CONCEPTUALIZING TECHNOLOGICAL CHANGE: TECHNOLOGY TRANSFER IN THE GREEN REVOLUTION

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(ABSTRACT)

Technological change, and technology transfer as an aspect of this process, is examined by providing a comparative assessment of models of this phenomenon from economics, history, sociology, and neo-Schumpeterian-evolutionary studies.

The Green Revolution, which is used as the empirical basis for testing these models, is generally referred to as the change in agricultural technology observed in some Third World countries in the 1960s and 70s as a result of the transfer of high-yielding varieties (HYVs) of seeds and a new culture of agricultural practice resulting in high productivity of the land.

It is found that most of the examined models of technological change do not completely account for this process. It is argued that technological change should be conceptualized as a process of knowledge change. Artifactual change, which the examined models accentuate, should be viewed as the manifestation of the knowledge change at a secondary

level. With the Green Revolution as the empirical basis, arguments are presented for a comprehensive model of technological change within the framework of "technology as knowledge."

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CHAPTER ONE
INTRODUCTION

Technological change, one of the most important conceptual problems in science and technology studies (STS), is a dynamic and multidimensional phenomenon involving invention, innovation, transfer and diffusion of technology. Technology is not simply tools, machines, and other such artifacts, but is also a form of knowledge created by humans. Technological change involves not only social, economic and organizational factors, but cognitive factors as well. In this dissertation, I will examine technological change by providing a comparative assessment of models of this phenomenon found in the literature. My study also considers technology transfer as an integral part of the process of technological change. I use the Green Revolution in India as a case study in presenting an account of technological change. After presenting and critiquing models of technological change found in various disciplines and areas of inquiry, I will test their completeness against the case study. The concepts of technology as knowledge and technological change as essentially a process of knowledge change form the framework for this study. The case for "technology as knowledge" has been made by others. I will present arguments for technological change as esentially a form of knowledge change.

Based on this framework, I will provide a complete account of technological change from a STS perspective using the Green Revolution as the empirical focus.

Although scientific change is a thriving research problem in history, philosophy, and sociology (the main participating disciplines of STS),[1] technological change has not yet attracted the same interest. This fact has little to do with the nature of technology itself as a knowledge system. Instead it results from the delayed acceptance of the idea of the intellectual and epistemological autonomy of technology as a knowledge system separate from science.

The intellectual autonomy of technology as a knowledge system has been well established. The previous prevalent assumption that technology is only science applied for practical purposes or simply that technology is applied science[2] has been discarded in STS. Historians of science writing on the history of technology have created a variety of misconceptions about the fundamental relationship between science and technology, and their interaction with society.

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[1] Besides these three disciplines, economics, political science and anthropology are some other disciplines which are interested in STS. These disciplines have more interest in technology than in science, because technology is more overtly related to economic growth and development, political-economy and cultural issues that we face.

[2] Wise (1985), Price (1965) and Beer (1965) explore this ahistorical assumption exceedingly well. They argue that this misconception was popularized by some science historians and science policy-makers.

Historians of technology have to retrieve the history of technology from the poor historiographic scholarship demonstrated by the historians of science.[3] Studies in the history, philosophy and sociology of technology have clearly established the autonomy of technology from science.[4] We owe more to the community of historians of technology for this development. The relationship between science and technology is dialectical, or interactive, rather than sequential and hierarchical.[5] According to Clark (1987:26), "...'science'

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[3] Price (1974:46) makes this point explicit by admitting that: "We historians of technology should bow our heads in even greater shame that so many administrators of science should derive such knowledge as they have of the science-and-technology interactions from cooked-up investigations like Project Hindsight and Traces instead of from any conventional wisdom of our own making."

[4] The formation in 1958 of the Society for History of Technology (SHOT) and its journal Technology and Culture, along with numerous books and papers are testimonial to this claim from the perspectives of history. The formation in 1975 of the Society for Philosophy of Technology and the numerous volumes of books published under its sponsorship credit the interest of philosophy in technology. In sociology, the movement to develop a sociology of technology is exemplified by the publication of a volume edited by Bijker et al. (1987). This movement may be better identified as social studies of technology.

[5] The relationship between science and technology is described with various metaphors. For example, "mirror-image twins" (Layton, 1971); science and technology as two autonomous spheres of knowledge, the former about the "natural world" and the latter about the "man-made world" (Wise, 1975); science and technology as a "pair of dancers" dancing to the "music of instrumentalities" (Price, 1984; 1965); and science and technology relate to each other "interactively" (Barnes, 1982). As an aside, Price attributes to Arnold Toynbee the dancing pair metaphor for science and technology. Toynbee in his Introduction: The Geneses of Civilizations, Vol. I (1962:3, n. 1) conceives of "Physical Science and Industrialism" as "a pair of dancers."

and 'technology' can be regarded as distinct social systems observing different rules of conduct, coming from independent professional traditions and being largely autonomous in the influence one has on the other." Technology and science benefit immensely from each other. The great progress in technology and science, particularly in the twentieth century, clearly manifests this process of mutual enrichment. In STS, science and technology are considered intellectually and epistemologically autonomous entities, related dialectically.

A major outcome of the acceptance of technology as an autonomous enterprise has been the recognition of "technology as knowledge."[6] This recognition essentially stems from the efforts of modern historians of technology,[7] who discarded the old methodology of writing the history of technology which treated technology as artifacts developed with ideas from science. These modern historians developed a new historiographic method of looking at technology as a body of knowledge with its own internal dynamics of change and progress. Technology has technological laws, which influence or help to create technological designs and new artifacts.[8]

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[6] The pioneering work in this regard was first done by Layton (1974).

[7] Besides Layton other pioneers in the field are Walter Vincenti, Lynn White, Carl Condit, Ladislao Reti, Eugene Ferguson, de Solla Price, Hunter Dupree, Robert Multhauf, Melvin Kranzberg and Carroll Pursell, among others.

[8] For more on this see Layton (1974).

The concept of technology as knowledge differs from science as knowledge in many respects. Technological knowledge can be often tacit,[9] less amenable to the written form and hence characterized as "papyrophobic"[10] in nature. Vincenti (1984:574-5) divides technological knowledge into three categories: (1) descriptive, (2) prescriptive, and (3) tacit. Descriptive and prescriptive categories denote varieties of explicit technological knowledge, and tacit denotes procedural technological knowledge. However, Vincenti argues that there are gradations of prescriptive knowledge, and sometimes this can be categorized as procedural technological knowledge as well because tacit and prescriptive knowledge are closely related in practice.

Although the fundamental building block of technology is ideas, technology is at the same time both a public and private 'good'.[11] Compared to other forms of knowledge, technological knowledge is more easily kept private and secret through intellectual property rights. But at the same time, the artifacts generated from such knowledge have to return to

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[9] The often "tacit" nature of knowledge generating processes was first recognized by Michael Polanyi (1958:49).

[10] This differentiation was made explicit by de Solla Price (1974:37). This distinction may be less prominent now than it was before because of the increasing prominence of research and development activities geared toward technological development, and of the proliferation of published work along with efforts intended for integrating and codifying technological knowledge.

[11] For pioneering work on this facet of technology, see Nelson (1989).

the public realm of economic systems mediated largely through the market mechanism for their dissemination, diffusion and ultimate survival. This paradoxical situation is unique to technological knowledge. Scientific knowledge, on the other hand, has to remain public in order to be accepted as certified knowledge.

Technological knowledge, in a different sense, is tacit to the extent that its transmission is possible without being presented as certified knowledge. This transmission is possible through craft traditions, family practices and shop-floor apprenticeship programs. However, this aspect of technological knowledge transmission is becoming less prominent as large segments of technological knowledge become part of the public domain. Technology also differs from science in that technology is a visual activity[12] often with visible and tangible effects.

Ideas form the core of technology. All our artifacts originate in thoughts and ideas. Technology is, in effect, the activities, both intellectual and physical, that humans engage in based on ideas and thoughts.[13] An anthropological measure

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[12] For more on this facet of technology, see Ferguson (1977).

[13] Florman (1976:58) argues that technology is not a thing but merely "one of the activities" humans engage in by choice or by force. Pitt (1988:448) argues that technology is "humanity at work." According to Huning (1985:11), the pioneering work on the "anthropology of technology" was first done by Ernst Kapp in his Grundlnien einer Philosophie der Technik (1877) ["Foundations of a Philosophy of Technology."] Kapp uses the

of technology reveals that the idea to use a stone or a stick for extending the power of the human hand evolved as a cognitive process, which, in turn, is inextricably linked to human evolutionary processes. The externalization of the cognitive responses to the natural world, first with the simple stones and sticks, then with the stone axes and the wooden ploughs, culminating in the sophisticated tools, machines and instruments of contemporary civilizations results in technological artifacts born out of ideas and thoughts and ultimately of human experiences. The development of technology as a knowledge system is attributable to the increasing sophistication of human cognitive processes and activities. Technology constitutes knowledge, and all technologies are embodiments of some form of human knowledge. Levinson (1988:106) argues that the technological artifacts we have developed augment the functioning of our cognitive faculties. The growth of technological knowledge is a direct manifestation of its cumulative nature. The process of technological change is both a cumulative and an evolutionary process.[14]

As Layton (1974) correctly points out, ideas and thoughts were always considered integral in the historical development of technology. But this important aspect of technology was

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term Organprojektion or "organ projection" to refer to technology.

[14] This argument is further discussed and developed in Chapter Five.

denied temporarily when technology was relegated to the status of applied science. According to him, "the separation of knowledge and technology is both recent and artificial" (1974:35). But analysts of technology, mostly historians of technology, who knew better have stood firm and reversed this ahistorical attribution. The works of several historians[15] of technology established ideas and information rather than material artifacts as the fundamental constituents of technology.

Thus it becomes apparent through this recent work in STS on the problem, that technological change is not a mere concatenation of artifacts but a <u>change in technological knowledge</u> itself. However, interest in technological change had been shown by many other disciplines, besides history, before it became a major research problem in STS. Nevertheless, this interest was not prompted by theoretical interest in explaining the nature or process of technological change but due to the well founded belief that the progressive change in the technological knowledge base of a society directly corresponds to economic and social change.[16] Political economists Hume (1955), Smith (1976/1776) and Marx (1952/1848

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[15] A few examples, besides Layton's work are, White (1969), Kranzberg and Pursell (1967), Condit (1959), Ferguson (1962), de Solla Price (1965), and Dupree (1969).

[16] One major manifestation of these changes was the dramatic improvements in the standard of living of the people (mostly in the West) who experienced the most rapid technological change during the past hundred years.

and 1967/1867) comprehended the importance of technological change in bringing about economic development and social change. It was Marx who saw the revolutionary role of technological change in generating economic growth.[17] Marx and Engels predicted that the bourgeoisie, whose historic role is to "constantly revolutionize the means of production," would create a modern capitalist economic system which in turn would be expropriated by the revolutionary proletariat to create a socialist economic system.[18] While they implicitly agreed that the capitalist system would be more efficient not only in terms of creating newer technology, new products and high profits, they contended that the means of production in a socialist system would be less alienating (to the proletariat) and would be more equitable.[19]

Although academic interest in technological change declined considerably after Marx, it picked up again in the beginning of this century. The first modern economist to show considerable interest in it was Schumpeter (1950/1942; 1939).

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[17] Marx in both A Manifesto of the Communist Party (1952/1848) and in Capital Vol. I (1967/1867) clearly emphasized the role that technological change (changes in the means of production) plays in the dynamics of capitalist economic systems.

[18] See Marx and Engels (1952/1848).

[19] Rosenberg (1988) argues that the relatively poor performance of socialist economies in generating new technologies through rapid technological change compared to the market-oriented capitalist economies was due to the former's neglect of efficiency and its emphasis only on equity.

Historian Usher (1954/1929; 1955) and sociologist Gilfillan (1970/1935), among others, followed suit. Although these analysts emphasized different aspects of technological change, particularly their emphasis upon certain idiosyncratic vocabularies,[20] their ultimate interests were intimately related to the process of change in technology.

Considerable interest in technological change began to be manifest among neoclassical economists in the 1950s with the works of Abramovitz (1956) and Solow (1957), followed by the works of Mansfield (1961), Griliches (1960), and Schmookler (1966), among others. Although they were not primarily concerned with the process or the internal dynamics of technological change itself, their interests were predicated on the assumption that economic growth was primarily due to technological change rather than due to the interminable infusion of capital into the economic system as was widely believed then.[21] Their interest in technological change was limited because they were primarily interested in the phenomena that were responsible for productivity increase. The

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[20] Schumpeter called this process "technological innovation," but excluded invention from the locus of technological change. Usher called this process "invention" which was a portmanteau for all the phases of technological change. Gilfillan developed his theories of technological change based on the premise of a "sociology of invention."

[21] Solow's (1957) empirically-based study of the United States economy for the period from 1909 to 1949 shows that technological change was responsible for 87.5 per cent of increase in output per man hour, while only 12.5 per cent of increase in output per man hour was due to increased use of capital.

predominant neoclassical model of technological change was based on a production function based theory of input/output relationships.

Interest in technology in general, and technological change in particular, on the part of economic historians, historians of technology, and sociologists of technology also began to emerge concurrently, but for the most part separately from each other and from mainstream economists.[22] Most of these analysts proposed their own interpretations of technological change and in turn developed models to represent and explain this phenomenon. They worked within their own areas of inquiry or disciplines. A few among them attempted to transcend the constraints of their disciplines to use perspectives and tools from other disciplines to explain technological change. However, these attempts did not go far enough, for obvious reasons, because in the final analysis they looked at technology through the microscopic eye of their individual disciplines and areas of inquiry. But as I will argue, in order to represent the dynamic and multidimensional character of technological change one needs to give up disciplinary loyalties and ground one's arguments in an interdisciplinary

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[22] A few of these analysts are Rosenberg (1976; 1982), David (1975), Hanieski (1973), and Habakkuk (1962) from economic history; White (1962), Hughes (1976; 1983), Constant (1973; 1980), Susskind (1973) from history of technology; Bijker and Pinch (1987), Law (1987), MacKenzie (1987) from sociology of technology; Dosi (1982), Nelson and Winter (1977), Sahal (1981a), and DeGregori (1985) from an evolutionary perspective.

framework.

The objective of analyzing technological change tends to vary from discipline to discipline, although most analysts implicitly concede that technological change is essential for economic development and social change. Economists may be primarily interested in the economic impact of technological change. Sociologists and anthropologists may be looking for the changes in the social structures and cultural practices and mores due to this phenomenon. Historians may tend to concentrate on chronicling the cumulative nature of technological change in the making of industrial civilizations. Philosophers concentrate on the moral and ethical implications of technological change and progress, and develop methodological tools for technology assessment. Nevertheless, despite these differences the needs for new technologies to solve human problems and for ways to develop new technologies remain a major factor influencing the thinking of analysts of technological change across disciplines.

It is not necessarily the case that technological change interests only those who are interested in its effects on progressive social and economic change resulting in improved well being of humans. It also has become a topic for intense intellectual debate among some analysts of technology. Some analysts consider technological change a dangerous force whose benefits result not only in social and material progress but ultimately destroys human freedom and liberty.[23] Thus the price for progress, they argue, is less freedom and liberty. These analysts argue that technological change has become an autonomous force beyond human control. This is an important charge that needs further scrutiny, but which is, however, beyond the scope of the present project.[24]

Interest in technological change is not only intense in the developed world but in the developing countries as well. The spectacular rise in the standard of living of the peoples in industrialized nations is attributed to the technological change that has been going on at an intense pace for the past two-to-three-hundred years. The increased pace of technological change in countries affected by the Industrial Revolution was responsible for this. The importance of technological change in enhancing the economic well being of humans is well understood.[25] Because of these precedents, developing countries are also interested in fostering

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[23] The detractors of technological change allege that rapid technological change is becoming a force beyond the control of humans and destroys freedom and liberty. Some analysts who hold these views are Ellul (1964), Mumford (1967) and Winner (1977).

[24] For a critical analysis of these arguments, see Parayil (1989).

[25] Analysts like Adam Smith (1976/1776) and Marx (1952/1848) pointed out this fact much before empirical studies by modern economists like Solow (1957), Abramovitz (1956), and others have demonstrated this in their works. Works by Coombs et al. (1987), DeGregori (1985), Solo and Rogers (1972), Fransman (1986), and Binswanger and Ruttan (1978) also have demonstrated this conclusively.

technological change for improving the standard of living of their peoples through measures like technology transfer.

Given that interest in technological change varies according to the disciplinary and individual objectives of the analysts, it should come as no surprise that there is no consensus yet on a consistent theoretical explanation of technological change. Likewise, it is an epistemologically risky exercise to look for a simple and consistent definition of technological change. This risk is primarily due to the lack of a consistent definition for technology itself. Most scholarly works on the subject circumvent the need for providing a definition of technological change.[26] Most analysts, unable to quite put their finger on it, skip this part and go on to explain the impact of technological change on human society or explain what its constituent components are or offer models based on case studies of technological change. This is not to deny that definitions of technological change are not found in the literature. In neoclassical economic literature we find the usage of capital-labor ratios to define biased or neutral technological change.[27]

Technological change may be defined as: <u>a temporal and</u>

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[26] For example, in De Bresson's (1987) <u>Understanding Technological Change</u>, there is no definition for technological change, and he does not even explain clearly what this means.

[27] In the biased technological change categories there are technologies that would be capital-saving or labor-saving. In the neutral category the capital-labor ratio is always one and the technology favors neither labor nor capital. See Hicks (1932) for more on these.

cumulative process which increases the ability of a people or society to solve their social, economic and other everyday existential problems. Technological change is, then, essentially a process of knowledge change--a cognitive process involving changes in the structure and content, and in the context of production of technological knowledge. Although the manifestation of the change is tangible and apparent in material (artifactual) forms, the integral part of this process is cognitive in nature.

A more rigorous definition of technological change is that it is the outcome of the activities that humans engage in through their collective or individual organizational structures, such as firms, households or any other institutional agents or social units to optimize their resources subject to constraints imposed by their own limitations in tandem with that of their environment.[28] The problems generated by technological imbalances, bottle-necks, technological disequilibria, and other technological puzzles act as focussing devices to find solutions. Technological change, therefore, may be analyzed or looked at as essentially

[28] This definition is conceptually closer to the idea of clearing out "bottlenecks," solving "technological imbalances," and "technological disequilibrium." See Hanieski (1973) and Rosenberg (1969 and 1976) for more on this. The puzzles thrown out by these are solved by any number of methods, such as, investing in R & D efforts, innovations on shop floors and in the fields and farms, new inventions, etc.

the outcome of a problem-solving activity.[29]

The manifestations of technological change may be the development of new products and machines and better and easier ways of solving society's problems. The nature, process and outcome of technological change may vary from countries, regions and cultures based upon their particular social, political and economic systems, this despite the fact that technology is increasingly transcultural.[30] The development of new technologies and the relative improvement in the standard of living in the market-oriented Western nations where efficiency is stressed more than equity have been far greater than in the socialist, centrally-planned nations where equity is stressed more than efficiency.[31] On the other hand, in much of the Third World where both free market and centrally-planned economic systems prevail, technological change is less rapid than in either the East or the West.[32]

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[29] The assumption that technological change may be examined as a problem-solving activity was used by Rosenberg and Vincenti (1978) in their work on the history of the Britannia Bridge.

[30] For an excellent treatment of the transcultural nature of technology, see DeGregori (1985) and Lower (1988).

[31] See Rosenberg (1988) for more on this.

[32] It is beyond the scope of this project to go into the details of why this is so. Lingering effects of neo-colonialism, unequal exchange prices between primary commodities (of the Third World) and the finished products and machinery (of the developed nations), simmering internal problems due to semi-feudal social relations, ethnic and linguistic tensions, etc. might be a few, apart from differing value-systems and beliefs regarding social progress and economic development.

One of the significant aspects of technological change, as mentioned earlier, is transfer of technology between nations and cultures, an activity that has been going on since antiquity. Although the present trend is the transfer of technology from the West to East, before the onset of the Industrial Revolution in Europe, much of technology transfer was in the opposite direction.[33] The borrowing and importation of technological artifacts and know-how speed up the process of change in the technological knowledge base of the recipients.[34] The transferred technology often acts as a catalyst for further change by encouraging new inventions and innovations on the newly acquired technology. Technological change may be generally characterized as the combined effect of several technologically-related activities, such as invention, innovation, development, transfer and diffusion.[35] It is not necessary that these components have to follow the

[33] Lynn White (1962) and Joseph Needham (1954) have chronicled the massive transfer of technologies from India and China to Europe before the Industrial Revolution. According to DeGregori (1985:29) "The vast majority of the technology of any people was developed by others. We are all or have been borrowers of technology. Technology transfer is a constant facet of human history." Susskind (1973) also makes a similar claim.

[34] A thorough theoretical grounding in the process of technological change is thus essential for formulating technology policies geared toward successful technology transfer.

[35] This may be taken as a third definition of technological change, although it refers to the temporal and cumulative, and the structural characteristics of this phenomenon.

same sequence in every case involving technological change, nor for that matter is it necessary to have all these forces present in every case of technological change. Although these individual components are conceptually distinct, it is empirically often difficult to tell when one ends and the other begins. Bryant (1976) argues that the best approach to studying technological changes would be to treat them not as chronological sequences, but, instead, as forces operating in an interactive-dialectical manner following an evolutionary course.[36]

Like Bryant, most analysts emphasize different aspects of technological change depending upon their area of specialization or disciplinary areas in which they have been trained. Thus they tend to see the whole process (of technological change) just in terms of invention, innovation, transfer or diffusion. Schumpeter (1939), for example, considers innovation as the key force that brings about technological change and neglects or deemphasizes other forces like invention and transfer. Usher (1954), on the other hand, treats technological change as a "cumulative synthesis" of inventive activities. However, a careful analysis of Usher's model reveals that the constituents of the cumulative synthesis concept include other aspects of technological

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[36] Bryant identifies only invention, innovation, and development as these forces. Bryant explains the process of technological change in the case of the diesel engine between the period 1890-1908.

change like innovation and diffusion.

Gilfillan's (1970/1935) thirty-eight "social principles of invention" include references to other aspects of technological change like transfer, development and diffusion of technology, although he conflates all these into invention. Neoclassical economists generally emphasize innovation and invention.[37] Institutional economists, on the other hand, consider all aspects of technological change important, but emphasize diffusion and transfer of technology more.[38] Historians of technology who pay more attention to the internal history of technology seem to emphasize invention and transfer of technology.[39] Analysts of technological change who approach technological change using systems theory emphasize innovation and diffusion processes more than the others.[40] Also, there are several analysts of technological change who consider technological change as similar to or epistemologically akin to scientific change.[41]

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[37] See for example Schmookler (1966) [invention] and Mansfield (1961) [innovation].

[38] See for example Ruttan and Hayami (1973), Ruttan and Binswanger (1978), and DeGregori (1985), among others.

[39] See for example, White (1962) and David (1975). Hughes's (1983) systems model of technological change emphasizes the crucial role of inventor-entrepreneurs.

[40] While Sahal (1981a) emphasizes both, Saviotti emphasizes only innovation.

[41] While Constant (1973 and 1980) and Dosi (1982) argue that technological paradigms characterize technological change a la Kuhn (scientific paradigms), Nelson and Winter (1977) chart the path of technological change along a technological

The divergence of views, grouped as they are by discipline, helps to frame the following question: do disciplinary biases influence models of technological change in providing a complete and clear picture of this process? To answer this question it should be ascertained whether the frequent characterization of technological change in the literature as one of the component forces of this dynamic process is only a semantic problem, or that it goes deeper, in turn hampering a clear and complete conceptualization of technological change. Since there are no competent theories of technological change developed from an interdisciplinary stand-point or for that matter from a disciplinary perspective, it is an important problem in STS to take a unified approach to studying this phenomenon without being constrained by disciplinary loyalties.

The objectives of this dissertation are: (1) to evaluate various models of technological change, some of which were mentioned above, to determine if they offer a complete account, (2) to evaluate the interdisciplinary potential of these models, (3) to offer a comprehensive explanation of technological change after discussing strengths and weaknesses of the models, and (4) to build the groundwork for a theory of technological change from an STS perspective. Comparison of these models is emphasized, because it is a valuable first step toward developing a unified approach to the study of

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trajectory.

technological change through the individual disciplines and areas of inquiry from which these models are drawn. Since almost all of these models are legitimated by using different empirical examples, their comparative assessment requires us to apply them to explain a single case study.

