lipton and Richard Longhurst, New Seeds and Poor People (London: Unwin and Hyman, 1990). For a critique of the Lipton thesis see Yujiro Hayami, "Agricultural Innovation, Economic Growth and Equity: A Critique of Michael Lipton," Southeast Asian Journal of Agricultural Economics (June, 1992), pp. 1-9. For a theoretical exposition see Yujiro Hayami and Masao Kikuchi, Asian Village at the Crossroads (Baltimore: Johns Hopkins University Press, 1982); Chapters 3 and Appendix A.

7. Mancur Olson, The Rise and Decline of Nations (New Haven: Yale University Press, 1982), p. 74.

8. Several other critics have also raised questions about the Hayami-Ruttan tests of the induced technical change hypothesis based on different data series, statistical methodology or models of the underlying structure of the technology. See, for example, L. Nghiep, "The Structure and Changes of Technology in Pre-War Japanese Agriculture," American Journal of Agricultural Economics 61:4 (November 1979), pp. 687-693; Sandra O. Archibald and Loren Brandt, "A Flexible Model of Factor Biased Technological Change: An Application to Japanese Agriculture," Journal of Development Economics

(forthcoming); Alan C. Olmstead and Paul Rhode, "Induced Innovation in American Agriculture: Record Perspectives Since 1880," Journal of Political Economy (forthcoming). The effect of the alternative tests have typically resulted in refinements of data, methodology, or qualification of earlier findings. They have not, however, raised serious questions about the value of the induced technical change model in interpreting the process of technical change in agriculture.

9. The relevance of the Kislev and Peterson criticism of conventional growth accounting, in which input qualities and/or prices are unadjusted for quality change, is illustrated in their discussion of the machinery prices measures used by Binswanger. After adjusting machinery prices for quality change the data, which appeared to be inconsistent with induced innovation, became fully consistent with the induced innovation process. In recent work progress has been made in incorporating inter-industry technology and resource flows among sectors. See specifically Mitoshi Yamaguchi and George Kennedy, "A Comparison of Conventional and General Equilibrium Growth Accounting: The Case of Japanese Agriculture, 1880 - 1970," Kobe University Economic Review 33 (1987), pp. 49-69; Dale W. Jorgenson, Frank Gollop and Barbara Fraumeni, Productivity and U.S. Economic Growth (Cambridge: Harvard University Press, 1988); F. M. Scherer, "Interindustry Technology Flows in the United States," Research Policy (August 1983), pp. 227-245.

10. Yujiro Hayami and Vernon W. Ruttan, Agricultural Development: An International Perspective (Baltimore: Johns Hopkins University Press, 1971), p. 59. See also Ibid, (1985), p. 89.

11. We have not attempted to review the several papers which have raised empirical questions about historical pervasiveness of the induced innovation process. See particularly Alan L. Olmstead and Paul Rhode, "Regional Perspectives on U.S. Agricultural Development Since 1880," (University of California Agricultural History Center Working Papers, Davis, CA, May 1991); Sandra O. Archibald and Loren Brandt, "A Flexible Model of Factor Biased Technological Change: An Application to Japanese Agriculture" Journal of Development Economics 35 (1991), pp.127-145. In our judgement it is no longer "interesting" to find historical cases that are consistent with the induced technical change hypothesis. It is of interest to try to understand the factors which block historical expression of induced technical change.

12. George L. Beckford, "Strategies for Agricultural Development: Comments," Food Research Institute Studies 11 (1972), pp. 149-154. Similar criticisms have been made by Keith Griffin, The Political Economy of Agrarian Change 2nd ed. (London: Macmillan, 1979), p. xvii and by Richard Grabowski, "The Implications of an Induced Innovation Model," Economic Development and Cultural Change 27 (July 1979), pp. 723-734.

13. Beckford, Ibid., p. 151.

14. Alain de Janvry, "A Socioeconomic Model of Induced Innovation for Argentine Agricultural Development," Quarterly Journal of Economics 87 (August 1973), pp. 410-35 (reprinted in Binswanger and Ruttan, 1978, pp. 297-323; John H. Sanders and Vernon W. Ruttan, "Biased Choice of Technology in Brazilian Agriculture," in Hans P. Binswanger and Vernon W. Ruttan (eds.), Induced Innovation: Technology Institutions and Development (Baltimore: Johns Hopkins University Press 1978), pp. 276-296.

15. Mancur Olson, The Rise and Decline of Nations: Economic Growth, Suffocation and Social Rigidities (New York: Yale University Press, 1982). For a critical evaluation of the Hayami-Ruttan theory of induced innovation, in reference to Olson's work see Günther Schmitt, "Toward a Theory of Induced Institutional Innovation," Quarterly Journal of International Agriculture 26 (April/June 1987), pp. 131-144.

16. Ibid., p. 23.

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