The "Green Revolution" is used as the case study to apply to these models.[42] The Green Revolution is generally referred to as the change in agricultural technology experienced in some Third World countries in the 1960s and 1970s as a result of which their agricultural productivity increased appreciably.[43] The technological change may be succinctly put as follows: It involved the use of seeds of high-yielding varieties (HYVs), primarily of wheat and rice, which was eventually followed by a new culture of agricultural practice involving fertilizers, pesticides, controlled water, credits, mechanical threshers, tractors, pumps, rural electrification and roads, in place of 'traditional' agricultural practice involving the use of seeds whose genetic make-up goes back

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[42] Methodological guidelines on constructing this case study are partly drawn from Yin (1984). The case study will be developed by basically answering the "how" and "why" questions. How did technological change in agriculture take place, and why did these occur? The data for constructing the case study is collected from works depicting the scientific, technical, historical, economic, cultural, anthropological and political aspects of the process of technology transfer and other aspects of technological change. I will present the data depicting the development and diffusion of modern agriculture, and provide a chronologically-based account of events that culminated in this complex process.

[43] See Ruttan and Binswanger (1978:359) for a detailed definition of the Green Revolution. Also see Dalrymple (1979).

thousands of years. Traditional agricultural practice relied also on pre-industrial technologies and was dependent on the vagaries of monsoon rains. The case study is developed with particular reference to India. It is developed to highlight technology transfer as an integral part of technological change.

The inability to increase agricultural productivity to meet the growing food demands of a rapidly increasing rural and urban population through traditional agricultural practices was due to the constraints imposed by the stipulations of traditional customs, semi-feudal land relations, geographic conditions, natural forces, and pre-industrial technologies. Traditional agricultural technology included wooden ploughs, water wheels, and other 'simple' implements crafted by local artisans. The energy required for agriculture was provided by humans and animals. The fixed extent of the arable land (a fixed variable input), another serious bottle-neck along with all the other problems mentioned above, acted as focussing devices for the variation and selection processes. The solution for increasing productivity was to induce technological change in agricultural technology. The change had to come not only at the artifactual level, but at the cognitive level--involving the creation of a new form of knowledge in agricultural technology itself. The Green Revolution was, in the final analysis, the result of the introduction of a "New

Agricultural Policy."

The rationale for using the Green Revolution as a case study is based on the fact that it is a comprehensive example, containing all the constituent forces involved in such instances. Also, this case study provides a clear exposition of the process of technology transfer from the West to the Third World. Examination of this case further corroborates the claim that invention, innovation, transfer, and diffusion do not follow a sequential linear law-like fashion, but instead, that these forces act interactively. Secondly, unlike most case studies involving embodied technologies (artifacts), this case study involves both tangible and intangible technologies. Thirdly, this case involves the processual steps that bring forth the change in knowledge more clearly than in other instances of technological change. Fourthly, this is a case study of a relatively new technology that emerged only three decades ago. And, finally by using a case study of technological change from the Third World, it is hoped that we can understand better the dynamics of technology transfer (to the Third World) and thus influence the formulation of enlightened technology policies there.

The case study is developed based on the contention that technological change is essentially a qualitative phenomenon. This is a fundamental premise in the reconstruction of the history of the Green Revolution. Mathematical and econometric models of technological change do not represent this phenomenon correctly or completely. For example, counting patent statistics in an industry as a representative trend of technological change in fact tells us very little about technological change.[44] There are some analysts of technological change who use econometric models to explain diffusion of new technologies.[45] Although these exercises might explain the rate of diffusion of a new technology, they do not tell us the underlying extant factors responsible for the adoption of new technologies. To accomplish this, nearly all the analysts of technological change use qualitative methods. The case study thus focusses on how different forces were brought together by the planners and policy-makers to create the Green Revolution.

I then apply the various models of technological change found in the literature, most of which are discussed along disciplinary lines, to the account of the Green Revolution as a method of testing them, in order to ascertain whether these models can transcend the narrow empirical basis within which they are legitimated and also to capture the essence of technological change as a multi-dimensional and dynamic process. One of the important issues examined is whether

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[44] It may reflect the rate of invention in a industry, but does not tell us how inventions are carried out. Schmookler's (1966) methodology of studying the trend of technological change using patent statistics suffers from such an inadequacy.

[45] This practice is popular among economists. See Sahal (1981a) and Mansfield (1966).

technological change follows the same pattern in every technology and whether it can be explicated by a universal model.

I first specify the central features of the discipline-based models, and show how these models would explain the process of technological change in the case of the Green Revolution. The central features of these models may be likened to a paradigm or disciplinary matrix (Kuhn, 1970), research programme (Lakatos, 1978), research tradition (Laudan, 1977), etc., as found in philosophy of science. Although it is not necessary that such corresponding categories be found in the literature on technological change, categories like technological paradigms (Dosi, 1982; Constant, 1972 and 1980), technological trajectories (Nelson and Winter, 1977), and technological guideposts (Sahal, 1981a) in the literature may be inspired by parallel developments in the discussion of scientific change.

The same explanatory technique will be used for accounting for the Green Revolution in each of the models chosen from the four disciplines or areas of inquiry - economics, history, sociology, and neo-Schumpeterian-evolutionary and systems theory. This method makes it easy to ascertain the strengths and weaknesses of these models. This way we will be able to find out whether some models are specific to certain technologies.

The organization of the dissertation is as follows. A detailed case study of the Green Revolution is provided in Chapter Two. The main focus of this exercise is a "reconstruction" of the history of the Green Revolution with particular reference to India.

In Chapter Three the models of technological change discussed in economics and history are presented and appropriate criticisms offered. Then prominent models from each of these disciplines are applied to the case study to account for the Green Revolution. The models chosen from economics are neoclassical, Schumpeterian, and institutional (induced innovation). The models of technological change offered by Usher and Hughes are the ones selected from history.

In Chapter Four models of technological change found in sociology and neo-Schumpeterian-evolutionary models are discussed and critiqued. Then prominent models from each of these areas are applied to the case study to account for the Green Revolution. From sociology, the models chosen are the social constructivist and the actor network-heterogeneous engineering models. From the area of technological change inspired by evolutionary studies, the models of Dosi and Sahal are selected.

Chapter Five brings together the conclusions drawn from this research project. The answers to some of the questions at the beginning of this Chapter are presented. How an interdisciplinary model of technological change can be built, and how the methods of STS can contribute to such an exercise are discussed in this chapter. Integrating the strong features from several of these models is an important element of this approach.

Finally, the most important question posed at the beginning of this project--what is technological change?--is answered. It is argued that the models of technological change discussed in this project did not comprehend it completely because they stopped their inquiry at the artifactual level. It is, therefore, further argued that technological change is not only artifactual change, but a form of knowledge change as well. The failure to conceptualize technological change as essentially cognitive change is the major reason for the failure of these models to adequately represent this multidimensional phenomenon.

CHAPTER TWO
THE GREEN REVOLUTION: A CASE STUDY

1. INTRODUCTION

The objective of this chapter is to reconstruct the history of the Green Revolution. We shall then apply the models of technological change discussed in various disciplines and areas of inquiry to ascertain their applicability to the problem of understanding the phenomenon of technological change. The case study will be developed with emphasis on the Indian experience, highlighting the process of technology transfer from different parts of the world to India. It shows how a combination of agricultural technologies transferred from the United States, Mexico and the Philippines was adapted to the Indian situation. The Green Revolution is an instance of a successful technology transfer, notwithstanding the many problems associated with it. These include making the technology location-specific and latent problems of unregulated use of pesticides and agricultural machinery.

The term "Green Revolution"[1] is generally used to denote the increase in cereal productivity experienced in some Third

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[1] The term "Green Revolution" was first suggested by William Gaud in a speech entitled "The Green Revolution: Accomplishments and Apprehensions," at a meeting of the Society for International Development in 1968 (Ruttan and Binswanger 1978:359). Also, see Dalrymple (1979).

World countries, as a result of the change in agricultural technology during the 1960s and 70s.[2] Generally, it involved the use of seeds of high-yielding varieties (HYVs), primarily of wheat and rice, and the introduction of a new culture of agricultural practice involving fertilizers, pesticides, controlled water, credits, mechanical threshers, tractors, and pumps beginning in the mid-1960s.[3] These changes were instituted in place of the 'traditional' agricultural practice involving the use of seeds whose genetic make-up goes back to thousands of years. The 'traditional' practice involved the use of pre-industrial technologies,[4] and it was largely dependent on the vagaries of monsoon rains. The average yield of rice per hectare before the introduction of the new technology was between 1.5 and 3.0 metric tons and after its introduction ranged between 5 and 10 metric tons (Chandler 1973:26). For wheat, the yield per hectare after the new technology ranged from 6 to 8 tons instead of the average yield of 3 tons before the new technology (ibid:27).

In areas where the Green Revolution was successful the increased productivity of the land was accompanied by lasting and irreversible changes in the knowledge content of

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[2] Some analysts refer this as the "First" Green Revolution. The 1980's is considered the beginning of the "Second" Green Revolution. See Raj Chengappa (1989).

[3] See Ruttan and Binswanger (1978:359).

[4] These include wooden ploughs, water wheels, and bullock carts, among others. The energy required for all agricultural activities provided by animals and humans.

agricultural technology of the peasant cultivators. Before the Green Revolution, almost all cultivators were peasants who mainly produced for subsistence. Markets were rudimentary or non-existent. Peasants obtained what they could not produce but needed for subsistence from other peasants by exchanging grains and whatever other commodities they produced. Agricultural laborers and other rural skilled laborers like carpenters and blacksmiths were mostly paid in grain or other agricultural produce. Their technology was pre-industrial, with energy supplied mainly by humans and animals.

The Green Revolution within a short span of two decades, replaced one way of life by another. The peasant cultivators became farmers for whom agriculture became a calling beyond subsistence as a result of the technological change.[5] They sold most of their produce in the markets. Agricultural laborers and other skilled workers whose help was needed in maintaining agricultural tools and machinery were paid in cash. Along with the increase in agricultural productivity came a higher demand for farm labor and with this came increased wages. Wages sometimes doubled in four to five years. Modern technology completely replaced the traditional technology. The social, political, economic, and cultural gap between rural and urban areas began to dwindle in areas where

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[5] Some analysts equate the transformation of agriculture from subsistence farming to one in which considerations of profit and market production dominated to a "business for profit." See, for example, Aggarwal (1974).

the Green Revolution took a firm hold.

A review of pertinent literature on the Green Revolution will be presented first, followed by a brief discussion of the historical background to the agricultural situation in India before the onset of the Green Revolution.

2. LITERATURE REVIEW

The phrase 'Green Revolution'[6] is used here to refer to the change brought about as a result of the application of science and technology to traditional agriculture, resulting in great increases in cereal productivity using primarily high-yielding varieties of rice and wheat. The phrase 'Green Revolution' was coined by William Gaud, in his address to the Society for International Development in Washington, DC in March 1968 (Dalrymple, 1979:723). Gaud was referring to the new high-yielding varieties (HYVs) of seeds introduced in Third World agriculture. These were giving bountiful harvests under controlled conditions. Murray Leaf (1984) claims that the Green Revolution can be construed in a narrow and in a broad sense. In the narrow sense, it is the increase in cereal productivity associated with the new technology. In the broad sense, it is the ecological, social, economic, and cultural changes that occurred as a result of the introduction of the

[6] A more detailed definition is offered by Binswanger and Ruttan (1978). Also, see chapter three of this dissertation.

new technology. In this project, I am concerned with the latter.

Falling into neither of the categories delineated by Leaf, Lester Brown (1970), one of the early enthusiasts of the Green Revolution, presents a case for the great potential inherent in this technological breakthrough for the people in the developing world. Brown compares the significance of the development and dissemination of the IR-8 rice seeds in the 1960s to the landing of the first astronauts on the moon. Brown's comparison of these two technological accomplishments is lopsided.[7] Part I of the book presents an historical outline of the technological breakthrough. Part II discusses the channel by which this technology was transferred to Asia, Africa, and Latin America, and the institutionalization of this process by the research institutions, support agencies, national and international development institutions, among others. The rest of the book discusses the "second generation" problems associated with the Green Revolution, such as problems related to the lack of marketing agencies, storage facilities, population, and unemployment. Brown's presentation seems to be a passionate attempt to glorify the Green Revolution as the last best hope to solve the food problem in the Third World. Though substantial progress has been made in cereal production due to the Green Revolution, Keith Griffin

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[7] He seems to be equating the significance of the development of the IR-8 to the Third World people with the landing on the moon to the Americans.

(1979) argues that Brown's claims of the results of the HYVs are exaggerated.

In contrast to Brown's assessment of the Green Revolution from an administrator-bureaucrat's perspective, Norman Borlaug (1970), recipient of the 1970 Nobel Peace Prize for his contributions to the Green Revolution, expresses his personal reflections on the history of the development of the HYVs from an insider's perspective. Borlaug explains that the great increase in wheat, rice, and maize yields in Mexico, India, and Pakistan and a few other Third World countries is based on sound research and careful technology management conducted at the International Rice Research Institute in the Philippines, the International Center for Maize and Wheat Improvement in Mexico, and several other national and international agencies and institutions. Borlaug's narration of the Green Revolution is anecdotal and often personal, and thus lacks analytical rigour.[8]

There are not many historiographic accounts of the Green Revolution. Most analyses of Green Revolution are done for impact studies or for economic history. The adoption of the new HYV seeds was not universal. The literature seems to be skewed around the Asian experience, particularly on India. Walter Falcon (1970) examines the state of the Green Revolution until 1970 in an attempt to uncover the problems

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[8] However, looking at from a different perspective, Borlaug's work may be treated as a primary historical source.

associated with the new technology. Falcon's concerns are with the factors associated with the introduction of the new seeds, such as irrigation, fertilizers, and pesticides which he calls the "First Generation" problems. The "Second Generation" problems that Falcon describes are issues related to marketing and resource allocation in the rural economy. The "Third Generation" problems, according to Falcon, are concerned with equity, welfare, and employment issues resulting from the technological change. Unlike Falcon's method of concentrating on equity and institutional aspects of the Green Revolution, Dana Dalrymple (1976, 1979, and 1985) presents an historical background of the adoption of HYVs with an objective to provide an analytical framework for the evaluation of the Green Revolution. Dalrymple attempts to delve into the factors behind the adoption of HYVs and the economic consequences of the adoption. He (1976) also provides a concise and well researched history of the development HYVs and shows that the dwarf varieties of rice and wheat originated in China and Japan respectively.[9]

Lacking Dalrymple's flair for analyzing historical details, Carl Pray (1981) delineates the short history of the transfer process of the Green Revolution from the point of view of an economic historian. Pray uses the Green Revolution as a case study to explain the transfer of the technology from

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[9] Ruttan and Binswanger (1978) complain that some analysts of technological change, still hold the view that the HYVs were the sole creation of a few Western nations.

the West to the Third World. His narrative is journalistic, and does not aid our understanding of the dynamics of technology transfer. In contrast to Pray, Ruttan and Binswanger (1978) use the Green Revolution to support their theory of induced innovation.[10] Ruttan also discusses various aspects of the Green Revolution in several other articles (e.g. 1975, 1977 and 1978b). Another neoclassical institutionalist, Hayami (1971), discusses the early history of the Green Revolution with particular reference to the development of HYVs in Japan.[11]

Perhaps the most prolific writer on the subject of the Green Revolution is Ruttan. Based on the empirical evidence gained from the study of the adoption and diffusion pattern of the Green Revolution, Ruttan (1977) delineates seven generalizations: (1) the new wheat and rice varieties were adopted rapidly in areas where they were technically and economically superior to local varieties (e.g. Indian Punjab); (2) neither farm size nor tenure has been a serious constraint on the adoption of the HYVs; (3) neither farm size nor tenure has been a source of differential growth in productivity; (4)

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[10] The theory of induced innovation, according to Ruttan and Binswanger (1978:358) authors "implies a dynamic, dialectical interaction between technical and institutional change." The problems that the innovation models have were discussed earlier in Section 2.

[11] The transfer of HYV rice seeds from Japan to Taiwan is an important episode in the history of the Green Revolution in the Third World. The genetic material for the modern varieties of HYV rice seeds came mostly from Taiwan.

the introduction of the HYVs has created an increased demand for labor; (5) the introduction of the HYVs has benefitted land owners more than tenants; (6) the introduction of the HYVs has created income and wage differential among regions; and (7) the effect of the introduction of the HYVs has been to reduce the price of food for consumers.[12] Although Ruttan's primary interest in the Green Revolution was in using it to explain his model of induced innovation, he provides much useful information for the present project. The information he gives on international aid agencies and agricultural research institutions is valuable for reconstructing the history of the Green Revolution.[13]

Concentrating in particular on just one element of the Green Revolution (unlike Ruttan, Hayami, Falcon, Dalrymple, and Pray, among others) a comprehensive coverage of the changes that occurred in Asian rice economy since the Second World War has been provided by Randolph Barker, Robert Herdt, and Beth Rose (1985). These authors are particularly interested in the period after 1965 when the modern high-yielding varieties of seeds were introduced in traditional agriculture in Asia. This book gives an excellent coverage of

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[12] Although Ruttan explains these findings in considerable detail, they do not help us comprehend the inner dynamics of the process of technological change. They, however, do provide the institutional characteristics of the distribution of the HYVs.

[13] More details on these are provided in Ruttan (1975 and 1978b).

the state of rice production and the associated technological factors, but avoids the technical content of the new technology since the authors rationalize that their audience is predominantly policy-makers in public bureaucracies. Shifting the focus from rice cultivation to the new technology, Barker (1971) argues that the technological change associated with the introduction of HYVs should not be considered as a one-shot achievement, but instead as an evolutionary process. Offering a much more coherent internalist account of the new HYV technology, Robert Chandler (1973) explains the scientific and technical basis of the new yield capacity of the new rice and wheat seeds. Chandler's analysis, although brief, is a good introduction to the technological factors behind the Green Revolution.

Literature on the technological details of the Green Revolution is scarce, while there is a proliferation of literature on the political, institutional, and socio-political aspects. In an edited volume Robert Anderson et al. (1982) review the agricultural revolution in Asia, concentrating more on the political and institutional aspects of the technological change. The volume stresses more on the institutional aspects, particularly the roles played by national governments and international agencies in developing the Green Revolution. Following this trend of concentrating on the institutional factors, the International Rice Research Institute (1975) commissioned a comprehensive study to find out the impact of the new HYV rice seeds in Asia. This study is less analytic than quantitative in nature and hence does not offer much in terms of understanding the technological change.

Continuing with the historical development of the Green Revolution in Asia, R.T. Shand (1973), in a collected volume, presents a detailed historical account of the Green Revolution. Studies of earlier developments in Japan, as compared to those taking place in a few developing countries in Asia, and the analyses of technological change from sociological, economic, and political perspectives are novel aspects of this volume. Another volume that concentrates on the Asian experience with a particular emphasis on South Asia are presented by Tim Bayless-Smith and Sudhir Wanmali (1984). "Understanding Green Revolution" is the objective of the book, and with this objective the editors of the volume present several micro-level case studies on the Indian experience of the Green Revolution. The analytic focus of most of the articles is on equity and distributional aspects of the Green Revolution. Bayless-Smith and Wanmali have essentially followed the same perspectives as B.H. Farmer (1977 and 1981) who also presents an overall assessment of the Green Revolution in South Asia. Though admitting that there were favorable production effects in South Asia due to the introduction of the HYVs, Farmer argues that the revolutionary character of the Green Revolution is an exaggeration because of adverse ecological and land-tenure situations in this region. Farmer's volume is based on field studies conducted by researchers and field workers in India and Sri Lanka. One facet of the HYV-based technology the volume highlights is that more than the seeds themselves, it was the irrigation facilities that improved the rice crops. Though generally critical of the negative impacts of the Green Revolution on landless peasants, the volume provides some valuable information about the Green Revolution in India, particularly the history of the introduction of the HYVs and the ensuing changes in traditional agriculture. Though the literature shows a bias toward the Asian experience, most literature on Asia is centered on the Indian experience.

C. Subramanian (1979) presents a comprehensive and authoritative account of his experience as one of the prominent architects of the Green Revolution in India. As the union[14] minister in charge of the agriculture and food portfolio, Subramaniam played a key role in formulating the "New Agriculture Strategy in Indian Agriculture," which was one of the important policy instruments that helped to start the Green Revolution. One of the most important contributions of Subramanian was the reorganization of agricultural research in India. Although he does not admit policy failures or contrary views, much of what Subramaniam presents in this thin

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[14] India has a federal structure like the United States. In India, the term "union' is used instead of "federal" to refer to the national government.

volume[15] stand on its own as authoritative and coherent. The launching of the HYV program on a national scale that he presents is comprehensive and innovative.

Although Subramaniam discusses the agricultural situation in India prior to the implementation of the policies that created the Green Revolution, I consult several other source for this purpose. The general productivity trend and agricultural practices during the colonial period were clearly documented and discussed by Blyn (1966), Sen (1967), Mukherjee and Lockwood (1973), Dasgupta (1977), and Bettelheim (1968), among others. Indian agriculture during the colonial period was analyzed by Barrington Moore (1967). Moore's discussion is highly evocative, and is one of the best historical writings on issues related to social and economic developments during the colonial period. Mohan and Evenson (1973) present details of the agricultural research system in India during the colonial regime. They clearly delineate the neglect of research on increasing food production by the colonial regime in favor of exportable commercial crops. Bettelheim (1968) and Dantwala (1973), among others, chronicle the disastrous food situation in India up to the middle of 1960s when the new agricultural policy was implemented on a massive scale by the

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[15] The book was primarily a collection of seminar presentations and classes given by Subramaniam, after his retirement from public service, at the Australian National University in 1978. This is probably the most authoritative primary source on the history of the Green Revolution in India.

Indian government.

The introduction of the Green Revolution technology in India was first done in the Punjab State of India. M.S. Randhawa (1974) profiles the significant role of education in fostering the Green Revolution in the Punjab. Leaf (1984) studied the impact of the new agricultural technology in a Punjab village by showing that the rural institutions had enthusiastically assimilated the changes without social dislocation. Arguing from an anthropologist's perspective, Leaf offers an excellent analysis of the cultural, social, and political changes in the Punjab during the period of the Green Revolution. Richard Kurin (1985:179) credits Leaf for not viewing the Green Revolution in "narrow agricultural terms, but as a complex set of events occasioning ecological, managerial, economic, religious, and political changes." However, Kurin criticizes Leaf's data as being not entirely representative of the whole of Punjab, and questions the wisdom of oversimplifying political realities. George Blyn's (1983) field study in the Punjab and Hariyana States concludes that the scale neutrality of the HYV-based technology with respect to land holdings helps small holders because of greater productivity of smaller holdings. Blyn concentrates on the economic indicators of the technological change and does not pay much attention to the technology itself. These studies of the Green Revolution based on field research in India provide valuable information on the economic, political, social, cultural, and others factors related to the new technology.

Following the same trend as above, R.K. Jayaprakash (1973) explains the technical details of the HYV seeds and the socio-economic impact of the adoption of the seeds in Indian agriculture. Jayaprakash's technical analysis of the new technology is lucid, but the impact study is rather loose as he heavily borrows statistics to explain it. In another study concentrating on the new seeds, Mahabal Ram (1975) presents the history of the development of dwarf rice seedlings during the ten-year period of the Green Revolution in India, which many analysts consider to be from 1965 till 1975.[16] Biplab Dasgupta (1977) looks at the social and economic consequences of the introduction of HYVs in Indian agriculture, and attempts to identify the factors behind the successes in adopting the new seeds in traditional agriculture. Moving away from the details of the seeds and instead to the diffusion of them in Indian agriculture, Bandhudas Sen (1974) presents the adoption pattern of the HYVs to analyze the economic consequences of the Green Revolution in India. This book again is another work in the "economics of the Green Revolution" and tries to account for technological change by relying on statistical data and hence limits its contribution to describing the Green Revolution with emphasis on the technology.

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[16] See Ruttan and Binswanger (1978:358).

One of the most recent works on the Green Revolution in India, particularly on the history of the development of a national agricultural research capacity, is provided by Lele and Goldsmith (1989). Their primary focus is the role of the Rockefeller Foundation in helping to develop the agricultural research system in India.[17] They argue that the ability to conduct research at the local and national level was the most important determinant of technological change. This understood, Lele and Goldsmith contend that the Indian agricultural planners sought out the most helpful sources. The services of the Ford Foundation, the Rockefeller Foundation, and the United States Department of Agriculture were very valuable for the development of a modern agricultural research capability in India.[18]

Like many of the authors mentioned above who are primarily concerned about the impact of technological change as a result of the introduction of the Green Revolution, Keith Griffin (1974) analyzes the social, economic, and political

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[17] Lele and Goldsmith conclude that the Indian experience in developing a successful national research capacity that enabled the nation to become self-sufficient in food production for a number of years should be a valuable lesson for African countries.

[18] Lele and Goldsmith concentrate on the involvement of the Rockefeller Foundation because they claim that enough has been written about the role of the other agencies mentioned earlier. Their work is based on archival sources which were recently made public by the Rockefeller Foundation about its experience in India, and also based on extensive interviews with Indian and American officials involved in the agricultural modernization of India.

implications of the introduction of HYVs in Asia. Griffin analyses the "biased" effects of technological change and resource allocation in rural areas that helped large land owners so that the benefits tend to concentrate in already well-off areas. He contends that the popular notion that peasants are irrational and hence averse to modernization of technology is incorrect. He concludes that lack of innovation is not due to lack of motivation on the part of peasants, but due to "inadequate opportunities" (1974:186).[19] Griffin's analysis of the impact of the introduction of the HYVs is cautious and critical. As outspoken as Griffin, Frances Frankel (1971) argues that the gains of the new technology were unevenly distributed, because the new technology was introduced in a setting where rich farmers had always enjoyed a technological advantage over small peasant farmers. She supports her studies with economic data from Punjab, Kerala, Tamil Nadu, Andra Pradesh, and West Bengal States of India. More than the technology, Frankel is interested in the social relationships due to economic disparities caused by technological change.

In a different approach from the economists and political scientists presented above, B. Bowonder (1979) has conducted

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[19] Frank Miller (1975) argues that Griffin's presentation of the Green Revolution re-emphasizes the need for a multi-disciplinary approach to the process of technology assessment. However, he further adds that Griffin's analysis seems to indicate that government policies are the most influential ones in shaping the impact of technology on society than the intrinsic qualities of the technology itself.

a brief technology assessment of the new agricultural technology in India. Bowonder concludes that though the achievements of the new HYV-based technology were impressive, proper assessments of the technology before its introduction could have avoided many of its negative consequences. He says that the "new technology intertwined with the lack of education inputs, lack of provision of equal opportunities for credit, along with the existence of wide disparities, has mainly favored the rich farmers" (1979:312). Though it is true that rich farmers were able to take advantage of the new technology more aggressively than small holders in some parts of the country, Bowonder's sweeping generalization based on seemingly unrelated quantitative data cannot be taken at face value.[20] In fact Gartrell (1977), a sociologist, disputes Bowonder's findings and instead shows that small holders took better advantage of the technology than rich farmers in India.

Some of the sociological studies conducted on the diffusion of Green Revolution are quantitative in nature. Frank Cancian (1967), in an examination of the economic status (wealth) and innovation in agriculture found the relationship to be inverse. Cancian concludes that theories of risk-taking may be more important than theories of diffusion of new technology for the adoption of the new technology. Hence policy-makers should concentrate on the lower strata of the

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[20] Also, works based on extensive field research conducted by Blyn (1983) and Leaf (1984) largely disprove this claim.

society (because it takes more risk) to introduce a new technology. Based on information about the adoption and diffusion of the Green Revolution in eighty-four villages in Andra Pradesh, India, Gartrell (1977) disputes Cancian's theory. Gartrell's study seems to be pointing at the fact that peasant farmers are rational, and they know when and how to take risk in the introduction of a new technology. Gartrell claims that government intervention, urban influence, greater mobility, and market penetration of rural areas tend to play a bigger role in risk-taking than economic status.[21]

Though there is not much published literature that discounts the production impact of the Green Revolution, there are plenty of radical political economists and environmentalists who complain about the skewed distributive effect of the benefits of the Green Revolution, and the environmental problems associated with the new "seed-fertilizer-pesticide" agricultural technology.[22] Based on the history of the production relations of agrarian society in

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[21] Although more analytic and evocative than the diffusion model in explaining the adoption of a new technology by the peasants, Gartrell, like the diffusionists miss one important point. That is, the peasant farmers take the risk only after they are convinced that the new technology is superior to the old one. It is the nature of the technology that is more important than the availability of markets and opportunities for social mobilities, etc.

[22] Pesticides and other chemical agents do reach the food chain in alarming amounts in areas where they are used without proper guidance and safety equipment. See a report on the increasing presence of pesticides in food in India in India Today June 30, 1989.

India as a result of the Green Revolution, Lakshman Yapa (1977) argues that farmers who have privileged access to agricultural inputs benefit more than underprivileged peasant farmers. He calls the extra profit a sort of "class rent," because this profit is earned because of the class privileges enjoyed by the rich landlords. Yapa (1977) complains about the ecological problems associated with the Green Revolution, and Ali Fatemi (1972) using a Marxist framework calls the Green Revolution a "conflux of contradictions." Based on field research in South India, Kathleen Gough (1978:12), concludes that "Although paddy production has increased by almost five times....the main impact of both land reforms and the green revolution has been bad for most of the small holders and cultivating tenants, and the agricultural laborers,.. except for the ...landlords and the more enterprising rich peasants."[23] Bernhard Glaeser (1987), in a collected work, re-examines the impact of the Green Revolution. Though not discounting the productive impact of the Green Revolution, Glaeser and others in this volume exhort the need for a different policy framework to alleviate the distributional problems associated with rural poverty in India and other

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[23] Indian experience shows that where land reform was speedy and successful the Green Revolution was successful as well. Also, Blyn's (1983) field research shows that small holders benefitted more than large holders because small farms were more efficient in using the technology than large ones (with the technology being scale neutral). Rapid land reforms is one of the important preconditions for bringing technological change in Indian agriculture.

Third World countries.

Most of the available literature on the Green Revolution is primarily concerned with the productive forces of technological change and the ensuing structural changes in the economic output. In other words, it deals with the technological change resulting from the introduction of the new technology and the ensuing increases in agricultural productivity and the distributive effects of the changes. Few historians of technology have ventured to study the Green Revolution, because of their concentration on technological change in the industrialized countries.

There are only a few works on the Green Revolution with a primary emphasis on technology. Most studies of the Green Revolution are concerned with the economic, social, cultural, political, and environmental impacts of the new technology. In the following reconstruction of the Green Revolution my objective is to explain the technological change from the traditional agricultural practices to the modern.

3. BACKGROUND: THE AGRICULTURAL SITUATION IN INDIA

The growth in agricultural production in India right up to the year 1965 was disappointingly low (Dantwala, 1973), and the possibility of severe famines was predicted. Although the failure of its agriculture to meet the needs of India's population from the time of independence in 1947 until 1965 reflected the neglect of agriculture in favor of the industrial sector in general, this failure should be compared to the deplorable agricultural situation in India during the British colonial regime.[24] It is only fair to say that the stagnation of agriculture during the colonial period left behind a worsening food situation in India.[25] Disastrous droughts combined with relatively little technological change and sluggish land reforms resulted in almost no increase in agricultural productivity. This brought India to the brink of famine in the mid-1960s. It was averted by massive shipments of subsidized food grains from the United States (Subramaniam, 1979; Brown, 1970).[26] These events in turn set the stage for

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[24] According to the estimates of S.R. Sen (1967) the average annual food grain increase in India from 1901 till 1947/48 was a meager 0.3 percent. In fact, during the 1930s the population growth rate outstripped the growth rate of foodgrain (Mukherjee and Lockwood, 1973). According to the estimates of George Blyn (1966), the average growth in food grain production from 1891 to 1947 was 0.11 percent. Dantwala (1973) estimates that from 1937/38 till 1952/52 the food grain production in India declined at a rate of 0.68 per cent per year. Whatever little increases in agricultural production from the time of independence till early 1960s was attributable to increase in acreage (Biplab Dasgupta, 1977). Famines were a frequent occurrence in British India. The most recent disastrous Bengal famine during 1942-43 left nearly 3.5 million people dead.(Bettelheim 1968:8).

[25] The stagnation in Indian agriculture during the colonial period was analyzed by Barrington Moore (1967) and George Blyn (1966). However, Christopher Barker (1984) points out that there was a resurgence in productivity of export-oriented cash crops during the colonial period.

[26] Based on the worsening food situation in India and other Third World countries, some western observers hoped that Malthus could be vindicated by the situation in the Third World. Words like "triage" and "basket case" were used by some cynical analysts. William and Paul Paddock (1967) predicted that massive famine would afflict India and other Third World

the development of new thinking on the part of policy makers and donor agencies to increase cereal productivity by inducing changes in the prevailing agricultural technology (Subramaniam, 1979).

Agricultural practices and technology in India, as in many other Third World countries, had not changed perceptibly for thousands of years. This is highly surprising when compared to the views of visiting English agricultural scientists and explorers of Indian agricultural technology in the eighteenth and nineteenth centuries.[27] Captain T. Halcott writes in 1796 that "Until lately I imagined the drill plough to be a modern European invention,... but I find it in general use here."[28] In a report written in 1820 Alexander Walker observes that, "I am at a loss to know what essential present [in agriculture] we can make to India."[29] Walker further adds that the "Hindoos" have been in possession of the drill plough (which he describes as one of the "most beautiful inventions in agriculture") since antiquity.[30]

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countries by the year 1975.

[27] It must be remembered that these reports were written before Queen Victoria became the Empress of India. While these visitors were in India, only parts of India was under the control of the British East India Company, a trade group which had been only nominally represented by the queen of England.

[28]. Thos Halcott (1796), "On the Drill Husbandry of Southern India," in Dharampal (1971), pp. 210-214.

[29] See Alexander Walker, (1820) "Indian Agriculture," reprinted in Dharampal (1971:179-209).

[30] ibid.:4-5.

While the agricultural technology in India at the time of the British invasion was comparable or even superior to the agricultural technology in Europe, it is amazing that while agricultural technology changed dramatically in Europe during the ensuing two centuries, it remained stagnant in India. This statement must be qualified, because the stagnation was felt only in peasant agriculture which used to be and continues to be the mainstay of the majority of people in the Indian subcontinent. Whatever new technology the British colonial administration introduced in agricultural practices was intended only to boost the production of commercial crops, such as cotton, tea, coffee, jute, rubber and spices which served its own interest (Mohan and Evenson, 1973; Barker, 1984).

Village-based subsistence agriculture used to be the norm for most peasants in much of rural India (Mukherjee and Lockwood, 1973). Almost all the agricultural "rent fund" was expropriated by the landlords. The peasants and agricultural workers maintained a marginal living.[31] There was little incentive on the part of peasant farmers, most of whom did not

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[31] The agricultural system was predominantly feudal. Most land owners rented their land to the peasants, or retained large numbers of bonded agricultural workers in heir farms where the workers were provided with the basic minimum for survival. One of these local security systems was called jajamani, which was "a set of moral, ritual, and economic bonds between patrons (often local land controllers) and clients (often agricultural laborers)" (Appadurai, 1989:173).

own the land, to innovate.[32] Such innovations as occurred in agricultural technology were confined to large commercial estates mostly owned by the British making no inroads into the hinterlands.[33] Thus, at the time of independence India was a vastly poor nation with almost ninety percent of its population living in nearly 600,000 villages dependent on agriculture (Mukherjee and Lockwood, 1973; Stakman et al., 1967; and Bettelheim, 1968). Indian agricultural technology at the time of independence was essentially the same as it had been hundreds of years earlier. Farm work was done manually by simple tools. Energy was supplied by humans and animals. Bullocks provided draft power for ploughing, irrigating, and hauling. Persian wheels drawn by animals were used for lifting irrigation water from shallow ponds and wells. The soil was fertilized by animal and human waste. Mostly, one crop a year was grown. The productivity of the land varied according to the vagaries of the monsoon rains.

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[32] While tilling the land was the traditional job of the lowest castes of the Hindu hierarchy, the land belonged to people of higher castes. The consolidation of power by the British saw the creation of a new class of land owners called the zamindars. The British colonial authorities entrusted the zamindars to collect a fixed revenue from the tillers. According to Wolf Ladejinsky (1973:239) the zamindary system was one of the worst abuses perpetrated upon the peasantry in colonial India. Having no rights on the land and their crops, the peasants obviously had no interest in looking for new technology and agricultural practices.

[33] These farms were owned by rich Indians and British citizens to produce commercial crops like tea, rubber, spices, and cotton. New agricultural technology was available for commercial estates at the same time as such technology became available in Britain.

The years after independence (1947) saw a steady decline in the production of cereals in India (Mukherjee and Lockwood, 1973). Thus the First Five-Year Plan (1951-56) was primarily devoted to agriculture and rural development. Small increases in production due to increases in irrigated land, new acreage, and favorable monsoons, made the planners think that the food problem had been solved. They therefore decided to concentrate on industrial development in the Second Five-Year Plan (1956-61) (ibid:53-54).[34] Instead of keeping up the momentum generated by the First Plan by improving land-reform programs, providing credits to buy seeds and fertilizers, constructing rural roads, power lines and irrigation facilities, and introducing new agricultural technology, the government unwisely changed its course of development by switching in favor of industries. This left the farmers and peasants to fend for themselves. A rude awakening as a result of the deteriorating food situation in the early to mid-1960s[35] forced

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[34] The planners had the idea that the rural sector would provide the cheap food for industrial expansion. The Arthur Lewis dual economy model of industrial development, and the modified Harrod-Domar growth models were popular at this time among Third World planners. The first prime minister of India, Jawaharlal Nehru preferred massive industrialization by investing in heavy industries. Nehru's plan was that the industrialization of the country would absorb the excess labor from the rural sector, and he believed that eventually the agriculture sector would take care of itself by the feedback from the progressive modern industrial sector.

[35] According to Biplab Dasgupta (1977) the economic situation in India during the mid-1960s was the worst ever during the post-independent period. Per capita income reached the lowest, unemployment was rising, and the country was heavily dependent on foreign food aid.

the policy-makers in India to concentrate on improving agricultural technology, aiming at self-sufficiency in cereal production (Subramaniam, 1979). But there was no more land to be brought under the plough, as almost all arable land was already cultivated. Therefore, the only way to attain self-sufficiency in food was to introduce modern technology that would augment cereal production with land as the fixed variable (Dasgupta, 1977).

4. THE AGRICULTURAL REVOLUTION:[36] AN HISTORICAL PERSPECTIVE

The tendency to characterize the rate, degree, and nature of change in the history of agriculture as "revolutionary" is as tempting as labeling important events as revolutions in other social sciences. "Agricultural revolution" has been a term widely used to describe historical events in agriculture in different parts of the world (Ross and Tontz, 1948). They point out that many of the changes that agricultural historians describe as "revolutionary," in fact, are "evolutionary" in nature.

There is no consensus yet among historians as to when the agricultural revolution occurred in Europe (Grigg, 1984). Lynn White (1962) claims that the demographic turn-around during the Middle Ages was caused by an agricultural revolution

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[36] The term 'revolution' is construed as a "relatively sudden set of changes that yield a state of affairs from which a return to the situation just before the revolution is virtually impossible" (Hockett and Ascher, 1964:135).

spurred by technological change. He claims that the revolution began in the sixth century and tapered off in the ninth century. Increased use of iron and the development of the horseshoe and collar[37] are considered to be the most important innovations that led to this change.

Commenting specifically on English agriculture, Ernle (1968) contends that the agricultural revolution was set off in 1760 and ended in 1820.[38] The Marxian analysis of English agriculture, the "Enclosure Law" which changed the structure of land ownership seems to have started the "agrarian revolution" in England (Marx, 1967/1867). The precursor to the Industrial Revolution was the Agricultural Revolution.[39] According to Marx (1967:673), the "antagonistic character of capitalistic production and accumulation" was first felt in English agriculture. The consolidation of land with the vigorous introduction of labor-saving technologies and the eviction of peasants who were otherwise tied to their feudal masters drove them to cities and urban manufacturing centers" (ibid).

Kerridge (1967) challenges both Marx's and Ernle's

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[37] The replacement of oxen by horses also signalled the change, according to White.

[38] Like Marx, Ernle also stresses on the Parliamentary Enclosure Act as the predominant factor responsible for this change. However, Ernle and Marx interpret the outcomes in different ideological frames.

[39] According to Meier (1984:169), "industrial revolution is dependent on a prior or accompanying agrarian revolution."

conclusions. He claims that the reasons and dates that Ernle and Marx cite for the agricultural revolutions in England are incorrect. He argues that the agricultural revolution took place in the sixteenth and seventeenth centuries, and not in the eighteenth and nineteenth centuries. Kerridge criticizes the "conventional criteria of the revolution" which was the "enclosure." He says it is an "unsatisfactory" explanation because there were several parcels of land which were not enclosed, and there were many instances when commoners gained the titles to the land which came under the enclosure law (1967:16). According to Kerridge, "convertible husbandry" and "floating meadows," among others, were considered to be the important agricultural innovations that dramatically increased the productivity of the land. Marx's and Ernle's observations are still more persuasive than Kerridge's because he bases his argument on only a few parcels of land that evaded the "enclosure." Kerridge's claim is weakened still further by his refusal to revise his claim that the greatest productivity in agriculture occurred in the sixteenth and seventeenth centuries, instead of in the twentieth century as almost all analysts and historians of agriculture agree.[40]

Most analysts of technological change in agriculture consider the so-called agricultural revolution as taking place

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[40] See Grigg (1980:182-3) for further details.

over a long period of time.[41] Apart from those mentioned above who hold this notion, Thompson (1968) contends that the English agricultural revolution started in the sixteenth century and ended in the beginning of the twentieth century. The turning point in English agriculture was around 1850, as factory-made implements began to be used in agriculture (Grigg, 1984:13). Artificial fertilizers began to be used around this time and the English model of agriculture started to spread to Europe (ibid). Grigg argues that although these changes in agricultural technology increased the yields in European agriculture, it was only in the 1930s that a truly "revolutionary" change in productivity became noticeable, despite the use of the term by earlier analysts (ibid:13-14). This change was attributable to the increased use of hybrid and high-yielding varieties of seeds.

This view may be further corroborated by the agricultural history of the United States. Although mechanization and the use of chemical fertilizers dramatically increased productivity of the land, few modern agricultural historians

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[41] This is contrary to the long-held notion that "revolutions" occur in a short period of time, followed by long periods of stasis. The opinion of Ross and Tontz (1948) seems to be historically more sound in this respect. They contend that most of the changes which were labelled as "revolutionary" are only "evolutionary" because the changes occurred in a long period of time, or some of the changes were only peripheral.

refer to these changes as truly "revolutionary."[42] One of the major reasons cited for the introduction of mechanized farming was the relative scarcity of farm workers because of the availability of better paid jobs in manufacturing as a result of the Industrial Revolution (Habakkuk, 1962:14). The labor-saving inventions in agriculture that began to proliferate checked the reversal of the trend forever. The introduction of hybrid corn in the 1930's and 1940's set the stage for dramatic increases in cereal productivity.[43] The HYV seeds began to be used on a commercial basis in the 1940s and 1950s in the United States, thus enabling an increase in productivity that may be identified as truly "revolutionary."[44]

Grigg (1984) correctly points out that agricultural productivity increased more rapidly in all parts of the world during the past thirty to forty years. Before 1850, most of the increases in agricultural productivity may have been caused by increases in acreage.[45] This factor may be compounded by the poor statistical records available to test the claims.

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[42] Ross and Tontz (1948) point out that many analysts called changes due to different innovations after the American Civil War as "revolutionary" although these changes were mostly minor and a "continuing" one.

[43] See Griliches (1960) for additional details.

[44] See Hayami and Ruttan (1985) for empirical details on productivity growth. Also see Grigg (1984).

[45] Also, the relative demand for foodstuffs before 1850 might have been lower than what it was after 1850 because of lower population growth rate. Population growth trends picked up momentum during the mid-nineteenth century along with the Industrial Revolution.

The mid-nineteenth century saw a turn-around in agricultural practices due to the scarcity of labor in agriculture which encouraged increased mechanization. Between 1850 and 1930, once mechanization had become a background constant, agricultural productivity was slow to rise, as new innovations became scarce (Grigg, 1984). Thus, the truly "revolutionary changes" in agriculture in the Western countries began after the 1930's as a result of the hybrid seeds. Unfortunately, it took several more decades for the "agricultural revolution" to reach parts of the Third World.[46]

5. A SHORT HISTORY OF THE HYVs

High-yielding varieties of seeds have become synonymous with the Green Revolution. HYVs are defined[47] as early maturing semi-dwarf types which respond to intensive agricultural practices resulting in higher yield compared to the traditional types which tend to lodge[48] and yields to drop under the same conditions.

Semi-dwarf rice and wheat seeds originated in China and Japan respectively (Hayami, 1971). The widespread belief that

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[46] The agricultural revolution in parts of the Third World began to be manifest in the 1960's and 70's. Ironically, the same phenomenon in the Third World got the rather impressionistic name the "Green Revolution."

[47] See Dalrymple (1976:3 and 1979:706) for an expanded definition of the HYVs.

[48] Lodging is a phenomenon when the plant absorbs the nutrients to increase the size of the straw. The plants destroy themselves by falling over due to top-heaviness.

the HYVs originated in the West is only partly correct.[49] Semi-dwarf rice first appeared in China around A.D 1000 (Dalrymple, 1979). These rice types caught the attention of Japanese farmers in the 1900s, because the productivity increased dramatically when chemical fertilizers were applied (ibid:706).[50] During the interwar period as rice became a scarce commodity in Japan, the imperial government decided to transfer the new seed-fertilizer-irrigation based technology to its colonies in Korea and Taiwan (Hayami, 1971). Semi-dwarf rice was highly productive in Korea, but was not successful in Taiwan because the relatively warmer climate there was not conducive to the seeds developed for temperate Japan (ibid).

HYVs of rice suited to tropical conditions in Southeast and South Asia were developed in the 1950s and early 1960s at the International Rice Research Institute (IRRI) in Manila. The earlier varieties developed at the IRRI were based on genetic materials drawn from China, Taiwan, and Indonesia (Ruttan and Binswanger, 1978:359-60). The development of most

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[49] Ruttan and Binswanger (1978:360) complain that analysts of the Green Revolution who know better still claim that the HYVs originated in the West.

[50] The major problem with traditional varieties was that the increase in productivity decreases after a certain threshold. Beyond this point the productivity decreases beyond what it would have done if no chemical fertilizers had been applied. The plant absorbs nutrients to increase the size of the straw, thus posing the danger of "lodging" (Chandler, 1973). Semi-dwarf seeds on the other hand do not lodge and the increased fertilizer usage is returned in terms of larger amounts of cereal yields.

famous variety - known as IR-8[51] - was based heavily on experience in developing the Norin variety in Japan and Ponlai variety in Taiwan (Hayami, 1971:461). These new HYV rice seeds were extensively introduced in several Third World countries in the mid-1960s with success (Dalrymple, 1979; Brown, 1970). The most popular variety introduced in India, besides the IR-8, was the Taichung Native 1 which was a half sister of the IR-8 (Chandler, 1973:26).

Semi-dwarf wheat originated in Japan in the 1800s (Dalrymple, 1976). The Japanese crossed their semi-dwarf varieties with several American varieties. The most productive variety that arose from these experiments was called the Norin 10 (Dalrymple, 1979:706). The Norin 10 was introduced into the United States and crossed with several American varieties by USDA scientists after the Second World War (Chandler, 1973:26-7; Dalrymple, 1979:706).

In 1954, an American variety called the Norin-Brevor was taken to Mexico at what is now known as the International Maize and Wheat Improvement Center in Mexico, where Norman Borlaug and his colleagues developed several varieties of the HYVs that were transferred to India and other Third World countries in the mid-1960s (Dalrymple, 1976 and 1979; Ruttan and Binswanger, 1978; Hayami, 1971).

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[51] The IR-8 was a short, stiff-strawed, and highly fertilizer responsive variety. The IR-8 yielded 5 to 10 tons per hectare in India.

The genetic material for the modern HYVs of rice and wheat originated in China and Japan respectively. Semi-dwarf rice varieties have been cultivated in China for thousands of years. It was the dwarfing characteristic of the plant that attracted the researchers, who took this genetic quality and crossed with other varieties which would be resistant to weeds and pests. Also, they were careful to avoid the problem of lodging when high levels of fertilizers were applied. Similarly, semi-dwarf wheat that originated in Japan was crossed with American and European varieties. The most successful varieties developed by the American scientists were taken to Mexico where the present ancestors of the HYV wheat used in India and other Third World countries were developed.

6. TECHNOLOGICAL CHANGE IN INDIAN AGRICULTURE

As we shall see, the technological change in Indian agriculture may be succinctly put as the transformation of the newly derived knowledge in agricultural technology, both Indian and foreign, into food.[52] A reconstruction of the history of the Green Revolution in India shows that there are

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[52] Although the sources (note 53 below) I have consulted for 'reconstructing' the Green Revolution may be influenced by the models that I intend to test in this project, I have consciously avoided using any particular model as the basis for developing the case study. However, reflexivity cannot be completely avoided. We are aware that there is no such thing as a historically objective 'fact' that can be abstracted without being tainted by the models or theories under which these analysts have presented their case. See Fuhrman and Oehler (1986) for problems on reflexivity.

four protagonists who played crucial roles in its success.[53] They are the Government of India, multilateral donor agencies, international agricultural research institutions, and the farmers and peasants of India. The institutions under the government of India which planned and coordinated the transfer and diffusion of the new technology are the Ministry of Food and Agriculture, the Indian Council of Agricultural Research (ICAR),[54] along with the various agricultural research institutes scattered all over India, and the various agricultural universities.

The multilateral donor agencies were the Ford Foundation, the Rockefeller Foundation, the United States Department of Agriculture, and the United States Agency for International Development (USAID).[55] The international agricultural research

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[53] The important sources consulted for the history of the Green Revolution in India are: Dasgupta (1977); Lele and Goldsmith (1989); Mukherjee and Lockwood (1973); Dantwala (1973); Baker (1984); Byres (1982); Subramaniam (1978); and, Read (1974), among others.

[54] The ICAR was established by the British in 1929 under the name 'Imperial Council of Agricultural Research', to conduct research on commercial crops for export (Mohan and Evenson, 1973: A-21). After independence, the ICAR was renamed to Indian Council of Agricultural Research, ironically with the same acronym.

[55] Ruttan calls the role of "experts" from the donor agencies played in development assistance as the "counterpart model (1978b:294). The USAID played a key role, as a liaison and financial supporter to US land-grant universities, in helping to set up agricultural universities in India (Read, 1974). Ruttan identifies the development assistance given to Third World countries in the form of setting up research institutions and agricultural universities as the "university contract model" (1978b:294).

institutions[56] are the International Rice Research Institute (IRRI)[57] and the International Maize and Wheat Improvement Center (CIMMYT).[58] There are several other international agricultural research institutes established after these.[59] In order to pool the resources for maximum benefit and also to avoid duplication of research endeavors, a Consultative Group on International Agricultural Research (CGIAR) was organized in 1971 (Ruttan, 1978b:275).[60] Finally, it was the farmers and peasants of India who, by adopting and adapting the new technology to their particular situation, made the Green Revolution a success.

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[56] For Ruttan, the emergence of the international institutions to help Third World countries is a form of an "international institute model" of development assistance (1978b:294). Ruttan's models though very interesting and useful, are not relevant to the present project, which is concerned with the reconstruction of the history of the Green Revolution. Ruttan developed these models to explain the theory of induced institutional innovation in Third World agriculture. For more on Ruttan's model, see Chapter Three.

[57] The IRRI was the joint efforts of the Ford Foundation and the Rockefeller Foundation. The land for the construction of the institute was provided by the Philippines government (Brown, 1970:50-51).

[58] CIMMYT was the joint efforts of the Ford Foundation, Rockefeller Foundation and the Mexican government (Brown, 1970:51).

[59] See Ruttan (1978) for further details on these institutes.

[60] Under the umbrella of the CGIAR, there are eleven international agricultural research institutes, a regional rice research network, and an international board on plant genetics (Ruttan, 1978b:295). Recently, two more international biotechnology research institutes were established under the CGIAR in Italy and India.

Though the technological change in Indian agriculture during the period from 1965 to 1975 is generally referred to as the Green Revolution (Ruttan and Binswanger, 1978:358), this period must be understood as the one during which the benefits of the technological change in agriculture in the form of greatly enhanced farm productivity became noticeable. After 1975, the rate of increase began to slow down, to be picked up again in the 1980s.[61] A reconstruction of the history of the technological change demands that we look at the developments in Indian agriculture beginning at least a decade earlier. Thus, we can observe three distinct stages in the process of the change. The first stage (1952-65)[62] was the development of national agricultural research. The reorganization of the national agricultural research system was the important event during this period. The second stage (1962-67)[63] was the transfer and diffusion of the HYVs to the

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[61] See Surinder Sud (1989) and Chengappa (1989). Chengappa calls the "revival" of Indian agriculture in the 1980's as the second Green Revolution.

[62] This stage may be extended back to 1948, a year after independence, when a high profile University Education Commission was set up to revamp the educational structure in India, including agricultural education. 1952 was chosen, instead, because it was in 1952 that the first USAID-university contract was signed, and later in the mid-1950's the Indian government sought the assistance of the Ford and Rockefeller Foundations and the USAID for establishing more agricultural universities, and for developing a high quality graduate school at the Indian Agricultural Research Institute (IARI) in New Delhi.

[63] In 1962, Indian scientists successfully tested the HYV Mexican wheat under Indian conditions. The HYV rice seeds were tested in 1964. 1965-66 was the growing season during which

Indian situation. The third stage (1965-75)[64] was the change in agricultural practice as a result of the introduction of HYVs. A combination of these three stages made the Green Revolution possible.

In 1948, a year after independence, the government of India set up the University Education Commission to revamp the educational system in India (Read, 1974:4).[65] The Commission recommended the establishing of 'rural universities' similar to the land-grant universities of the United States (Prasad, 1981:17). These recommendations stem from the "bookish" nature of existing agricultural education in India which resulted in little of practical value in addressing the immense

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the HYVs were extensively introduced at the national level (Lele and Goldsmith, 1989 and Subramaniam, 1979).

[64] The farmers began to adopt the new technology extensively, beginning the 1965-66 growing season. The increase in agricultural productivity increased steadily until 1975. After 1975, the increase in productivity began to taper off and levelled off on a S-shaped productivity curve. By this time in parts of India farmers had realized a three-fold increase in their yield compared to the 1965 base.

[65] Agricultural colleges and research institutions were built by the British colonial administration beginning in the late nineteenth century, basically to cater to the interests of British plantation business (Mohan and Evenson, 1973, and also, see n. 31). Various central research institutes and central commodity committees on sugarcane, tobacco, oilseeds, jute, coconut, lac, arecanut, and spices were set up under the imperial ministry of food and agriculture (Mohan and Evenson, 1973). The Indian Agricultural Research Institute (IARI) was established in 1923, and an Imperial Council of Agricultural Research (ICAR) was later formed in 1929 to coordinate the research activities (Prasad, 1981). According to Lele and Goldsmith (1989:312), the ICAR (of 1929) "did not exercise leadership to focus research on pressing problems" in the food situation in India.

agricultural problems (Lele and Goldsmith, 1989). The high powered committees consisting of Indian and United States agricultural scientists and educators appointed by the Indian government in 1955, 1959, 1962 and 1963 recommended the revamping of the Indian Council of Agricultural Research, which was originally set up by the British under the name of Imperial Council of Agricultural Research in 1929 (Mohan and Evenson, 1973). Accordingly, all the central research institutes and commodity committees were brought under the ICAR. Also the joint Indo-US committees recommended strengthening indigenous research efforts and college-level training, and establishing agricultural universities in all the States of the Indian Union[66] (Moseman, 1970:110).

The establishment of agricultural universities, patterned after the land-grant universities of the United States, is considered by many analysts an important event in the history of the Green Revolution that helped to transfer agricultural knowledge from the United States to India. Three U.S. institutions played key roles in the development of modern agricultural research capacity in India. The United States Agency for International Development (USAID) helped with investments to start up the land-grant type universities, the Rockefeller Foundation helped with the development of a

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[66] India has a federal structure, and generally referred to as a "union" of States with democratically elected governments. Also, there are a few federally administered union territories with elected local governments.

national agricultural research system, and the Ford Foundation helped with farm extension work (Lele and Goldsmith, 1989:313; Read, 1974:97-101).

The first land-grant type agricultural university was established in Pant Nagar, Uttar Pradesh, which is now known as Gobind Ballabh Pant University of Agriculture and Technology (Prasad, 1981). This university was modelled after the University of Illinois.[67] Other U.S. land-grant universities (Kansas, Ohio, Missouri, Pennsylvania and Tennessee) entered into partnership arrangements with the Government of India to establish several other agricultural universities (Read, 1974).[68] The USAID provided the contract funds and represented the United States on behalf of the land-grant universities. According to Read (1974) hundreds of researchers and agricultural professionals from these universities went to India to help with the establishment of the universities and their research facilities. Also, thousands of Indians trained in the United States went back

[67] See Brass, P.R (1982) and Singh, D.P. (1982) for a detailed account of the institutional transfer process which culminated in the establishment of this land-grant university patterned after the University of Illinois.

[68] These universities are: Punjab Agricultural University (Ohio State University); Haryana Agricultural University (Ohio State University); University of Udaipur (Ohio State); Madhya Pradesh Agricultural University (University of Illinois); Orissa University of Agriculture and Technology (University of Missouri); Maharashtra Agricultural University (Pennsylvania State University); Andhra Pradesh Agricultural University (Kansas State University); and Mysore University of Agricultural Sciences (University of Tennessee) (Read, 1974).

to India to teach and conduct research. The agricultural university cooperation between the United States and India was terminated at the end of 1972 at the request of the Indian Government, but already a significant technological capability had been transferred to India.[69]

In terms of developing an agricultural research system that acted as the catalyst to developing a national research capability, the Rockefeller Foundation played a key role more than any others. The Rockefeller Foundation, which had been running maize programs in Mexico and Columbia and had become the "leading repository of knowledge about maize in developing countries" was invited by the Indian government to help Indians to develop hybrid maize (Lele and Goldsmith, 1989:314). Simultaneously, the Indian government sought the Foundation's help in establishing a high-quality graduate program at the Indian Agricultural Research Institute in New Delhi under the federal government (ibid).[70]

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[69] According to Read (1974:105), the reason for the Indian Government's decision to terminate the USAID-university technical assistance programs was based on "foreign policy differences" between the Indian and the United States governments. President Nixon's unilateral support for Pakistan in the India-Pakistan War of 1970-71 was the major reason. Nixon and Kissinger bitterly opposed India's liberating Bangladesh from the Pakistani army.

[70] The several Indo-US committees recommended the revamping of the IARI, because IARI was, until then, engaged in theoretical work which was not overly helpful in solving the crucial agricultural problems that India was facing. Although the agricultural universities could step in to assume that role, their mandate was to serve the State governments and other regional entities. The central government wanted to train a cadre of agricultural scientists at the IARI to assume

The Indian government's intention was to train a cadre of highly qualified agricultural scientists. Traditionally, agricultural sciences did not attract bright students, because of the low prestige ascribed to agriculture-related professions (Stakman et al., 1967:251).[71] The Rockefeller Foundation gave high priority to the Indian government's request to set up a graduate school. Their best and most well known scientists were assigned to India: Ralph Cummings, U.J. Grant, and Albert Moseman, individuals well respected among the agricultural research community in the United States (Lele and Goldsmith, 1989). The graduate school at the Indian Agricultural Research Institute was inaugurated on October 6, 1958, and 150 students were admitted that year for MS and PhD programs (Stakman et al., 1967). Ralph Cummings became the first dean of the graduate school (ibid). The Rockefeller Foundation scientists in India felt their assignments were highly prestigious, because they felt that they were helping to develop the agricultural research facilities of an important Third World nation. They were also allowed easy access to the ministers and secretaries of agriculture and

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leadership in organizing research at national level, as well as in coordinating research at the state and local levels.

[71] The reason attributed to this goes back to the caste system in India. Farm work was considered, traditionally, the job of the lowest caste. This caste-based notion perpetrated a false consciousness among many Indians that working with hands (i.e., manual labor) is menial. Somehow this prejudice towards farm work got extended to agricultural sciences as well. See Robert Anderson (1983) for a comparative study of agricultural and nuclear sciences in India.

allowed to extend their tour of duty for up to ten years and more (Lele and Goldsmith, 1989). Today, the IARI is a well known agricultural graduate school and research center, having graduated several thousand Masters and Doctoral students, not only from India but from many other Third World countries in Asia and Africa.

In order to give the agricultural sciences high prestige, top administrative positions were given to scientists, instead of civil servants, which had been a custom[72] dating back to the British rule (Subramaniam, 1979). In order to attract bright students to this field, an Indian Agricultural Research Service was developed, similar to the Indian Administrative Services, to give permanency and guaranteed career growth to the agricultural scientists (Lele and Goldsmith, 1989:323). In 1960, an Indian, A.B. Joshi, took over the deanship of the IARI graduate school from Ralph Cummings (ibid:321).

Unlike the Rockefeller Foundation, the Ford Foundations's role was confined to funding the development of agricultural universities and adaptive research on HYVs. The Ford Foundation gave financial assistance to the development of agricultural universities, along with the USAID (Lele and

[72] The British imperial government created a highly regarded Imperial Civil Service (ICS) to attract bright British and later Indian citizens to work in India on behalf of the Queen of England. Traditionally, all top appointments in the government went to the ICS officers, including those positions as heads of scientific and technological institutions. After independence, the Indian government continued the trend, and they even started an Indian Administrative Service (IAS), similar to the erstwhile ICS.

Goldsmith, 1989). Since extension work was mostly conducted by state governments in concert with the agricultural universities, the Ford Foundation gave financial support to sustain this operation in the early stages. The Ford Foundation also supported the "Integrated Agricultural Development District Programmes" or (IADP) (Read, 1974:98), which was a program intended to help farmers in selected districts in different parts of the country. According to Read, "The Ford Foundation's India policy was to concentrate attention on those important agricultural areas not receiving support from USAID or other agencies" (ibid). By the mid-1960s, the agricultural research system in India was well on its way to making the Green Revolution a reality, thanks to the concerted efforts of the Government of India, United States Agriculture Department and the Agency for International Development, the Rockefeller Foundation, and the Ford Foundation.

The American system of federally supported agricultural research appealed to the Indian government.[73] Having a federal structure, the Indians wanted to adapt the American system of first developing a federal agricultural research capability and then to support state-level research projects. The last joint Indo-US Agricultural Research Review Team recommended some sweeping changes in the largely civilian-dominated

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[73] The American system was largely based on Washington's support to subsidize research at state agricultural stations (Lele and Goldsmith, 1989:313).

bureaucratic agricultural research system (Lele and Goldsmith, 1989). But owing to pressure from the powerful civil service, the concerned ministers of agriculture were not able to implement the recommendations until C. Subramaniam took over as India's minister of agriculture in 1964. He single-handedly overhauled the agricultural bureaucracy in India giving, power and credibility to the agricultural scientists (ibid:322).

The first action that Subramaniam (1979:14) took was to remove the permanent civil service officer,[74] who was serving as the Director-General of the Indian Council of Agricultural Research (ICAR) and to employ an eminent agricultural scientist, B.P. Pal, as the new Director-General.[75] Subramaniam then appointed a committee of agricultural scientists to go over the latest joint Indo-US expert committee[76] to recommend to him the necessary measures for implementing the recommendations of the Parker Commission on reorganizing the scientific research infrastructure (ibid:15). At the recommendation of the new team, Subramaniam brought all the

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[74] Subramaniam does not mention who this civil service officer was.

[75] Another eminent Indian agricultural scientist, M.S. Swaminathan, took over as head of the IARI from A.B. Joshi. Swaminathan, who obtained his doctorate from the University of Cambridge in 1952 later became the Director-General of the ICAR.

[76] The Indo-US committee headed by Marion Parker from the United States was appointed to examine the "reorganization of agricultural science in India" (Subramaniam, 1979:15). The committee submitted its report in 1963. Also, see Lele and Goldsmith, 1989:340, n. 35).

independent research institutes and commodity committees under the ICAR. The third most important step that Subramaniam took was to establish an Agricultural Research Service, similar to the UK and US Agricultural Research Services to provide guaranteed career paths to the agricultural scientists (1979:17-19). Subramaniam argues that the reorganization of the agricultural research system was absolutely warranted because the introduction of the new agricultural technology required a dedicated cadre of agricultural scientists and technologists to face every challenge thrown up by the new technology (1979:21).

In 1962, Indian agricultural scientists had successfully tested the semi-dwarf HYV of Mexican wheat (Lele and Goldsmith, 1989). Two years later, the HYV semi-dwarf rice developed at the International Rice Research Institute (IRRI) in the Philippines was also successfully tested (ibid). However, Subramaniam notes that several senior scientists and influential members of the Planning Commission opposed the massive introduction of the new seeds, arguing that they were not suited to Indian conditions (1979). The importation of the HYV wheat seeds was nearly prohibited by the government due to opposition from the Planning Commission and several other powerful quarters in the government (Hopper, 1978:69). Subramaniam (1979:25) notes because of these pressures, the decision to introduce the new seeds was postponed to the growing season of 1965-66 instead of the previously planned

1964-65 season. Convinced of the high-yielding capability of the new seeds, Subramaniam, along with his trusted agricultural scientists went ahead with the decision to import 18,000 tons of HYV the new wheat. They distributed the seeds to the farmers at subsidized rates for sowing during the 1965-66 growing season (Subramaniam, 1979; Lele and Goldsmith, 1989; Chandler, 1973).

According to several analysts, the importation of the 18,000 tons of Mexican wheat seeds to India in 1965-66 is considered the most important step in the history of the Green Revolution.[77] Hopper (1978) and Lele and Goldsmith (1989) describe this importation of HYV seeds from Mexico as the largest seed transfer in the history of the world. However, though not disputing the importance of this decision, identifying this as the "most important" reason for the Green Revolution is presumptuous and does not mesh with other events in its history. The establishment of the national agricultural research system might equally be the most important step. Without this, the launching of the national demonstration program (see below for more) that created the demand for the importation of the new "miracle" seeds would not have been possible. Five years after the introduction of the HYVs on a

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[77] See Lele and Goldsmith (1989); Brown (1970); and Hopper (1978).

massive scale, the yield of wheat doubled (Hopper, 1978:69).[78]

Having reorganized the agricultural research system in India, Subramaniam decided to demonstrate the effectiveness of the new HYV seeds to the farmers (Subramaniam, 1979:44). Massive public information campaigns about the new technology using radio, the press, and cinema were organized by the government in 1966 (ibid:41). But it was not an easy task to convince the farmers to switch to the new technology, because having no precedent they did not want to bear the risk of a disastrous harvest again after several droughts. The farmers were willing to take the risk only after they were convinced that the new technology was much more productive than their age-old technology.[79] Hence, in 1965 it was decided to launch a thousand demonstration programs all over the nation (ibid:47).

According to this plan, a minimum area of two hectares of each selected field was devoted to the new varieties. These parcels of land were entrusted to the extension officers and agricultural scientists. These government officials were given the task of demonstrating the effectiveness of the new technology as a model farm to the community. The decision was

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[78] Mahmood Mamdani (1972:61), based on field research in a Punjabi village, reports that the wheat yields often trebled.

[79] This is consistent with the actions of the corn farmers of Iowa in the 1930s. Ryan and Gross (1943) contend that the farmers adopted the hybrid corn only after trying it on a trial basis on a small plot and after fully convinced of the high productive potential of the HYV corn seeds.

also made, in case the new technology did not provide a bumper crop, for the government to compensate the farmers for the difference. The 200 tons of HYV seeds brought from Mexico was distributed for the demonstration programs. These became a huge success. The 200 tons of seeds provided another 5,000 tons of seed. However, this 5,000 tons was immediately bought up by the farmers, and the demand for the new "miracle" seeds became phenomenal.[80] Because of this, the Indian government decided to import 18,000 tons of HYV seeds from Mexico (Subramaniam, 1979:47-48). The Green Revolution took off from this point onwards. According to Norman Borlaug (1972), India's decision to import and to implement the new HYV technology set off a chain reaction, not only in India, but in Pakistan and elsewhere.

The seeds were subsequently changed to accommodate the consumer preferences.[81] Modifications were also required because of the need to withstand particular problems due to the varied soil and climatic conditions in India compared to

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[80] Mamdani (1972:61) reports that the price for one kg of the "miracle" rice was one rupee in 1966 in the market. The popularity of the seed made the demand soar and the market price of the new "miracle" seeds surged phenomenally. He says that some farmers even bought the seeds at one hundred rupees per kg during the 1967 growing season.

[81] The IR-8 rice was found to be sticky and chalky, and not very much liked by the consumers. Similarly, the Mexican wheat was of reddish hue. Indians preferred amber and white colored wheat. The Indian agricultural scientists were able to develop new seeds to satisfy the tastes of the consumers, at the same time as retaining the genes that guaranteed high productivity (Chandler, 1973).

the conditions in Mexico for the wheat seeds and in the Philippines for the rice varieties. Indian scientists took the feedback from the farmers and consumers seriously, and were successful in quickly developing two Mexican wheat lines that "performed better in the field and the kitchen" (Lele and Goldsmith, 1989:327). Similarly, adaptive research on the rice seeds obtained from the Philippines yielded 221 varieties by 1983 (ibid). In the 1976-77 growing season, 71.8 per cent of the land under wheat and 35.6 per cent of the land under rice were devoted to HYVs (Dalrymple, 1979:708).[82] The remaining land was not brought under HYVs not because the technology was inadequate, but because this land did not yet have irrigated water and other inputs necessary to sustain the new varieties.

7. CONCLUSION

Technological change originating outside India was successfully transferred because of the urgent need felt for the new technology within India. But it became successful and generally welcomed by the peasant farmers only when it became compatible with the economic, social and physical conditions in India.[83] The HYVs that made the Green Revolution possible

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[82] By 1983-84, the acreage under HYVs increased to 76 percent for wheat and 54 per cent for rice (Lele and Goldsmith, 1989:327).

[83] Pray (1981:79) observes that the British and American attempts to transfer wheat varieties to the tropics during the colonial period did not succeed, because no adaptive research was conducted to prevail in a different economic, social, and physical conditions. The seeds themselves are not enough to

were developed after extensive adaptive research to fit the particular ecological and economic conditions, and culinary preferences. Although the institutional structure of the research system has a seemingly uniform nature in much of the world, the seeds had to be location-specific to become viable. The research system that enabled the assimilation of the new technology was largely transferred from the United States. The Indians were highly successful in transferring and adapting the technology, including the institutions and knowledge embodied in it. The HYVs need constant renewal after a few years as their yield potential decreases. The Indians were successful in developing new seeds because they had already acquired the technological capability afforded by genetic manipulation. The effort to solve a major problem in agriculture production in turn enabled the country to become self-sufficient in food and to develop a highly successful agricultural research capability of its own. The agricultural success story is thus "a prime example of mutually reinforcing foreign and local research efforts" (Lele and Goldsmith, 1989:328).

The technological change that ensued from the introduction of the HYVs was a result of the interaction of the new technology and a variety of social, cultural, economic and

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provide bumper crops. There should be extension services, availability of several inputs like fertilizers, controlled irrigation, pesticides, etc., which were not available during the colonial period.

political factors. The model of economic development that the Indian leaders pursued in the beginning was patently biased against agriculture. It was borrowed from the centrally-planned economic model[84] of the Soviet Union which favored rapid industrialization at the expense of agriculture. Agriculture was neglected until the rude awakening of the 1960's when the country was threatened by famines. This precarious situation was temporarily solved by the massive importation of food from the United States. According to Subramaniam the United States government put great pressure on India to change its agricultural policy.[85]

Leaf's (1984) extensive field research in the Punjab State of India, which is the most successful state in India at exploiting the benefits of the technological change in agriculture, shows the changes in economic and social factors to be dramatic and irreversible. Mamdani (1972) also recounts

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[84] The collectivized agricultural system of the Soviet Union was a disaster and continues to be so. The poor performance of Soviet agricultural sector, probably, made the Indian planners to desist from borrowing this model and instead decided to turn to the West. However, the model of Indian agriculture is unique. It is neither capitalist nor collectivized agriculture. Indian agriculture is still in the hands of millions of small to medium farmers.

[85] Subramaniam (1979) narrates an incident in which he was personally lectured by President Johnson to inform the United States government periodically of the programs that the Indian government was implementing to redress the food situation as a condition for the speedy release of concessional US food shipments. According to Subramaniam, the decision to embark on the "New Strategy in Indian Agriculture" was to regain the political self-esteem lost as a result of becoming dependent on foreign food aid.

the change in social and rural economy as a result of the Green Revolution. In a brief but highly perceptive account of the technological change in agricultural practices in the Punjab, Aggarwal (1974:381) argues that the Green Revolution resulted in the "transformation of peasants into farmers." Before the Green Revolution, the extent of the markets did not reach rural areas. The need to gain credits to buy seeds and other inputs forced peasants to enter the market. The need to sell their products in the market also strengthened the role of the markets in the life of the rural people. According to Leaf (1984:114), one of the crucial decisions that the farmers had to make was how much of each crop to grow. They had to consider the costs and benefits of each crop according to its market price before the growing seasons. The role of markets in farmers' decisions to take risks in adopting the new technology was illustrated by Gartrell's (1977) field study in Andhra Pradesh in South-Central India.

The perception that all peasants are "irrational" and "fatalistic" and that they do not respond to new methods of agricultural practices used to be rife among economists and agricultural planners. This myth was proved incorrect by the peasants in the Punjab and other parts of India. They accepted the new technology when they were convinced of its potential benefits after the successful demonstration programs described earlier (see Subramaniam, 1979). Leaf (1984) also observed the same among the peasants and farmers he studied during his field research. Some of the "irrational" actions of landless agricultural workers and small subsistence farmers make complete sense. For example, Mamdani's field research in the Punjab shows that poor farmers shunned family planning programs because, in a peasant household, the potential income is equal to the number of hands (both male and female) available for work. Devoid of any social safety nets like unemployment compensation or welfare programs, the only means of survival is to have all the able-bodied family members work. So, the head of the families of peasant households do not want to limit the number of children. Also poor parents consider it important to have more children so there will be more children to whom they can turn when they are old and cannot work for a living. According to Mamdani "people are not poor because they have large families." On the contrary, "they have large families because they are poor" (1972:14).

The peasants chose the Green Revolution technology when they were convinced of its superiority over its traditional counter-parts. The factor that convinced the peasants most about the new technology was the spectacular increases in yield (Ruttan 1977; Binswanger and Ruttan 1978). Blyn's (1983) field research in India shows that both land-holders and landless laborers benefitted from the new technology.[86]

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[86] Of course, in absolute and relative terms, the land-holders benefitted more than the landless. See Ruttan (1977) and Blyn (1983). The agriculture wage did go up as the volume of harvest also went up.

Randhawa (1974) and Aggarwal (1973) claim that farmers of all sizes benefitted from the technological change. Lipton (1977) also claims that small farmers benefitted from the HYV technology. The new technology demanded more laborers for boring tube wells, digging canals, weeding, and preparing seeds, among many other agriculture-related jobs (Rudra, 1987; Blyn, 1983; and Aggarwal, 1974). Despite the fact that labor-saving technologies began to proliferate, the demand for human labor went up (Aggarwal, 1974 and Randhawa, 1974). In fact, during harvest seasons there is an acute shortage of farm laborers in those areas where the Green Revolution has become a success (Aggarwal, 1974). Migrant farm workers from far-away States like Bihar, Rajastan, and Uttar Pradesh found ready employment during harvest seasons (ibid). Blyn found that small-holders were more productive than large-holders, because the former were more efficient in using the input factors than the latter. Blyn (1983) and Ruttan (1977) claim that though the HYVs were scale-neutral,[87] small farmers were more efficient because they were able to use the input factors more optimally than large farmers. Blyn further concludes that farm size and the nature of the land-tenure system did not constrain the adoption of the new technology.[88]

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[87] The basic premise is that proportionate amounts of inputs in large and small farms yielded same yield per acre in both large and small farms.

[88] Most share-croppers pay a constant rent to the land-owners. Cognizant that the new technology would enhance the yields, they happily adopted it because they did not have to

Culturally, the most profound change induced by the Green Revolution was the transformation of peasants into farmers. Prior to the Green Revolution, the cultivators were subsistence farmers. The whole village economy was dependent on the farm. The villages were self-sufficient to the extent of providing the basic minimum for most of their inhabitants, except for the large land owners and money lenders. When the weather faltered everyone paid the price. With the Green Revolution, peasants who used produce for subsistence found their crop productivity increase by two hundred to three hundred per cent within a few years. They began to learn about new agricultural techniques and ways to ameliorate new problems that cropped up. The proliferation of agricultural machines created added job opportunities for repairs which were supplied by the skilled artisans of the villages. Supporting industries began to emerge in areas where the Green Revolution became successful. The erstwhile peasants' way of living began to change tremendously. Transistor radios, TVs, fans, refrigerators, and wrist-watches became part of the new farm households. The children went to schools and colleges and opted for jobs other than farming. The economic disparities between upper and lower castes began to dwindle. The social and cultural changes in the States where the Green Revolution

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pay additional rent from the increased yields.

was successful became irreversible.[89]

Finally, most literature critical of the Green Revolution did not question the productive gain from the new technology.[90] Their complaints were related to the equity issues in the distribution of income and of the increases in cereal output to the poorest in the society. However, the inequalities in income distribution are decreasing in areas where the Green Revolution has been successful. Agricultural laborers have gained in terms of higher wages and more days of work due to the higher volume of crop productivity (Blyn, 1983:719). Smaller farmers have been found to be more productive than larger holders. The militancy of agricultural workers to gain higher wages in areas where the Green Revolution became successful (for example in parts of Kerala and Tamilnadu States) may be considered a positive sign of social and political changes rather than regressive trends as some detractors of the Green Revolution portray such events. The detractors of the Green Revolution are attacking the wrong enemy. The technology does not by itself dictate income distribution. These problems had to do with government subsidies, taxation, and agricultural wage policies.[91] In fact,

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[89] For more on these changes, see Leaf (1084), Aggarwal (1074), and Mamdani (1972).

[90] Some of the works in this regard are Griffin (1974), Fatemi (1972), Gough (1978), Glaeser (1987), and Rudra (1987).

[91] The power of agricultural workers translated into the best and far reaching minimum wage legislation in Kerala. The Kerala Agricultural Workers Act of 1974 provides permanency

the studies mentioned above show that poverty has become less in areas where the Green Revolution has spread, but continues where there is no technological change in peasant agriculture.[92] If the Green Revolution had been uniformly spread to all the States in India, the grinding poverty that afflicts those who live in areas of least agricultural modernization would have decreased considerably.

The reasons for the lack of agricultural modernization still not reaching these States are many. Some of the most notable reasons are: archaic and feudal land tenure systems, virtually no land reforms, the political power in the hands of feudalist land owners and upper caste Hindus, and the apathetic and fatalistic outlook on life that vast majority of poor peasants still hold on to. It is beyond the scope of this case study to go into the details.

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to attached laborers to the farms, a provident fund and old age pensions, permanent labor conciliatory services at the district level, greatly reduced hours of work (between six and eight hours), scheduled breaks, tea and lunch, and a minimum wage which is the highest in India (Herring, 1989).

[92] Extensive data on income and employment patterns in areas where the Green Revolution was successful convincingly refute the alleged view that the new technologies adversely affected these patterns. See, for example, the studies conducted by Johl (1975) and Randhawa (1974).

CHAPTER THREE
MODELS OF TECHNOLOGICAL CHANGE: ECONOMIC AND HISTORICAL MODELS

1. INTRODUCTION

The focus of this Chapter is to evaluate models of technological change discussed in economics and history. After discussing and critiquing various models, I will select a few of the more prominent ones from these disciplines to account for the Green Revolution. The objective of this exercise is to test the completeness and adaptability of these models. The neoclassical, Schumpeterian, and institutionalist (induced innovation) models are the ones selected from economics. The models selected from history are the cumulative synthesis model of Usher and the systems model of Hughes.

2. ECONOMIC MODELS

2.1 LITERATURE REVIEW

Although classical political economists and philosophers, such as Adam Smith (1976/1776), David Hume (1955), and Karl Marx (1952/1848 and 1967/1867) mentioned technological change as an important factor responsible for social and economic change in their writings, they provided no clear exposition of this phenomenon. Hume and Smith were interested in the process by which a predominantly agrarian society changed into one where industry and commerce flourished.[1] Hume's theories on economics and technology set the intellectual agenda for Smith. Martin Bronfenbrenner (1971:131) argues that Hume's "Political Discourses" "anticipated Smith in so many matters of both positive and normative economics." Smith's theory of the division of labor and his 'pin factory' example point to his extant interest in technological change.

Marx's interest in technological change is reflected in his keen observations on the 'progressive' nature of industrial capitalism stimulated by technological change, and also from his statement that "(T)he bourgeoisie cannot exist without constantly revolutionizing the instruments of production" (1952:421). Marx understood the economic and the socio-cultural structure of capitalism as one in which the ruling class (bourgeoisie) knew the importance of technological change for inducing enormous economic gains (surplus value/profits). Marx correctly pointed out that the bourgeoisie was a dynamic entity wedded to the notion of "technological dynamism,"[2] unlike the earlier classes which were resigned to the imperatives of <u>status quo</u> social order and traditional technology.

Unlike the feudal lords and the mercantilists, the

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[1] Nathan Rosenberg (1976:89-90) provides a detailed explanation on this point.

[2] This is the term used by Rosenberg (1976:127) to describe the interest of the bourgeoisie in technological change.

bourgeoisie knew the importance of the new methods of production with the help of new machines, and considered it important to invest in machines that would create new machines (Marx, 1967). According to Marx, the new machines which evolve as a result of technological change help the bourgeoisie to extract maximum surplus from the labor force, and the "immiserisation" of the working class, further, leads to the alienation of them from the machines or the means of production.[3] Marx (1967) contends that there is a dialectical relationship between changes in the modes of production, which may be considered as technological change, and changes in social relations of production. These observations of the classical philosophers and economists are to be construed more as world views than as models of technological change.[4]

The concept of technological change interested many modern economists of all persuasions, and their models will be discussed to find their applicability to explain technological change in this project. One key issue most of these economists concur about is the production-function representation of technological change.[5]

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[3] For more on Marx's views on technology and on technological change, see Rosenberg (1982) and MacKenzie (1984).

[4] Accordingly, these 'models' are not used for explaining specific cases of technological change. I shall not attempt to test these models as part my project.

[5] It must be added that only neoclassical economists, who are normally assumed as mainstream economists adhere to the notion of the production function representation of

One of the first modern classical[6] economists who took keen interest in explaining the dynamics of economic development induced by technological change is Joseph Schumpeter (1950/1942 and 1939). Schumpeter's views on technological change may be deduced by analyzing his theories and findings on "Economic Evolution" and business cycles. Schumpeter argued that the process of "creative destruction" spearheaded by innovating entrepreneurs created economic change. In Schumpeter's schema, a new innovation on an existing production process destroys the old process, effectively scrapping the old technology in favor of the new one. Schumpeter considered only innovation as the most important constituent of technological change, and considered invention an act outside the realm of legitimate economic and business practices (1939:84). He argues that innovations cluster because of business cycles.[7] Schumpeter defines "innovation as the setting up of a new production function" (1939:87). The modus operandi of innovation, according to him,

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technological change. However, unlike mainstream neoclassical economists, neoclassical institutional economists consider technological change as an endogenous economic activity.

[6]. Robert Wolfson (1958/59) contends that Schumpeter worked within the classical and neoclassical traditions, but only institutional economists took Schumpeter's works seriously.

[7] The discontinuity and the clustering of innovations that Schumpeter emphasizes in the economic development process under the leadership of innovating entrepreneurs attracted some analysts to build models of technological change. See Nelson and Winter (1977), Dosi (1982), and DeBresson (1989).

is the construction of new plants, creation of credits, and facilitating the emergence of the entrepreneurs or the "New Man."

Strassmann (1959) argues that Schumpeter's description of "creative destruction" as the process of a new production method (technology) replacing an old one is only partially correct. Strassmann holds, based on empirical examples from the United States between 1850 and 1914, that old technologies did co-exist with new technology, in situations where the new technology was anticipated by the industries. Strassmann (1959:336) contends that total technological change, that is, the complete replacement of the old technology by a new one, took place in an industry only when the "rate of obsolescence" occurred with "unforseen rapidity." Solo (1951) questions the Schumpeterian assumption that inventions are not part of business practices. She contends that like other business practices, costs incurred for R and D activities with specific objectives for inventions are legitimate and significant. Usher (1955) also criticizes Schumpeter for ignoring inventive activities in technological change, and, instead, offers the explanation that Schumpeter's innovator is similar to the inventor in most circumstances.[8]

Unlike Schumpeter, Jacob Schmookler (1966) emphasizes "invention" as the most important factor responsible for

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[8] For a detailed criticism of the Schumpeterian dichotomy of invention and innovation, and the Schumpeterian view on technology, see Parayil (1990c).

technological change. Schmookler argues that economic growth is caused by an essentially economic activity known as "invention." Schmookler claims that based on his research on the history of American railroad industry inventive activity can be seen as directly correlated to increased sales of capital rail equipments. In essence Schmookler is saying that technological change is an endogenous process, which is caused by economic growth. This is contrary to that of other neoclassical economists, notably, Solow (1957), Abramovitz (1956), Mansfield (1971), and Griliches (1963) who claim that economic growth and development are caused by technological change. Although an advance over other views, Schmookler's demand-push model of technological change ignores supply-side factors in inducing technological change. Rosenberg (1976) argues that Schmookler's models is tautological in the sense that it can be fitted to any historical study of technological change because of its emphasis on demand factors alone.

Analyzing the causes of economic growth using production-functions induced by technological change based on aggregating economic outputs is in vogue among neoclassical economists. Robert Solow (1957), in a classic study of the growth of the United States economy from 1909 to 1949, concluded that 87.5 per cent of the increase in gross output per man hour was attributable to technological change, and the remaining 12.5 percent to increased use of capital. Solow defined technological change as any kind of shift of the production-function. Moses Abramovitz (1956) in a quantitative growth study of the United States economy from 1860 to 1956 attributed the productivity increase to a "residual factor" about which he said economists are woefully ignorant.[9] These two authors treat technological change as an exogenous factor, unlike Schmookler. Coombs <u>et al</u>. (1987) criticize this "residual" method of accounting for technological change. They argue that by treating the effect of technological change as an unexpected outcome, Solow is not, in fact, modeling technological change. Nelson and Winter (1982) also severely criticize the empirical method of identifying the "residual" a technological change as "intellectual sleight of hand."[10] They claim that the neoclassical production-function theory does not address the issue of technological change, and its adherents try to cover up this deficiency by resorting to spurious empirical methods.

Unlike Solow's assumption of a disembodied technological change (technological change occurring independent of input factors), Griliches (1963) argues that increases in agricultural productivity in the U.S. during the period from 1940 to 1960 can be attributed to improvements in the quality

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[9] A careful analysis shows that this `residual' is technological change.

[10] Nelson and Winter (1982:197-98), in fact, go even further in their criticism of the neoclassical approach to technological change. They contend that labeling technological change as a residual is similar to the famous case of the "neutrino" in physics - an example of "labeling" an error term that proved fruitful later.

of input factors, such as better technical training to workers, fertilizers, and hybrid seeds. Griliches's study (1960) of the diffusion of hybrid corn revealed that technological change is affected by the speed with which the new technology is accepted by the farmers and their rate of profitability. However, Griliches's study does not reveal much about technological change in general because it places primary emphasis on the diffusion of new technology, rather than its invention and innovation, among other, aspects of technological change.[11] Mansfield (1968 and 1961) claims that technological change, defined as an "advance in knowledge" (1968:10) of the "industrial arts," is a direct correlate of the rate of technological innovation in an industry. Mansfield's claim that "a new piece of knowledge is a technological change when it is first discovered" but not when it is used by others in a different setting, and contention that technological change is closely related to advances in science, though they are correct to some extent, need not be universally true. All the quantitative studies mentioned above depend on an aggregate production-function representation of technological change.

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[11] See Hanieski (1973:535, n.2) for a detailed criticism of analysts who compartmentalize different components or forces of technological change and isolate one among these forces as the most important one for further analysis.

Working within the neoclassical paradigm,[12] Binswanger and Ruttan (1978), Ruttan (1975, 1978a, 1978b), Ruttan and Hayami (1973), and Hayami (1971) offer an institutionalist model of technological change based on the "theory of induced innovation." The main thrust of the induced innovation model is that the "production of the new knowledge that leads to technical change is the result of a process of institutional development" (Ruttan, 1978a:327). Unlike Veblen and other traditional institutionalists who believed that technology was the dynamic factor in economic and social change, the neoclassical institutionalists hold that institutions are the dynamic factor and technology and other socio-cultural factors are static. Hence they argue that "creating a demand" for institutional change would take care of changes in the productive systems of the society. Technological change would follow if individuals and groups of individuals believe that it is "profitable" and less "costly" to bring changes in the "design of institutions" (Ruttan, 1978a:331 and Grabowski, 1988:385-86).

By treating technological change as an essential byproduct of institutional change, these authors do not present a clear picture of how technological change really takes place. They

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[12] Unlike mainstream neoclassical economists, the neoclassical institutional economists believe that institutions are endogenous variables. The latter group uses modern choice theory to analyze institutional change, within the framework of the concept of "methodological individualism" (Grabowski 1988:385).

assume that through undertaking institutional change that would allow for economies of scale, and facilitating the reduction of transaction costs,[13] the individuals and groups who are involved would opt for that particular technology which would help them attain these benefits. Although the institutionalists claim that they consider institutional change an endogenous process of the economic system, they exclude major institutional structures from their analyses. For example, Douglass North and Robert Thomas the major theoreticians of this school, exclude from their model the "basic rules governing decision-making" in the society (Grabowski, 1988:387). Also, Hayami and Ruttan do not discuss the role of ideology and culture in the institutional innovation process. Above all, the neglect of the role classes play in social and economic change is a major deficiency of the induced innovation model. Grabowski (1988) contends that the neoclassical institutionalists take into consideration only secondary institutions in the analysis of institutional change.

As opposed to the neoclassical economists who work within the framework of production-function metaphor of technological

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[13] Transaction costs are generally understood as the expenses incurred for R and D activities. Since, in most cases, the knowledge created from R and D activities is a public good, that is, a product that may be available for the public, few private firms and individuals foot all the expenses for research. Hence, the government steps in to fund a sizeable proportion of research and development expenses. The cost incurred to develop a product out of an idea or invention is also a transaction cost.

change,[14] Rosenberg offers a non-production-function representation of technological change. Rosenberg (1976 and 1982) is probably the first economist, as opposed to Schumpeter, Solow, and Mansfield, among others, to suggest that economic growth and development may be attributable to technological change, but this revelation does not tell us much about the process of technological change. Rosenberg (1976) argues that in order to adequately understand technological change we must examine the development of the technology in its proper historical sequence. He also points out that we must take into account other contextual factors, such as social and political factors, besides the economic and historical ones.

According to Rosenberg, "Technological change encompasses, of course, a highly complex and wide-ranging collection of human activities" (1976:1). In order to understand the complexities of technology, contends Rosenberg, we must "move from highly aggregated to highly disaggregated modes of thinking" (1976:2). He argues that "complex technologies create internal compulsions and pressures which, in turn, initiate exploratory activity in particular directions" (1976:28-29). He further argues that instead of the parallel or vertical development of technologies found in pre-industrial societies, industrial societies exhibit the

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[14] It must be remembered that neoclassical institutionalists also believe in production functions.

phenomenon of "technological convergence" which can be attributed to the development of new technologies and their diffusion. According to him, the improvement or modification of a component initiates a process of change, culminating in further modifications and revisions. For example, the experience gained in the production of firearms facilitated the development and production of sewing machines, and skills acquired in the production of sewing machines and bicycles further facilitated the production of automobiles (1979:30). Rosenberg argues that the pattern[15] of technological change explained above which first initiated in the machine tool industry may be repeating itself in twentieth century chemical and electronics industries.[16]

While Rosenberg stresses temporal factors in his model of technological change, the neoclassical tradition ignores the dimension of time. While for Rosenberg technological convergence culminates in the diffusion of new technologies by a process called "learning by using" (1982), the neoclassical economists, particularly those adhering to institutionalism, see this as a process of "induced

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[15] The pattern that Rosenberg alludes is the "technological convergence" explained earlier.

[16] Although highly appreciative of Rosenberg's works, Strassmann (1977:559) complains that what is lacking in Rosenberg's works "is any definition of technology and any formal reasoning about it." All that Rosenberg (1976:1-2) would admit about technology is that we must approach it with "highly disaggregated modes of thinking" because it is interrelated with other complex social and institutional factors.

innovation" (Binswanger and Ruttan, 1978). The important variables in the neoclassical analyses are factor substitution and relative price ratio. Rosenberg argues that besides economics, we need the perspectives of other disciplines, such as history, sociology, and politics to conceptualize the process of technological change. This is a recommendation with which I concur.

2.2 ACCOUNTING FOR THE CASE STUDY

2.2(a) NEOCLASSICAL MODEL

Mainstream economics in market-oriented economic systems is presently dominated by neoclassical economics.[17] Following Lakatos, the 'hard core' of the neoclassical program consists of three main theses: (1) The theory of equilibrium via the market mechanism (Coats, 1969); (2) The theories of marginal utility, marginal productivity, and the method of comparative statics (Blaug, 1980); and, (3) The 'homo oeconomicus' thesis that assumes "human beings as simply a bundle of preferences" (Van Weigel, 1986). Glass and Johnson (1988) put the above alternatively as individualism, rationality, private property rights, and market economy. The positive heuristics of the neoclassical programme are: "(1) divide the markets into buyers and sellers, or producers and consumers; (2) specify

[17] Some authors call it "Orthodox Economics" in advanced capitalist countries like the UK, USA, and Germany. See for example, Glass and Johnson (1988).

the market structure; (3) create "ideal type" definitions of the behavioral assumptions so as to get sharp results; (4) set out the relevant ceteris paribus conditions; (5) translate the situation into an extreme problem and examine first- and second-order conditions; etcetera" (Blaug, 1980:148).[18] The protective belt or the auxiliary assumptions are: (1) "rational economic calculations," "constant tastes," "independence of decision making," "perfect knowledge" (of market conditions), and "perfect mobility of factors" (of production) (Blaug, 1980:148).

Analyses of economic behavior of the firms and other micro-units of the economic system under the above assumptions are known as micro-economics, and analyses of the whole economy[19] under the above assumptions are called macroeconomics. Neoclassical theory on technological change postulates that this process can be represented by production-functions (Sahal, 1981a). A production-function is a relationship between various combinations of inputs or factors of production,[20] and output.[21] The production-function of a

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[18] The first two among these five are generally undertaken to create perfectly competitive market structures to enable easy entry and exit for firms and other economic actors. The rest may be needed for optimization of resource allocation to achieve least cost production conditions and hence maximum profit.

[19] Both national and international economies are part of this.

[20] Examples of factors of production are: land, labor, and capital. In mainstream neoclassical theories, only labor and capital are used. In classical theories, land and labor are

firm can be represented both geometrically and algebraically.[22] Graphically, it is a plot of the isoquant,[23] which is a representation of different techniques employed in producing the same output. Technological advance (progress) is represented by a forward shift of the production- function (isoquant) (Atkinson and Stiglitz, 1969).[24] The production-function of an industry is the combined (aggregate) production-functions of all the firms in the industry. Solow (1957) has shown that it is possible to have a single aggregate production-function for the whole economy or a particular sector (industry) of the economy.[25] Solow's attempt to account for the factors that were responsible for the

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used as input factors. Schumpeter considers only land and labor in his production functions.

[21] The output, for example, may be corn, gun, butter, etc.

[22] A typical mathematical representation may be: $O = f(K,L)$, where O = output, K = capital, and L = labor.

[23] An isoquant is defined as the locus of factor combinations that give the same output on a plot with labor on the horizontal axis and capital on the vertical axis. Alternatively, the horizontal axis could be capital per labor and the vertical axis could be output per labor. In the former case, the isoquant would be a convex parabolic curve, and in the latter case the isoquant would be an exponential curve.

[24] Hicks (1932) argued that in a neoclassical production function with labor and capital as inputs, there can be three types of technological change. Capital-saving, labor-saving, and neutral technological change, which are self-explanatory.

[25] Sahal (1981a:21), on the contrary, argues that a "wide class of well-behaved microeconomic production functions do not aggregate into well-behaved macroeconomic production function. ... The two may well be complementary in the sense that psychology and neurophysiology are."

growth of the American economy for the period from 1909 to 1949 shows that the increase in capital per labor was responsible for only 12.5 per cent of the increase in output per labor, and the rest he attributes to a 'residual' factor called technological change.[26] The neoclassical approach to technological change, including the Schumpeterian version of it, in essence, is represented by production- functions. Let us apply this model to understand the Green Revolution.

In order to apply the neoclassical model we have to identify the units of analysis, which is the 'firm'. In our case it would be the peasant households,[27] both small and large farmers who have been practicing agriculture until the Green Revolution with traditional technologies. The second major assumption is the existence of a perfectly competitive market where all the participants have perfect knowledge about alternative ways of production using new technologies. The

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[26] Although Solow received a Nobel Prize in economics for this work, which made this a respectable part of neoclassical economics, Schumpeter (1934) and Hicks (1932) had "proposed that innovation (technical change) could be viewed as a shift in the production function" (Nelson and Winter, 1982:197). Nelson and Winter strongly criticize the methodology of aggregating technological change as a 'residual' as an intellectual sleight of hand.

[27] Assuming the households as 'firms' begs many questions. Unlike the firms in an industry, peasant households are a natural entity most of whom did not become farmers by choice, but by tradition. The households in capitalist economic system may be approximated to the firm, particularly in the United States where large-scale commercial farming dominates the agricultural sector. But in a semi-feudal/pre-capitalist economic system, the peasant households can be hardly equated to the firms in a capitalist system.

third major assumption is that there was a demand for the new technology, and a ready supply of it, all under the assumption of elastic market prices.[28] Under these conditions, the households would engage in agricultural production by using inputs according to their relative prices, that is they engage in factor substitution.[29] The resultant technological change would be the forward shift of the isoquant. The Green Revolution could be assumed as the progressive outward shift of the isoquant that represents the continued increase in productivity of the land.

The above characterization of the Green Revolution employing the neoclassical model is highly unrealistic and ahistorical.[30] Serious difficulties arise in conceptualizing technological change in this framework. The technological change itself was considered exogenous (in neoclassical theories), besides the unrealistic assumptions we would have to adopt to get this in the first place. The history of the

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[28] The prices for both the technology and the agricultural products are assumed elastic.

[29] A simple case would be as follows. If the relative price of labor is high, the households would substitute labor with labor-saving technologies. On the other hand, if the price of capital is higher than labor, the households would substitute it with more labor.

[30] Jon Elster (1983:100) contends that it "is a supremely efficient tool for equilibrium analysis of economic life, including intertemporal equilibria, steady-state growth, and other phenomena that takes place in <u>logical</u> as opposed to <u>historical</u>, time" (emphasis added). The economic and technological problems involved in the Green Revolution are dynamic, and the neoclassical model fails to grasp the conceptual issues inherent in dynamic analysis.

Green Revolution amply shows that it did not occur the way the neoclassical model would have described it. In the case of Indian farmers and peasants, almost all the pre-conditions for engaging in factor-substituting optimizing behavior was absent. There was no market, to start with, in most rural areas before the onset of the Green Revolution, and approximating peasant households as equivalent to firms is unrealistic.

Many prominent analysts of 'underdevelopment' in the Third World, early on, challenged the 'relevancy' and adequacy of neoclassical paradigms to understand the process of economic growth and development there. These criticisms extend to understanding the process of technology transfer to the Third World and also to the process of technological change. Gunnar Myrdal (1958) held that the "value free" theories of neoclassical economics do not apply to the conditions prevailing in the Third World, because all theories and hypotheses are "value-laden." He seriously challenged the "stable equilibrium," "comparative advantage," and "free trade" theories of neoclassical economics as inapplicable to Third World countries. The assumption of comparative statics in neoclassical economics was questioned, and instead a dynamic approach was proposed by Rosenstein-Rodan (1943) and Lewis (1954), among others. Meier (1977:77), another critic of the neoclassical model, contends that the "short-period analysis of neoclassical economics based on the assumption of population, institutions, and entrepreneurs is irrelevant to the conditions prevailing in the Third World."

In addition to the above criticisms of neoclassical theories, Streeten (1976) argues that concepts which are taken for granted in neoclassical economics, such as "capital," "income," "employment," "price level," "savings," and "investment" are absent in most Third World countries. All these critics argue that in order to properly address the problems of the Third World a structuralist approach was necessary (Meier, 1984). For example, the India of the 1950s and 1960s when the new agricultural technology was being introduced amply reflected the concerns of these analysts. India did not have most of the factors that the neoclassical model assumes for its version of technological change to work.

It was basically a feudal society where nearly eighty per cent of the population depended on land one way or the other. There was no market for credit (other than usurious money-lenders), buying new seeds and other inputs, and selling the surplus produce. Most of the peasants were illiterate, and hence the assumption of perfect knowledge of alternative production techniques was unrealistic. The communication facilities to disseminate information in rural areas were minimal or non-existent. In addition to these objections, the neoclassical model of technological change does not consider time as an important variable. It is atemporal and ahistorical in its conceptualization of technological change. There is no provision for incorporating the contributions of the four protagonists in the Green Revolution, and to explain the three stages identified in the history of the Green Revolution. This is a particularly glaring omission, because there is no provision for accounting for the process of knowledge transfer from the United States and other countries which helped to shape the agricultural research system in India. The neoclassical theory assumes that the production-function at a particular instant reflects all the conceivable techniques of production, including those available in foreign markets. If a factor of production available in a foreign market has a comparative advantage over the local factor, then the local producers import that factor of production. This sort of an explanation for the process of technology transfer involved in the case of the Green Revolution is unsatisfactory and unevocative, if not wanting in historical justification.

The second major problem with the neoclassical assumption would be that the peasants had several techniques to choose from, and from these they chose the Green Revolution technology because of relative factor prices in favor of the latter. This assumption also follows from the belief that they were well aware of the alternative techniques. We know that the farmers did not accept the technology the moment they heard about it. It took prodding from the government. They accepted it only after they were convinced of the benefits of the technology. The simplistic notion that firms (households) accept the best among possible alternatives of technologies as assumed in the neoclassical theories does not wash in the case of the Green Revolution. Technological change is a much too complicated phenomenon than the production-function model assumes it to be.

The conceptualization of capital and technology is rather fuzzy in the neoclassical model. The claim that capital is a malleable and jellylike entity that can be used in any proportion depending on the factor prices is not correct. The very idea of "measuring" capital was seriously challenged by Joan Robinson.[31] This objection becomes particularly glaring in the case of the Green Revolution. The neoclassical model sometimes considers technology synonymous with capital,[32] complicating matters still further.

The only assumption that the neoclassical theories would correctly describe in the case of the Green Revolution is the role of governments and other public agencies in research and development.[33] Since the knowledge required for inventing new

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[31] This became the well known "capital controversy" between the two Cambridges: Joan Robinson, Nicholas Kaldor, and L. Pasinetti of Cambridge, UK (representing the Keynesian school), and Paul Samuelson and Robert Solow of Cambridge, Mass., (representing the neoclassical school).

[32] The normal conceptualization of capital is that it is a collection of machine(s).

[33] This used to be a case particularly relevant to the agricultural sector of the economy more than the manufacturing and service sectors. However, with the proliferation of biotechnology firms, including some universities like Harvard and UC Berkeley, amassing patents on new biotechnological products, the distinction seems to be disappearing.

technologies is a public good that cannot be patented or privatized, new agricultural technologies had to be generated by the active participation of the government.[34] Governments have to bear all the transaction costs, including the production of new technologies and the cost incurred in transferring these technologies to the ultimate users - the farmers. This is a fact that was historically correct in the Green Revolution.

2.2(b) SCHUMPETERIAN MODEL

We know that both neoclassical economists and Schumpeter conceived of technological change as the setting up of a new production-function. But unlike the neoclassicists, Schumpeter considered the process of innovation as dynamic. Schumpeter developed his model of "Economic Evolution" through the process of product innovation spear-headed by entrepreneurs as part of his treatise on business cycles in capitalist economic systems. Notwithstanding the fact that Schumpeter ignored the process of invention in the process of technological change, his model suffers from acute conceptual problems when it comes to explaining technological change in non-capitalist or pre-capitalist and socialist economies. The Schumpeterian model of technological change is ill-equipped

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[34] According to the postulates of welfare economics, optimal resource allocation does not take place. Hence, governments must step in where private firms and households would not. See Arrow (1962) for more on this point.

to understand the Green Revolution.

The applicability of the Schumpeterian theories of economic development to Third World situations was seriously challenged by Wallich (1952), Nurske (1952), Singer (1953), Bonne (1960), and Rimmer (1961), among others.[35] As Singer (1953) correctly points out, Schumpeter's model does not consider technology transfer from the advanced countries to less developing countries. This should seriously dampen any attempt to use the Schumpeterian model to understand the Green Revolution. In order to explain the technological change in Indian agriculture, we have to look for the "New Man" or entrepreneurs whom Schumpeter entrusts with the innovative process.[36] The peasant farmers hardly qualify to assume the mantle of the charismatic entrepreneurs. In the case of the Green Revolution, the innovator-entrepreneurs were the government of India and a few international donor agencies. The entrepreneurs, in this case, were not motivated by profit maximization, but other motivations like altruism, extending a market economic system to the Third World, establishing self-sufficiency in food, and political independence, among others.

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[35] For on more this point, see Parayil (1990c).

[36] For a detailed criticism of the Schumpeterian model when it comes to explaining the lack of entrepreneurs in most Third World countries, see Wallich (1952). Wallich argues that in most Third World countries, governments have to step in in place of the Schumpeterian entrepreneurs.

2.2(c) INDUCED INNOVATION MODEL

The "induced innovation" model of Ruttan, Binswanger, and Hayami, among others, is only a variant of the neoclassical model. It considers firms and households as the units of analysis, and functions within the maximization and optimization frameworks. It considers institutional factors endogenous to the economic system like Schumpeter, but unlike orthodox neoclassicists. Another important concept that the neoclassical institutionalists borrow from Schumpeter is "methodological individualism." The induced innovation model which considers technological change an inevitable byproduct of institutional innovations may be able to explain the Green Revolution better than orthodox neoclassical and Schumpeterian models. The major thrust of the institutional neoclassicists' approach is that "institutional innovations occur when it appears profitable for individuals or groups in a society to undertake the costs of bringing about such change" (Grabowski, 1988:385). The institutionalists hold that institutional change "precedes," and is more "fundamental," than technological change (Ruttan, 1978a:332-3). Although this assertion casts a shadow on the diffusion model's ability to completely explain the process of technological change, this model, however, can explain the process of technology transfer in a much more coherent way than its counterparts.

The Green Revolution in this context may be characterized as the result of peasant farmers' demand for changes in the institutional structure within which they practiced their trade. The institutions that experience change, according to Ruttan, are markets, public bureaucracies, and organizations,[37] among others. Ruttan and Binswanger (1978:360) argue that the changes in biological technology that led to the diffusion of the HYVs were the results of the "changes in relative resource endowments and factor prices...." The peasants opting for particular input factors accept them as a response to changes in the relative factor prices of mechanical power, animal power, labor, and new seeds, "rather than as a complement to the green revolution seed-fertilizer package." (ibid:361). Here the institutionalists uphold the orthodox neoclassical position, which we have already discussed as being unhelpful in understanding how the new technology was accepted in the first place. This view might be useful to understand the actions of the peasants only <u>after</u> the changes had already started.

As Grabowski (1988) pointed out earlier, the institutions that the diffusion process would change are secondary ones (markets, bureaucracies, etc.) and not primary institutions (social relations, political power structure, cultural mores,

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[37] An organization is a decision-making unit, normally a family household, a firm, a bureau that exercises control over resources (Ruttan, 1978a:329). In the Green Revolution the most important organization was the peasant households.

ideology, etc.).[38] The field research by Leaf (1984), Mamdani (1972), and Aggarwal (1973), among others have demonstrated that profound changes have taken place not only in the market relationships, but in social, religious, and political discourses as well. There is no way to find out these changes by applying the diffusion model to understand the Green Revolution. The diffusion model, by adhering to such secondary institutions like markets and bureaucracies, does not shed light significantly on the primary institutions.

The Green Revolution did bring about changes in some institutional structures because of changes in the means of production, and not the other way around, as the diffusion model would claim. That is, "demand" for institutional change "supplies" technological change.[39] The institutionalists tried to remedy the lacunae in the orthodox neoclassical approach in explaining technological change by assuming that institutions are endogenous to economics and that technological change in turn is endogenous to institutions. Nevertheless, by retaining such concepts of the neoclassical model as the production-function, optimization, and

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[38] The institutionalists do claim that their model theoretically applies to primary institutions also. But arguing that changes in these fundamental institutions can be created by price incentives is far-fetched.

[39] Cognizant of these criticisms, Ruttan amended his position to argue that technological change and institutional change follow a dialectical relationship. Change in one induces change in the other, instead of a one way relationship of change in institutions inducing change in technology.

maximization, they seriously undermined their efforts.

The neoclassical diffusion model's ability to explain the process of adoption of a new technology may be further challenged from the perspectives of diffusion studies practiced in sociology and anthropology.[40] The model fails to identify and explain the particular communication pattern among the members of the social group and between different social groups while adopting the new technology. The model also does not specify the channels of communication, the time frame, and finally the process in which the alteration of the social structure as a result of the Green Revolution more specifically.[41] However, the induced innovation model can explain the process of technology transfer involved in the Green Revolution more satisfactorily.

Within the framework of the induced innovation model Hayami and Ruttan (1973), and Ruttan (1975) distinguish three "phases" of international technology transfer: (1) material transfer, (2) design transfer, and (3) capacity transfer. Material transfer is characterized by the simple transfer of

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[40] Ruttan (1978a:331) complains that diffusion research in sociology and anthropology is only concerned with the process of "overcoming the irrational forces of custom, culture, and personality in order to take advantage of the opportunities opened up by technical advances."

[41] Rogers (1983:11) defines innovation from a sociological perspective as the "process by which (1) an innovation (2) is communicated through certain channels (3) over time (4) among the members of a social system." For further insights on diffusion research in sociology, see Katz, Levin and Hamilton (1963). For works on diffusion in anthropology, see Cochrane (1971) and Spier (1970).

new materials, such as seeds, plants, animals, and machines. So, systematic adaptive research is conducted either by the transferrers or by the transferees. Users like farmers are left to experiment with the new materials on a trial and error basis. Because of the absence of any systematic adaptive research efforts to diffuse the new technologies, most of these new materials tend to disappear or fail to take a firm root in the new 'climate'.[42]

According to Hayami and Ruttan, the second phase of the transfer of technology involves primarily the export of certain designs, such as blueprints, formulae, and books, and "exotic" machines and materials for the purpose of copying their designs rather than for direct use. The transferee tries to duplicate the designs transferred, sometimes with modifications and adaptations to suit the local conditions. Hayami and Ruttan contend that the agricultural technologies transferred during the Green Revolution do not fall under these categories. It falls under the third phase, capacity transfer. This assumption is not correct, as there was material transfer in the case of the Green Revolution. For example, the massive importation of HYV wheat and rice. It may be argued that the capacity transfer process was more

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[42] Pray's (1981) observation that the British and American attempt to simply transfer wheat seeds to their respective colonies in the tropics did not succeed because of a lack of adaptive research is noteworthy in this regard.

visible and perhaps more important as the case study amply illustrates.

Capacity transfer involves the transfer of "scientific knowledge and capacity" (Hayami and Ruttan, 1973:125). According to this scheme, the primary objective is to "create the capacity for the production of locally adapted technology according to the prototype technology existing abroad" (ibid). Accordingly, plants and animals are bred to suit the local ecological conditions. Experts from the transferring country travel to the recipient countries to train local scientists and technologists to create the capacity to help themselves to conduct research. The history of the Green Revolution shows that this is what happened, to a large extent. The development of highly successful indigenous agricultural research capability in India was a capacity transfer of similar technological knowledge that existed in the United States after the 1950s.

Ruttan (1978b) further identifies three separate models of institutional transfer of technology within the capacity transfer scheme. The temporary migration of experts to the recipient country to train and impart advice to local officials and scientists is called the "counterpart" model. The role of expert agricultural scientists from the Ford and Rockefeller Foundations and the U.S. Department of Agriculture in transferring agricultural research capability to India falls under this model. The establishment of agricultural universities and other research institutes with the help of foreign benefactors is called the "university contact" model. The third model is called the "international institute" model. Here different international research institutes help local and national research organizations transfer know-how and adapt it to fit the transferee's particular situations. The role of the International Rice Research Institute and the International Centre for the Improvement of Maize and Wheat in transferring HYV rice and wheat seeds to India are notable in this regard.

Ruttan developed these models after studying the history of the Green Revolution. These models therefore represent a taxonomy of events that transpired in the history of the Green Revolution. Although a great improvement over the orthodox neoclassical and Schumpeterian models of technological change, the induced innovation model still falls short of capturing the complete picture of the technological change involved in the Green Revolution. These models do not completely capture the dynamics of technology transfer because the explanations for the motivations for transferring the technologies, according to the induced innovation model, were narrowly construed.

3. HISTORICAL MODELS

3.1 LITERATURE REVIEW

Until recently, historians of technology conceptualized technological change primarily as an inventive activity. Most writings on history of technology were history of individual technological artifacts. Kranzberg and Davenport (1975) concur with this notion of the historian's perspective on technology. They write that the founding of the Society for the History of Technology, and its journal Technology and Culture was intended to study the "history of technological devices and processes," and the "relations of technology to science, politics, social change, economics, and the arts and humanities" (1975:10). An excellent work intended for legitimizing the field of history of technology is offered by Staudenmaier (1985). Based on an evaluation of articles published in Technology and Culture since its foundation, Staudenmaier presents an historiographical description of this vibrant new field. He touches upon many of the theories and models of technology and technological change in his pioneering work.

Though lacking these characteristics and intentions in their analyses, the explanations of technological change offered by Usher and Gilfillan were important contributions to the historical models of technological change because they provided insights into the internal changes that occur in artifacts when one replaces another in the same industry.

A.P. Usher (1954/1929 and 1955) offers a well developed explanation of technological change based on the history of mechanical inventions. Usher emphasizes the "continuity" of technological progress, claiming that technological change is a cumulative process, in which smaller changes and inventive activities accumulate over a period of time.[43] Usher draws a sharp difference between invention and acts of skill. He argues that the "insight" "required for acts of skill is within the capacity of any trained individual." However, for inventions, the "act of insight can be achieved only by superior persons under special constellation of circumstances" (1955:43-44).[44] According to Usher, "Inventive acts of insight are unlearned activities that result in new organizations of prior knowledge and experience" (1955:46).

Usher identifies three approaches to addressing the issues involved in the inventive process: the transcendentalist, the mechanistic, and the cumulative synthesis. He rejects the transcendentalist approach which claims that inventions are the acts of genius, and also the mechanistic process which

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[43] This view of technological change may be contrasted to Schumpeter's to understand the dichotomy in their views on invention and innovation. Schumpeter argues that "innovations are changes in production functions [technological change] which cannot be decomposed into infinitesimal steps. Add as many mail-coaches as you please, you will never get a railroad by so doing" (Schumpeter, 1951:136).

[44] Usher contends that these differences can be explained by Gestalt Psychology (1955:43). According to Usher, "The Gestalt analysis presents the achievements of great men as a special class of acts of insight, which involves synthesis of many items derived from other acts of insight" (1954:61).

claims that inventions are carried out "under the stress of necessity and that the individual inventor is merely an instrument of historical processes" (Ruttan, 1959:78). Thus Usher settles for cumulative synthesis as the right explanation for inventive activities. The individual acts of insight which lead to an invention can be "formalized as a genetic sequence of four steps" (Usher, 1954:65). They are: (1) perception of a problem, which normally is an unfulfilled want; (2) setting of the stage, which is an important step that involves the work of an experimenter, which on a lower level may be a process of trial and error and on a higher level may be a systematic experimentation; (3) acts of insight in which the actual solution to the problem is found; and, (4) critical revision in which the newly perceived solutions are studied in their proper context which may lead to the development of a "technique of thought or action" and "full mastery of the new pattern."

For Usher, a major invention is the cumulative effect of several individual inventions. In fact most individual inventions set the stage for the major inventions. According to Ruttan, the cumulative synthesis theory is appealing because it "provides a unified theory of the social processes by which 'new things' come into existence that is broad enough to encompass the whole range of activities characterized by the terms science, invention and innovation" (1959:80). Although Usher's social and historical explanations of the cumulative synthesis process are appealing, his fondness for explaining the inventive process as an "act of insight" within the confines of Gestalt psychology alone may be controversial.[45] He argues that in order to have the insights for inventions, the inventor must be a "superior person." This elitist view of the inventor may not always be the case.[46] Further, Usher's tendency to credit the person who invented the theory that enabled the creation or improvement of an artifact, and to exclude the person(s) responsible for the actual invention and development of the artifact in his processual model is not correct.

Following a somewhat similar line of argument as Usher, Gilfillan (1970/1935) contends that technological change consists of large numbers of minor improvements and modifications, with innovative breakthroughs taking place rarely in the history of a technology. Gilfillan delineates thirty-eight "social principles" to describe the "nature of invention." Most of these "principles" are simple

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[45] This is, notwithstanding Usher's caveat that "The Gestalt psychology affords an explanation of the process of invention that is intermediate between the mystic determinism of the transcendentalists and the mechanistic determinism of the sociologic [sic] theories" (Usher, 1954:61). He further adds that "The completion of the analysis of the processes of innovation will necessarily be the work of the psychologists." (ibid:83).

[46] See Gamser (1988), Von Hippel (1988), and Biggs (1980) for an opposite argument. These analysts argue that the users of technology, including ordinary customers and farmers are innovative and show inventive skills in developing new products and technologies.

generalizations of technological activities of an industrial society. For example, he claims that "an invention is an evolution, rather than a series of creations" and it resembles a biological process (1970:5). One of the claims of Gilfillan is that inventions which "revolutionize" a device or industry are commonly made by outsiders who are only nominally related to the area of inquiry concerned with the invention. Gilfillan's empirically-based arguments are primarily concerned with disproving the transcendentalist argument for the process of invention. Gilfillan bases his arguments on the history of the development of marine engines in shipbuilding. There is an element of trust that Gilfillan posits in the mechanistic process for the partial explanation of inventive activity.[47] Though Gilfillan's and Usher's explanations are cogent, they offer only a partial explanation of technological change, and one of their main problems was the perception that technology was mostly tool-and-machine embodied. However, Usher's emphasis on "continuity" and "accumulation" of smaller changes over a period of time in the history of a technology makes it a valuable model of technological change, compared to the atemporal and discontinuous models of the neoclassical economists.

As a departure from these views, Lynn White (1962, 1963 and 1967) argues that Christianity played a central role in

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[47] An element of naive social determinism as the basis for the need to invent is apparent in Gilfillan's work.

the technological changes taken place in the Middle Ages. White argues that unlike Eastern religions, Christianity established the dualism between man and nature legitimizing the exploitation of nature as a proper act ordained by God (1967). White claims that "Western labour-saving technology is profoundly humane in intent, and is largely rooted in religious attitudes" (1963:291). White (1962) identifies the increased use of iron, the replacement of the oxen by horses, the harnessing of natural power (water power, wind power, etc.), and the successive modernization of the plough as the major technological changes that revolutionized agricultural revolution in medieval and early modern Europe. But above all, it was the invention of the stirrup[48] that paved the way for modern warfare, conquest of nations, and the creation of the stages that subsequently engendered the industrial civilization.

White's views of technological development have been severely criticized by P.H. Sawyer and R.H. Hilton (1963). Sawyer and Hilton accuse White of resorting to "technical determinism" by supporting his arguments with a "chain of obscure and dubious deductions from scanty evidence about the progress of technology" (1963:90). Sawyer and Hilton are more concerned about the historiographic methods of White than his theorizing on technological change. Though no parallel can be

[48] The stirrup was originated in India and it was taken to China by Buddhist monks where it was perfected. It was taken to Europe, probably, by Arab traders.

drawn from White's observations of technological change in the Middle Ages to technological change in the twentieth century, White's use of institutional factors, particularly, social influences, can be useful.

In a different approach to the historical development of Western technology, David Landes (1969) claims that the reasons for this change were attributable to the particular political, institutional, and legal developments in Western Europe. Landes claims that besides these factors, the Europeans' great faith in rational thinking helped them to manipulate their environment more than anyone else in history. This claim of Landes's becomes suspect contrasted to the writings of Joseph Needham (1969) who argues that the Chinese of the medieval period had a far superior economic and social system based on rationality than the Europeans of this period.

Paul David (1966, 1971 and 1975) follows basically the same externalist approach as Landes in his analysis. Analyzing technological change since the beginning of the nineteenth century, David (1966) argues that, although the reaper was invented in the 1830s, it took more than two decades for its adoption by Midwestern farmers because they discarded the labor intensive techniques of harvesting only when the rising cost of labor forced them to accept the new labor-saving technology. David (1971) in a comparative study of technological diffusion and change between the US Midwest and England found that the mechanization of reaping in England depended on the environmental conditions. David argues that economies of scale are a major determinant of technological change, because only those farmers who had large tracts of land could afford to acquire farming machines.[49] He argues that there is a "threshold farm size" at which reaping machines become economically viable. David's insights on how environmental factors affect technological change is useful. But his thesis that farm size is the prime cause for mechanization is controversial. Commenting on the "threshold farm size" thesis, Alan Olmstead (1975) argues that smaller farmers were able to exploit the divisibility of machines by contracting out harvesting services. Therefore, he concludes that small farm size did not deter the technological change.

As opposed to the internalist approaches of Usher and Gilfillan and the externalist approaches of David, Landes, and White, Thomas Hughes (1976, 1983, 1986 and 1987) uses a systems concept[50] to explain the development of a technology and its change. Hughes (1983) shows how small electric utilities grew and developed into large power systems in Western European countries in late-nineteenth and early-

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[49] The basic premise of the argument is that because of the "lumpiness" of capital goods, only those who can make use of the maximum service of the new machinery can exploit the economy of scale and hence obtain maximum return on their investment.

[50] The "rationale" that Hughes posits for using systems concept is that the "history of all large-scale technology--not only power systems--can be studied effectively as a history of systems" (1983:7).

twentieth centuries. Hughes argues that all large-scale technological systems go through five "phases" during the development and growth stages in their history. In the first phase, the invention and development of the system are analyzed. The professionals who play predominant roles during this phase are called "inventor-entrepreneurs," whom he considers different from ordinary inventors. Hughes considers Thomas Edison as the quintessential inventor-entrepreneur. The second phase of the system involves the transfer of technology, which according to Hughes differs from region to region. Hughes argues that different factors (for example, the nature of the technology, politics, and legislative prerogatives, among others) influence the course and process of technology transfer. The third phase is concerned with the growth of the system. Hughes's analyses of the growth of the systems are based on two key concepts, which are "reverse salients"[51] and "critical problems." Using these concepts which Hughes claims he borrowed from military history, he argues that "When engineers correct reverse salients by solving critical problems, the system usually grows if there is adequate demand for its product" (1983:15). The fourth phase of the system is called "system momentum." Like natural

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[51] Westrum (1989) contends that the concept behind 'reverse salients' was first developed by Rosenberg in 1969 by the term 'technical imbalance'. Westrum, further adds that 'reverse salient' "may be more exciting, but Rosenberg deserves credit for his earlier very insightful development of what is essentially his idea" (1989:190).

systems, Hughes's system also has mass, velocity, and direction. The mass consists of the physical artifacts, and the institutional factors and the professionals associated with the system. The rate of growth of the system is subsumed as the velocity, and the goal-orientation of the system organizer's is considered the direction of the system. The last (fifth) phase of the system is "characterized by a qualitative change in the nature of reverse salients and by the rise of financiers and consulting engineers to preeminence as problem solvers" (Hughes, 1983:17). The primacy of the inventor-entrepreneurs seems to attenuate at this stage of the system development.

Hughes claims that technological systems are socially constructed (1987:51). He contends that since technological systems are "invented and developed by system builders and their associates, the components of technological systems are socially constructed artifacts" (1987:52). Hughes differs from the network theory of Callon, in such a way that he identifies inventors, industrial scientists, engineers, managers, financiers, and workers as components of the system, instead of being counted as elements of a network.[52] Hughes argues that

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[52] Hughes removed all barriers between his notion of technological change and that of network builders and social constructivists by calling all the components and elements of the system as partners in a "seamless web" (1986).

system evolution[53] may be characterized as invention, development, innovation, transfer, growth, competition, and consolidation, though not necessarily in any particular sequence. These stages can overlap or backtrack (1987:56).

Terry Reynolds (1984) though highly appreciative of Hughes's meticulous research and scholarship, nevertheless raises the general concern whether "system" has been accepted as a unit of analysis of Hughes's particular case study of a technology or the standard unit of analysis for all histories of technology. John Law (1987a) questions Hughes's indifference to using the same analytical method to explain micro- and macro-phenomena. While Hughes's model has been regarded more of a socio-technological method of analysis (Law, 1987a), Kuhn's sociologically-inspired historical analysis of scientific change as a "paradigm" has been accepted by Edward Constant (1980) as the guiding principle for explaining technological change.

Constant (1980), using the evolution of the turbo-jet engine as an exemplar, claims that technological change is akin to a paradigmatic scientific change with some minor changes to the notion of communities of practitioners and anomalies expounded in Kuhn (1970). According to Constant, "technological knowledge is expressed in well-winnowed traditions of practice that are the possession of well-

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[53] Here "evolution" may be considered as equivalent to change. Hughes' explanation of system evolution has several factors in common to technological change.

defined communities of technological practitioners" (1987:224). These communities are made of individual adherents to the tradition and organizations of all sorts. In essence, the "community of practitioners" can be conceptualized as the formal unit of analysis in Constant's model of technological change. Constant's model of technological change is based on his notion of "functional failure" and "presumptive anomalies." The failure of a technology forces the "community of the technology practitioners" to seek alternative radical solutions to the problems. Presumptive anomaly occurs when advances in other disciplines, such as science, indicate some future conditions under which the existing technology might fail. Presumptive anomaly can occur even without a functional failure.

W. Lewis (1982) and E. Ezell (1982) find Constant's work highly evocative and claim that his model of technological change is an exemplary one without offering their own analysis of why it is so. This enthusiasm has to be qualified because it is not necessary that there ought to be a presumptive anomaly in the history of a technology for its replacement by a better technology. Also, Constant's claim that the emergence of revolutionary ideas, or new ways of conceptualizing alternative technological solutions always come from the outside of the community of technology practitioners has already been raised by others, which in any case is not historically correct.[54] The technological change in telecommunications taking place now, in which the analog technology is giving way to digital technology, is not due to a presumptive anomaly in the analog system.[55] Also the information revolution engendered by the digital technology is not the work of outsiders but of people closely involved with the telecommunications industry.

Finally, by his exclusive dependence on the "community of practitioners" to analyze the process of technological change [which is characterized as a "series of major technological innovations culminating in the turbojet" (1980:32)], Constant avoids other critical factors, such as economics, patents, and cultural influences, among others, which are also responsible for technological change.[56]

One of the most recent scholarly works on technological change and progress is offered by Richard Hirsh (1989). Hirsh presents an account of the state of electric power technology

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[54] Although Constant rejects the Chicago school of sociologists' (including Gilfillan's) theory of the "Sociology of Invention" out of hand, claiming it as inadequate to capture the complexity of technological change and "simply wrong" (1980:2), this claim is same as one of the thirty-eight principles (No. 32) developed by Gilfillan (1970) on the "Sociology of Invention."

[55] For a detailed exposition of the recent technological change in telecommunications, see Parayil (1990a).

[56] Constant admits this deficiency in his model. He admits that by adopting the model he was forced to a trade off. That is, his conceptual framework "partially obscures" other critical factors mentioned above.

in the United States since 1960s when the euphoria for nuclear power began to decline. He argues that after having exhausted the benefits of technological advances, and system optimality and economies of scale derived from large-scale systems, the electric utility industry entered into a period of "stasis." Hirsh uses the concept of technological stasis as a conceptual model for technology, in general, and argues for the case through economic, political, and business perspectives in the electric power industry. Although the concept of stasis is not intended as a universal model of technological change, it nevertheless provides important insights into the process of technological change based on an excellent empirically-supported case study.

3.2 ACCOUNTING FOR THE CASE STUDY

3.2(a) USHER'S MODEL

The historical models of Usher and Hughes are the focus of this section. The 'hard core' of the Usherian programme is the theory of cumulative synthesis. That is, great technological developments are the cumulative syntheses of a very large number of minor achievements. Usher does not subscribe to the notion of technological change as a cataclysmic and discontinuous process. Instead, he argues that technological change is, basically, the result of the impact of minor inventions and other technological activities cumulating over a period of time.

Inventions are the major determinants of technological change in the Usherian scheme.[57] The four steps involved in the process of an invention, which may be characterized as technological change are: (1) perception of the problem, (2) setting the stage, (3) the act of insight, and (4) critical revision. According to Usher, technological change is an evolutionary process, involving both minor and major (strategic) inventions in the history of a technology. This "processual" approach is particularly appealing when explaining the development of the HYVs of rice and wheat in the history of the Green Revolution, although it is difficult to delineate the four stages, mentioned above, specifically.

The history of the Green Revolution clearly reveals that the "invention" of the HYVs was a great technological achievement that can be conceptualized as a process of cumulative synthesis involving several smaller steps. Semi-dwarf varieties of rice and wheat were known for a long time.[58] However, it was the Japanese farmers who began to exploit the

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[57] Having no significant theoretical works in technological change as a precedent, Usher's theory of invention is in fact a portmanteau for different technological activities that culminate in technological change. However, it must be stressed that Usher puts more emphasis on innovative activities than development and diffusion.

[58] The particular "inventions" that created the semi-dwarf varieties until the beginning of the twentieth century are difficult to delineate from the historical materials available, other than to suggest that continuous cross-breeding between plants with dwarfing characteristics might have created the semi-dwarf varieties, or it could have been a product of random mutations.

smallness of the varieties in the 1900s for higher cereal productivity by applying chemical fertilizers. The development of early HYVs were to be credited to Japanese farmers who manipulated the genetic characteristics by cross-breeding them with local and foreign varieties. One of these successful wheat varieties, Norin 10, was introduced in the United States from where the Norin-Brevor variety was taken to the International Maize and Wheat Improvement Center (CIMMYT) in Mexico. The genetic make up of modern HYV wheat was obtained from the Norin-Brevor by the efforts of Borlaug[59] and his colleagues at CIMMYT. Thus, the "invention" of the modern HYV wheat may be characterized as "an invention.....that represents a substantial synthesis of old knowledge with new acts of insight" (Usher, 1955:50).

The history of the HYV rice shows no foremost single individual who could be credited with the "invention" of the IR-8 and other important and popular varieties. The IR-8, for example, was developed by the scientists at the International Rice Research Institute (IRRI) in the Philippines. The IR-8 was obtained by genetically manipulating rice varieties from Taiwan, China, and Indonesia. Exploiting the genetic quality of high fertilizer responsiveness of the IR-8, hundreds of varieties of HYVs were developed by both Indian and IRRI scientists. A similar trend followed in the case of HYV wheat.

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[59] Borlaug was given the 1970 Nobel Peace Prize for his pioneering works in plant genetics that helped to develop the modern HYV wheat.

The HYVs are only one element of the Green Revolution. The cumulative synthesis model may be able to explain the development of other components, such as tractors, diesel and electric pumps, irrigation systems, and fertilizers. However, we know that a disaggregated account of the various elements of the Green Revolution may not necessarily tell us much about the determining factors that brought about this technological change. Also, it is not clear whether we should extend the same method of analysis to the development of research capacities and other such intangibles. Because, from the Green Revolution it is impossible to find parallel factors, as in the case of the HYVs and other tangible technologies, to use in the case of the development of research capacities with which to develop the four typologies that Usher developed for explaining "invention." Besides, Usher's original model was intended for explaining technological change in mostly mechanical technologies that were tangible.

If we disregard the four-stage analysis that Usher developed, and instead take the theory of cumulative synthesis as the basis for technological change, we can explain, in general, that the Green Revolution was made up of several smaller steps. The cumulative synthesis of the actions that the four protagonists took which were discussed in the case study, in fact, culminated in the Green Revolution. The case study in its entirety, from the mid-1950s to the mid-1970s, may be taken as an evolutionary process that culminated in the technological change. This includes invention, transfer, diffusion, development, and innovation of agricultural technologies, both local and foreign.

Although Usher's cumulative synthesis model based on the four-stage process applies well to the development of the HYVs more than to the whole technological change itself, his model fails to address the disembodied nature of technological change, particularly the transfer and diffusion of the agricultural research system from the United States to India. Although Usher's scheme of invention occurring as a result of cumulative synthesis is a discontinuous process, a closer reading of his model shows that technologies do not become extinct in the strict Usherian sense. The inventive process is something that individuals and institutions involve themselves in to invent new artifacts based on existing ideas or to improve upon old artifacts. Thus, the technology at any one moment is the cumulative synthesis of previous technologies with improved efficiency. Although cumulative synthesis is a plausible explanation of technological change, the development of new technologies only because they are functionally superior to their previous counterparts may not be necessarily the case with every technological change. Technological change occurs not only because of the exigencies dictated by normative concepts like functional superiority,[60]

[60] A typical functional superiority example would be improved energy or mechanical efficiency.

but also due to such other factors as environmental and public safety considerations, potential for capital saving, facility for automation, and substitutability of parts and input energy sources.[61] This suggests that we need a broader account to accommodate these Usherian factors.

3.2(b) HUGHES'S MODEL

If the unit of analysis in Usher's cumulative synthesis model of technological change is an individual (mechanical) invention in the history of (mechanical) technology, the unit of analysis of Hughes's model of technological change is a system. Hughes contends that the history of all large-scale technologies can be conceptualized in systemic terms. Hughes delineates five phases in the history of a system: (1) the early beginning of the system during which the inventive activities in its development are dominated by inventor-entrepreneurs; (2) a technology transfer phase; (3) system growth in which reverse salients and critical problems are ironed out; (4) system momentum in which the system gains orientation and stability; and, (5) the mature state of the system during which the dominance of inventor-entrepreneurs gives way to the leadership of financiers and consulting engineers. In terms of technological change and technology transfer, phases two and three are more important than the

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[61] See Chapter One for a detailed theoretical exposition of "what is technological change?"

other three phases.

The conceptualization of technological change in the case of the Green Revolution according to Hughes's model would be the growth of peasant agriculture dominated by 'simple' technologies and its transition to near-commercial farming systems dominated by modern technologies like HYVs, tractors, pumps, and chemical fertilizers. However, serious problems arise here. Peasant agriculture systems and modern seed-fertilizer-controlled irrigation agriculture systems dominated by farmers are two different systems with different dynamics of system development. For example, the important factor that drives peasant agriculture is subsistence farming which carries the least amount of risk. Although the productivity of the land is low, peasants can expect a subsistence crop every year, unless major natural disasters strike. On the other hand, modern technology-based agriculture is largely predicated on the concept of risk taking, although one of the most important functions of the new technology is to progressively reduce the amount of risk by the process of "learning by doing" and "learning by using," among other methods of technological innovation. Agriculture based on new and high-yielding seeds, fertilizers, pesticides, controlled water, and mechanical implements make the new agricultural system qualitatively and quantitatively different from traditional agricultural system which is based on subsistence farming principles. The obvious trade-off is much higher productivity of the land in the latter case, in turn generating an entirely new system dynamics.

Hughes does not discuss how the transition from one system to another takes place. Instead, he expands the boundaries of the system to accommodate future development as well as new components which have totally different system dynamics.[62] It is implicitly assumed in Hughes's systems model that the system was built from the ground up. Nevertheless, he provides no explanation for the system of energy sources and their technologies before the utility system came into being. Although, in Hughes's case it was not necessary to explain this segment of the technological change, because he was interested in only capturing the change after the transition from 'traditional' energy technology to 'modern' electricity-based technology had already been accepted in principle. Let us, on the other hand and for the sake of simplicity, assume agriculture (both modern and traditional) is the system. The beginning of the system was the peasant agriculture which became the modern agriculture system as a result of the infusion of a radically new agricultural technology in place of a technology that was in use for several hundred if not thousands of years. This is an approximate characterization of a system. Identifying each peasant and farmer household as

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[62] Although a typical system construed in engineering terms has a well defined boundary, Hughes does not provide any boundary conditions. He is fuzzy about this important dimension of systems.

a system (unit of analysis) might be a more realistic approach. But with the latter approach, Hughes's model does not obviously apply.

In the case of the Green Revolution we know that agriculture modernization in India began in the 1950s and 1960s. The first phase of the system's development would be the dominance of inventor-entrepreneurs. From the history of the Green Revolution we know that there were no such charismatic characters who undertook inventive and entrepreneurial activities. We may be able to find a few individual inventors like Borlaug, but the entrepreneurs who invested in research and development were governments and a handful of international donor agencies.

The technology transfer phase applies better than the first phase (discussed above) in the case of the Green Revolution. The modality of technology transfer that Hughes delineates is one of exporting inventions to a foreign market and soliciting capital from the local sources. The new inventions are protected by patent rights in the host country. But the diffusion of the new technology and the system growth were determined by the host country's legal and economic constraints. Although there were no intellectual property rights issues involved in the case of the Green Revolution, the transfer of research capacity was regulated by political, economic and other institutional constraints. The similarities of the process of technology transfer between the electric power industry (the subject of Hughes's study) and the Green Revolution are superficial. In the case of the electric power systems, the actors were individual investors and in the case of the Green Revolution the actors were governments and international agencies. In the former case the immediate motives were profits, and in the latter case the motives were to prevent famines and to attain food self-sufficiency.

The third phase of Hughes's system development model is concerned with system growth. The reverse salients and critical problems that crop up in the growth of the system had to be solved.[63] The reverse salient in the agricultural situation in India during the 1950s and 60s was declining productivity due to droughts and stasis in technology. The seeds were of poor quality because of lack of selection and continuous inbreeding. Peasants saved a portion of their crops every year as next year's seeds. Lack of electricity and diesel fuel in the rural areas prevented the peasants from using pumps and other power augmenting sources for irrigation. The non-availability of credits further hampered the progress of agriculture. These critical problems had to be solved to counteract the reverse salients on the agricultural front.

The most critical of these problems was the low

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[63] One of the major critical problems in the case of the electric power systems that Hughes (1983) cites was the difficulty in direct current (DC) transmission. The problem was solved by the development of alternating current (AC) generators. Although Edison opposed the introduction of AC power systems because he had already invested heavily in DC power equipment, AC systems prevailed.

productivity of the land because of the poor quality of inputs.[64] The development of the modern HYV varieties of rice and wheat at the IRRI in the Philippines and the CYMMIT in Mexico was to address this critical problem. Although the high productivity of the HYV seeds was clearly known, the concerned authorities in India who wanted to introduce these seeds had to fight powerful bureaucrats and a few anachronistic agricultural scientists.[65]

The fourth phase of Hughes's model is called system momentum. The parallel that Hughes draws between natural systems and the supposedly "socially constructed" technological systems might be difficult to conceptualize. The 'mass'[66] of an agricultural system may be the physical artifacts (HYVs, irrigation systems, mechanical gadgets, fertilizers, etc.), institutional factors, and the farmers and all the research and extension workers involved in the modernization process. The velocity of the system may be construed as the rate at which the new technology was diffused and accepted by the peasants. The direction of the system may

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[64] This problem was compounded by the constancy of land under the plough, as all arable land in a country like India was already cultivated by the 1960s.

[65] A parallel can be drawn between Edison and the officials who opposed the HYVs, the former for his own personal gains, the latter for ideological purposes and ignorance.

[66] In an electric utility system the 'mass' consists of the physical artifacts and the institutional factors, including the people associated with the system.

be subsumed under the policy directives of the government and other public agencies to increase agricultural productivity by inducing changes in traditional agricultural technology. It is difficult to abstract these concepts from the case study to give exact values. These concepts can be construed only in metaphorical terms and not literally.[67]

The final phase of a system that Hughes narrates is related to how the system attains a stage of maturity. This may be construed in the case of the Green Revolution as the Second and Third Generation problems.[68] The productivity differences and the impact of the new technology are assessed by social scientists. Although this is a departure from what Hughes postulated, the increased role of social scientists in analyzing the impact of the Green Revolution and in proposing ways to alleviate some of the negative consequences of technological change may be a better signal of a system maturity than the primacy of financiers and consulting

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[67] For example, velocity is a vector that is obtained by dividing the distance by the time elapsed. In order to determine the direction, we have to find all the force vectors and add them together and then determine the resultant force vector. The coordinates of this resultant vector determine the direction of the whole system.

[68] The First Generation problem was generally considered as raising the productivity of the land. The Second Generation problems had to do with marketing, problems of markets, and resource allocation (e.g. allocating credits, investments in infrastructure development, etc.). See W.P. Falcon (1970) for more on these issues. The Third Generation problems were related to equity, income distribution, etc. Environmental problems, including those related to the usage of pesticides, etc. can be considered the Fourth Generation Problems.

engineers which Hughes considers dominates the final stage of a system.

Hughes's systems metaphor can be applied to the case of the Green Revolution only if we take extreme liberty with what constitutes the boundary conditions. Agriculture, the first organized enterprise of humans, is a rather difficult entity to be brought under the constraints of a system. A safe method might be to treat the segments of the agricultural enterprise as different systems,[69] for example, the agricultural enterprise after the 1960s, in the Green Revolution. Notwithstanding several conceptual incongruities, to a large extent, Hughes's model can be applied to the Green Revolution. Hughes's model of system evolution or technological change is primarily intended for socio-technological systems which are more localized than agricultural systems. Also, Hughes's analysis tends to be more amenable to technological systems in advanced capitalist economies. Although his analysis of economic factors in the development of power systems is rather rudimentary, still the assumption of the pre-existence of the financial system in his analysis makes it less applicable to a country like India where most of the institutions that Hughes takes for granted were non-existent at the onset of the Green Revolution and, to a large extent, remain so. My earlier concern whether Hughes's system model can be applied to

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[69] Since the very idea of systems is recursive, under system analysis this is an acceptable practice. The complexity of a system increases as the system grows or shrinks.

another system with a different dynamics of growth and development still remains.

CHAPTER FOUR
MODELS OF TECHNOLOGICAL CHANGE: SOCIOLOGICAL AND EVOLUTIONARY MODELS

1. INTRODUCTION

The focus of this Chapter is to evaluate sociological and neo-Schumpeterian-evolutionary models of technological change. First, I will present a review of the pertinent literature and offer appropriate criticisms. Applying these models to account for the technological change in the Green Revolution is the methodology proposed for testing them. Only two models will be chosen from these two areas: the models of Bijker and Pinch, and Law and Callon from sociology; and the models of Giovanni Dosi and Devendra Sahal from neo-Schumpeterian-evolutionary studies of technology.

2. SOCIOLOGICAL MODELS

2.1 LITERATURE REVIEW

Sociologists' interest in technology, in general and technological change in particular, is very recent.[1] The attempt by mostly European sociologists to develop a

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[1] A caveat is in order. The works of the Chicago School of sociologists (e.g., Gilfillan, Ogburn, and Thomas, among others) during the interwar period is an exception. I make this claim based on the fact that after the Second World War there was no interest in technology, per se, on the part of American and continental sociologists before the European sociologists ventured into the field again in the 1980s.

'sociology of technology' is the result of this interest. Two factors can be cited as the basis for this interest, which are the debate going on about the science-technology relationship and the empirical studies in the sociology of knowledge championed by relativist sociologists. According to Wesley Shrum (1988:397), the characteristics of these new "sociology of technology" are the refusal of its protagonists to "distinguish between science and technology,"[2] and their insistence that the "object of study is a heterogeneous set of organizational and individual actors embedded in a multidimensional array of forces." Three separate models of technological change or development can be counted as the constituents of this nascent sociology of technology: social-constructivist, systems, and actor-networks.

Until the emergence of this new sociology of technology, the only major sociological investigation on technological change was conducted by Gilfillan (1970/1935). Attempting to develop a "sociology of inventions," Gilfillan widens the frame of reference for the analysis of technological change to include non-technical factors which interact with changes in technical factors. Wealth, education, population, and "industrialism" are some of the "non-technical" factors Gilfillan adds to the "milieu" of his "social principles of

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[2] This characterization of Shrum's is an overstatement. The relativist view on science and technology is one of interaction between two equal partners. See, for example, Barnes (1982).

invention." Gilfillan presents thirty-eight such "social principles of invention." Technological change, for Gilfillan, is akin to a Darwinian evolutionary process which is largely subsumed under the "inventional" process. Gilfillan uses the evolutionary theory as more than an analogy, and claims that "The ship or any invention is a biologic organ, in the same sense that a bird's nest is" (1970:14). While some of the principles are insightful, a few are controversial, and the rest straight generalizations of ordinary and obvious observations from everyday events. Irene Taviss (1974:137) underplays the importance of Gilfillan's model, and instead argues that Gilfillan is "concerned about demystifying "the inventor" and about denying any facile technological determinism." Gilfillan does not offer a model, but instead a generalized commentary on the process of technological change based on the social history of the invention of the ship.

As a radical departure from Gilfillan's approach, Trevor Pinch and Wiebe Bijker (1987) follow a "social constructivist" approach to technological change based on the social history of bicycles. Pinch and Bijker developed their model with theoretical guidance from the "Empirical Programme of Relativism" of Harry Collins (1981).[3] The social-

[3] Bijker and Pinch claim that their objective is to develop a "sociology of technology" with which to analyze technological change. They claim that their intention of building a sociology of technology is to treat "technological knowledge in the same symmetric, impartial manner that

constructivist approach assumes that artifacts and technological practices are underdetermined by the natural world, and their constructions are socially determined. Pinch and Bijker see the developmental process of a technological artifact as an "alternation of variation and selection"[4] in a "multidimensional" mode[5](1987:28). The method of justification that Pinch and Bijker use for their arguments is the concept of "interpretive flexibility" of artifacts.[6] This property of the artifacts is used to explain the process of "closure"[7] through which the artifacts are stabilized by the "interests" and "actions" of relevant social groups.

Bijker and Pinch adapt the above concepts, which were originally developed for science, to the case of technology as follows: In the case of science, scientific facts are

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scientific facts are treated within the sociology of scientific knowledge" (1987:24).

[4] Bijker and Pinch (1987:50, n.30) argue that this assumption is compatible with the concept of evolutionary epistemology of Toulmin (1971) and Campbell (1974), which Constant (1980) implicitly used in his model of technological change.

[5] Bijker and Pinch argue that their model operates in a multidimensional mode to remedy the "linear" "models used explicitly in innovation studies and implicitly in much history of technology" (1987:28).

[6] This assumption holds that there is more than one interpretation for the "sociological facts" behind the "social construction" of artifacts. The focus of explanation moves from the technological realm to the social realm.

[7] "Closure" occurs when social mechanism limit interpretative flexibility and allow for scientific controversies to be terminated before they are resolved.

interpreted with respect to nature. For technology, they argue that technological artifacts are interpreted with respect to culture. Bijker and Pinch contend that based on their historical case study of the development of bicycles, it appears that interpretive flexibility was shown in the design characteristics of bicycles (1987:40). They argue that "closure" in technology means the "stabilization of the artifact and the disappearance of problems" (1987:44). They identify two types of closure: (1) rhetorical closure: in this case a technological controversy is solved by convincing the concerned social group that the problem has been solved, sometimes using "facile" advertisements, among other methods; (2) closure by definition of the problem: this depends upon the particular section of the social group involved with the technological problem. In the case of the air tire in bicycles, it was a "theoretical and practical monstrosity" for the engineers and the public, and for them, argue Bijker and Pinch, it also meant an "aesthetically awful accessory" (ibid). The authors contend that their analysis can account for the development of both successful and failed artifacts. They conclude that the content of an artifact is described by the "meaning" ascribed to it by the social groups, which (meanings) themselves were influenced by the wider society.[8]

[8] Bijker (1987) adds two more concepts to further expound the nature of the social group and the members or "actors" of the group. These are "technological frame" and "inclusion." Technological frame is the "concepts and techniques employed by a community in its problem solving" (1987:168) efforts.

Clark et al. (1988) use the social-constructivist model to explain a micro case study of a technological change, involving telephone exchanges, in the telecommunications industry. They argue that the important issues are the factors that select the technology to satisfy the change demanded by the interests of the social groups in the industry, and once the new technology is chosen the change occurs independent of these selection factors.[9] The social-constructivist model is too localized in its analytic focus and concentrates on micro-level changes only. Besides, by leaving out the multidimensional aspect of technological change in their analysis, the model loses its universality. The model developed by Bijker and Pinch is more descriptive than prescriptive. They do not specify conditions or possibilities under which technological frames become dominant and the way in which groups and individuals get excluded and included in the technological frame. By arguing that technological development is socially determined and social factors only direct the growth and stabilization of artifacts, Bijker and Pinch exclude other extant factors, like economics, from the locus of technological change. However, it must be conceded

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This is a concept akin to a Kuhnian paradigm. Inclusion was introduced as a concept to measure degree of participation of the members of the community involved in the construction of the artifact.

[9] For a review of Clark et al., and also for an evaluation of the "social constructivist" model, see Parayil (1990a).

that Bijker and Pinch have developed a model which is more interdisciplinary than most other models discussed earlier.

Following the same "sociology of technology" framework as Pinch and Bijker, Donald MacKenzie (1987) and John Law (1987b and 1987c) adopt a systems approach a la Hughes to explain technological change. Taking a systems perspective to explain technological development (change) pertaining to missile guidance and its accuracy, MacKenzie argues that technological issues are "simultaneously organizational, economic, and political" (1987:02). He argues that technological change in the form of "extreme accuracy in ballistic missiles" has a large social component in its development. MacKenzie explains the development of missile accuracy as one of solving "critical problems" created by the "reverse salients" in the instrumentation system of the missile guidance systems.[10]

Law presents a "nonreductionist sociological perspective on technological change" (1987b:227-28) based on the history of Portuguese maritime expansion, since the first Portuguese navigator, Vasco da Gama anchored in Calicut, India in 1498. Law looks at the expansion of Portuguese power and the development of their technology of war from the "standpoint of system-building or heterogeneous engineering" (1987b:231-

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[10] The reverse salient, in the case of missile accuracy, was detected in the inertial systems. The critical problems were tracked down to the gyroscope of the flight guidance system. According to MacKenzie, the solution to the critical problem, the design of inertial instrument became the "normal technology" a la Kuhn.

32). Both social and technical factors play crucial roles in technological change spear-headed by "heterogenous engineers." People, techniques, skills, artifacts, and natural phenomena are the entities that make up "heterogeneous engineers," and the construction of technological devices is achieved by linking these entities based on contingent factors.[11] Although, MacKenzie and Law invoke the systems metaphor in their models, the terminology they employ is different from the one Hughes uses in his model. The authors' proclivity to depend heavily on contingency factors to explain technological change may perhaps limit their models' adaptability to other cases of technological change, considerably. Westrum (1989) argues that Law uses the concept of "heterogeneous engineering" as if he invented it. According to him, Law's use of the concept is only a poor imitation of the concept that is explained in systems engineering in a highly sophisticated fashion.

Law's concept of linking together "heterogeneous" elements that make up the change is further elucidated by Michel Callon (1986 and 1987). Callon argues that in his sociological framework there is no rigid social/natural divide, and the "actor" (the technological artefact in question) acting in an "actor-world" enrolls other entities to form an "actor-network." Based on the history of the development of the

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[11] Law uses the principle of symmetry from the strong programme to argue that the same type of explanation must be used for all the elements (animate and inanimate) in the heterogeneous network.

electric car in France in the early 1970s, Callon argues that the technological development of the electric car involved the linking together of animate and inanimate objects such as the batteries, electrons, engineers, and financiers, among other numerous entities in such a way that each entity has its role defined by the organizer of the electric car.[12] Callon's assertion that the "actor worlds" constantly create new combinations of the entities to induce the change does not offer a purpose or new orientation to the process of technological change. It appears, for Callon, technological change is a random phenomenon. The actor-network model has the same drawback as that of the social-constructivist model, which is its neglect of macro-level changes. Shrum (1988:403) complains that the actor-network does not address the problems "concerning the relations between micro and macro levels," and questions Callon's claim that "nothing exists but a multiplicity of actor networks with 'no overall structure'." The actor-network model is not analytic,[13] because of the lack of restrictions applied to the elements of the networks, and also it does not specify under what circumstances any new element may be "included" in the network. Hence it is doubtful

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[12] Here Callon uses the symmetry concept with a twist, going further than what Bloor (1976) intended in its original formulation.

[13] Callon admits this. He stated his objective as to "transform the study of technology into a tool for sociological analysis" (1987:84), and show that engineers are sociologists as well in their actions.

whether it can accurately depict the varying complexity of this multidimensional phenomenon.

2.2 ACCOUNTING FOR THE CASE STUDY

2.2(a) SOCIAL-CONSTRUCTIVIST MODEL

In this section, I shall use the social-constructivist model to attempt to understand the technological change discussed in the case study. The particular model which Pinch and Bijker (1987) develop to explain technological change is called the 'social construction of technology' or SCOT. The bedrock of the social-constructivists' concept of technological change is the assumption that the construction of technological artifacts is "underdetermined" by the natural world.[14] According to them it is the social factors alone that determine the construction of technological artifacts. Not only the construction of artifacts but technological 'practices' are also socially determined, according to this scheme. Technological artifacts are explained and their construction interpreted with respect to the culture of the community in which the construction takes place.

Because of its strict adherence to micro-phenomena and to the construction of physical artifacts, the social-constructivist model may be inadequate to capture the process

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[14] The social constructivists did not provide sufficient substantiation to support this claim which was originally assumed only for science. But we know that the natural world also plays a role in the shaping or 'construction' of technology.

of technological change in agriculture, which is an amalgamation of several micro-and macro-level events. In the Green Revolution, technological artifacts and practices from a variety of agricultural and engineering fields coalesced within a framework of different social, economic, political, and cultural factors. HYVs, chemical fertilizers, electric and diesel pumps, tractors, threshers, irrigation canals, roads, banks, extension services, national and state governments, international donor agencies, and international agricultural research institutions, among others, are technologies each of which is "socially constructed" in disparate social circumstances. However, when these were brought together a significant technological event took place. The social-constructivist model is inadequate to explain the process by which the traditional technological system gave way to a new and modern counterpart. However, by applying the social-constructivist model we might be able to account for many of the individual components that make up the Green Revolution. With that in mind, consider the following "social construction" explanation of the HYVs.

The social groups involved in the construction of the HYVs were trans-continental and trans-cultural in nature. They included, among others, farmers and agricultural scientists from several countries from the Far East to the Far West. One of the major problems with the traditional varieties that the farmers had was that the plants lodge[15] when chemical fertilizers were applied.[16] The best way to attain proportional yield when fertilizers were added was to develop a variety that would not absorb the added energy in the form of larger plant size to the detriment of production of additional grain. The easiest solution to this problem was to extract the dwarfing genes from the dwarf and semi-dwarf varieties which were known for hundreds of years in the Far East and add this characteristic to the traditional varieties. Because of the dwarfing genes, the traditional varieties would not absorb the added energy in the form of fertilizers to produce larger plant size, but instead, the added energy input would be converted into enhanced cereal output.

The "interest" of the concerned social groups (in this case agricultural scientists) was to develop a high-yielding variety based on the above discovery to suit the particular ecological conditions of India.[17] The interest of the scientists and their financial supporters at the CYMMIT and the IRRI was to develop HYVs for peasant agricultural conditions in Third World countries situated predominantly in the tropics. HYV seeds had to be developed for wet, semi-

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[15] See Chapter Two (n.48) for an explanation of 'lodging'.

[16] This may be adduced as a "closure."

[17] Until the 1950s the HYV varieties were developed to meet the climatic conditions in the temperate climatic regions, which were mostly in the presently developed countries.

arid, and arid climatic conditions. The problems were acute, but not insurmountable. The new HYVs were found to be highly susceptible to pests and weeds in the intensely humid and hot conditions in the tropics and sub-tropics. Although one of the most successful rice varieties, known as IR-8, yielded bountiful harvests, the cooking quality of the rice was poor and disliked by the consumers and occasionally it fell victim to unexpected pests.[18] Similar problems cropped up in the case of HYV wheat. Local adaptive research conducted by Indian scientists was able to alleviate these problems by developing several new varieties that conform to the culinary preferences of the people and the geographic peculiarities, at the same time retaining the high-yielding qualities.

Although the change in the seeds was only one element of the technological change in Third World agricultural technologies, the ensuing Green Revolution brought about irreversible changes in the social structure. Peasants who produced for subsistence only were transformed into farmers who produced for a market and who subsequently underwent cultural, political, and economic changes. The social-constructivist model fails to capture the whole gamut of changes that took place during the agricultural transformation. By concentrating exclusively on micro-level events the model neglects macro-level issues. The process of

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[18] These were pests that did not affect the traditional varieties.

technology transfer and the process of institutionalization of technological knowledge in the form of research capacity through this transfer process remains to be explained by the social- constructivist model. I fully concur with Law's assertion that "in explaining technological change the social should not be privileged" (1987a:13). It should be treated as only one among several factors that shape and influence technological change. Further, the social-constructivists' assertion that technology is entirely "socially constructed" and social factors are "frozen" in a technology once it is chosen, and hence technological change occurs independently of social factors is not corroborated.[19]

The Green Revolution does not support the claim that it was entirely socially constructed. Leaving aside the difficult issue of how a social factor can be explicitly delineated in the case study, we can only assume that social, political, economic, cultural, technical, and scientific factors, among others, acted together in a dialectical manner to bring about the change. It is difficult to define a clear boundary for the social factor from the cultural or political factors. The major problem that prompted the policy-makers to act, that is to bring a change in the agricultural situation, was not only technical but social, political, economic and cultural. What

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[19] For a model of technological change based on this claim, see Clark et al. (1988). Nevertheless, the "processual" explanation of technological change offered by Clark and his colleagues is refreshing and more analytical than the original social-constructivist approach of Bijker and Pinch.

manifested as a socio-economic, and technical problem at a local level (for the peasants and rural people who were faced with food shortage), in turn became a political and economic problem for the government (in terms of the need to deal with foreign governments and international organizations - in the beginning for food aid and later for technology transfer). By claiming that only social factors can explain the construction of the Green Revolution we would be abstracting all the other extant factors to a determinist factor (theory) of social necessity. It was also not true that once the (agricultural) technology was chosen, only the technology decided its course of future development and change as is assumed in the social-constructivist model of technological change.

2.2(b) ACTOR-NETWORK-HETEROGENEOUS ENGINEERING MODELS

In terms of explaining technological change, the "heterogeneous engineering" and "actor-network" models of Law and Callon, respectively, are more promising than that of Pinch and Bijker. Since their models are methodologically and conceptually closer, nothing is lost by conflating the heterogeneous engineering and actor-network models. The basic methodological premise is to build a system in which the elements, both animate and inanimate, are joined together to eliminate "closure" and foster "stability." In terms of explaining technological change, Law (1987c:114) contends that "no change in vocabulary is necessary; from the standpoint of the network those elements that are human or social do not necessarily differ in kind from those that are natural or technological." While Law's protagonists are heterogeneous engineers, engineer-sociologists are the main agents of change in Callon's model. Both Law and Callon adhere to the symmetry concept of explaining social, cultural, technical, and all other extant factors in the process of technological change by the same vocabulary and by other such analytical tools.

The network builders might identify the following as the elements of their network: peasant farmers, oxen, wooden ploughs, traditional seeds, Persian wheels, bullock carts, dwarf and semi-dwarf varieties of rice and wheat, chemical fertilizers, modern high-yielding varieties (HYV) of rice and wheat, the Indian government and all the agricultural institutions under its command, the Ford Foundation, the Rockefeller Foundation, the United Sates Agency for International Development, the International Rice Research Institute, the International Maize and Wheat Improvement Centre, agricultural universities, agricultural research papers and periodicals, numerous human beings directly involved with the technologies, plant genes, irrigation canals, electricity, tractors, and markets. The method of building the system is to assemble these entities and forces together in such a way so that "collisions" and "closures" can be understood and avoided or eliminated. Contingent factors play key roles in the system building and the concomitant technological change. Technological change in this context would depend upon the particular technologies and extant factors specific to the technology being analyzed.

The heterogeneous engineering and actor-network models depend heavily on contingent factors for explaining technological change, and hence portray this multi-dimensional phenomenon as a process more serendipitous than purposeful. We know that technological change is a phenomenon that is created by purposeful actions. Although the complete consequences are difficult to predict in advance, changes occur not by chance but by design. The actor-network model fails to capture this facet of technological change more than the heterogeneous engineering model. These models which put primary emphasis on micro-level events seems to assume that the complete dynamics of a macro-event like technological change can be explained by explaining the parts alone.[20]

The case study clearly shows that the technological change in Indian agriculture did not take place by chance. The need for a change in the technology was clearly felt, and the protagonists who were affected by the problem as well as those who voluntarily came forward to help and those whose help was solicited got together to eliminate the "closure." It became apparent to them that the major bottleneck was the low yield due to poor seeds and new technologies which could improve the

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[20] The old economic adage that the whole is more than its parts seems to hold in this instance.

productivity of the land.

The technological change did not occur simply by bringing together all the elements (actors) mentioned earlier. In the network model what we have is only a cluster of elements (actors) with no overall structure. It is not apparent how, where, or when a new actor is to be included. Lacking a heuristic for building an actor-network, these models lack analytic rigor. Although the network models are intended as an attempt to breakdown the barrier between micro- and macro-level concepts and events, simply linking them together does not do it. Complex macro-level events, such as the development of research capacity, the transfer of knowledge, development of HYVs, etc. cannot be represented by a simple element (actor).

3. EVOLUTIONARY MODELS

3.1 REVIEW OF EVOLUTIONARY MODELS

The models of technological change explained in this section are neo-Schumpeterian and use evolutionary and systems concepts. While some models use the evolutionary concept as a metaphor, others use it to explain technological change as a process of adaptation and change in its literary sense. While one model uses systems theory explicitly, another model uses evolutionary metaphor in a systems mode.

Attempting to formulate a theory of technology in the institutionalist tradition of economics, Thomas DeGregori

(1985) argues that technological change is essentially an evolutionary process. Without offering empirical studies to support his arguments, he contends that the dynamics of technological change has a close parallel to human evolution. According to DeGregori, "technology involves the adaptation of the environment to the organism" (1985:14). In DeGregori's model, culture plays an important role in transforming technology. Unlike human evolution, he finds a purpose for technological change, which is to improve human living conditions by "thoughtful, intelligent action directed toward problem solving" (1985:24).[21]

Milton Lower (1988), another institutionalist who analyzes technology from the Veblenian perspective of seeing technology as knowledge and an aspect of culture, considers technological change analogous to biological evolution. Though Lower considers technological change an aspect of culture, he sees a trans-cultural aspect to technology. This aspect of technology makes it easy for the transmission of the technology to other cultures. Because of this the borrower adapts the technology to fit the former's cultural environment. Unfortunately, Lower does not offer a concrete example of a case study that involves technology transfer to legitimize his model. These institutionalist perspectives on

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[21] DeGregori's contention that technological change is a purposeful activity conducted by humans may be his best contribution. This claim may be useful to dampen the claim of many technology analysts (e.g., Winner, Ellul) that technological change is deterministic.

technological change are based on their reflections on technology and economics, and do not seem to be intended as concrete models because of the fact that deGregori and Lower did not discuss them using specific case studies of technological change.

Though not as radical as deGregori and Lower in rejecting neoclassical economic orthodoxy completely, Richard Nelson and Sidney Winter (1977 and 1982) reject only the neoclassical production-function approach to modeling technological change.[22] They retain other neoclassical assumptions, such as markets, firms, and profit maximization in their analysis. They, instead, offer a neo-Schumpeterian evolutionary model of technological change. Nelson and Winter consider that the production-function framework has only limited analytical scope and reject the perfect-rationality and the utility-maximization concepts in neoclassical economics. They argue that technological change follows a "natural trajectory" in a "technological regime" which may be considered as a "meta production function" (1977:57). Certain natural trajectories could be common to many technologies, such as economies of scale and accessibility to mechanization. Nelson and Winter see technological change as a stochastic process taking place

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[22] Nelson and Winter are particularly critical of the production-function representation of technological change in neoclassical economics. For a searing criticism of the neoclassical economists' method of treating the effect of technological change on economic growth as a residue, see their (1982:197-98).

in a conceptual framework provided by a "selection environment." Market, political institutions, regulatory agencies, and other social entities are the deciding factors that organize and set up the selection environment.

Fransman (1985:609) argues that the neo-Schumpeterian model of technological change developed by Nelson and Winter is not complete, and may be "seen as being in a 'pre-paradigmatic' stage of its development." That Nelson and Winter stress only "firms" like Schumpeter's "heroic entrepreneurs," as the catalysts for causing the change is a weakness of their model, because of its neglect of such other "actors" as consumers, and universities, among others. Referring to the model of Nelson and Winter, Fransman further adds that "while central aspects of the technical change process have been identified, these together with other economic, socio-political and cultural aspects have not yet been rigorously welded into an acceptable theory of the determinants of technical change" (1985:610).

Like Nelson and Winter, Giovanni Dosi (1984) conceptualizes technological change in an evolutionary framework. Dosi rejects both the "demand push"[23] model and the

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[23] This model assumes that technological change is a reactive mechanism. This neoclassical assumption holds that technological change occurs because of market forces, such as consumer sovereignty, optimizing behaviors, and general equilibrium conditions.

"technology pull"[24] model. Instead, he argues that technological change follows a pattern similar to scientific change. Arguing that science has epistemological parallels to technology, Dosi extends the analogy of scientific paradigm (research programme)[25] to develop a "technological paradigm." Dosi (1984:83) contends that the equivalent of "puzzles" in technology is "cluster of technologies." He defines "technological trajectory" (of Nelson and Winter) "as the pattern of "normal" problem-solving activity (i.e., of "progress") on the ground of technological paradigm" (ibid). According to Dosi, continuous change in technological innovation indicates "progress" along a technological trajectory defined by the technological paradigm. On the other hand, discontinuities in technological innovation are marked by the emergence of a new technological paradigm.

Although he cautioned that the epistemological analogy between science and technology is meant to be "impressionistic," Dosi's adherence to the notion of paradigms is not impressionistic but literal in the Kuhnian sense. The

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[24] This model assumes technology as an autonomous force, and claims that change occurs because of the internal compulsions of the technology. This supply-side concept takes for granted a "uni-directional" conception of "science-technology-production." The first gives the ideas, the second develops the tools and machines, and the third produces the goods.

[25] Dosi takes this position arguing that rather than dwelling on the differences between the Kuhnian and Lakatosian positions on scientific change, he finds compelling similarities in their models (paradigms and research programmes) that can be applied to technological change.

paradigm concept runs into problems when explaining the "cumulative" nature of technological change. Also, the assumption of competing technological paradigms existing in an industry is rather tenuous, given the fact that firms and other economic units motivated by profits tend to use the same technology if patent restrictions are not operative. Van den Belt and Rip (1987:139) contend that they "seriously doubt the historical adequacy of the assumption of a plurality of competing technological paradigms" in the Dosian model of technological change.

Like Dosi, and Nelson and Winter, Sahal (1981a, 1981b and 1985), an industrial engineer by training, argues that technological change is an evolutionary process. Favoring a systems concept of technology, Sahal argues that there are "technological guide-posts" such that innovations and change depend on the "gradual modifications of an essentially invariant pattern of design" (1981a:18). In essence, Sahal claims that technological change occurs in an expected manner following "innovation avenues," and "technological guide-posts" act as pointers to the innovation avenues. Irvin Feller (1982) claims that Sahal's approach of technological change is to integrate the macro-level dimensions of technological change followed by the neoclassical economists and the micro-level approach using the evolutionary metaphor which includes the concept of micro-level firm behavior. Sahal uses two methods to "test" his hypothesis of technological change. The first method is to use econometric techniques for testing hypotheses, and the second method is to formulate "lawlike relationships" between technology and economic agents to represent technological change. Feller argues that Sahal's econometric testing suffers from his uneven data on different case studies of technological change. He, further, adds that Sahal's "search for lawlike relationships [is] disquieting and most often unconvincing" (1982:47). Sahal's search for quantitative methods to model technological change obviously loses its applicability because of the simple fact that technological change is mostly a qualitative phenomenon.[26]

Unlike Sahal who uses the evolutionary and systems concept, Saviotti (1983) emphasizes the systems concept and offers one of the more sophisticated models of technological change based on systems theory. Saviotti argues that though economists consider technological change as the cause for economic growth and development, only engineers and historians seem to understand the intrinsic properties of this process. In his systems representation of technology, the internal structure of the technology is represented by the technical, and the external or environmental characteristic is represented by the service modes of a technology. According to Saviotti, technological change can be described as the "process of adaptation of technologies to their external

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[26] This argument does not exclude the use of quantitative methods for explaining technological diffusion as a legitimate method.

environment" (1983:785). The adaptation takes place with the internal variables kept relatively constant, similar to the concepts of self-regulation in complex electronic systems and homeostasis in biological systems. Saviotti argues that from this perspective, technological models represented by 'technological regimes', 'internal trajectories', 'technological paradigms', and 'technological guideposts' can be interpreted as examples of "homeostasis of complex technological systems" (ibid). He does not make clear what he means by "technical factors" when he refers to the internal characteristic of a technology. In his model of technological change, Saviotti argues that the change takes place with the internal factors kept constant. But actual case studies of technologies show that internal factors also change, particularly the knowledge content of the technology, and hence Saviotti's model too faces some problems when it is applied to real-life situations.

3.2 ACCOUNTING FOR THE CASE STUDY

3.2(a) DOSIAN MODEL:

The central tenet of the Dosian model of technological change is that it is a process similar to a scientific change. Like scientific change, technological change is characterized by paradigm shifts.[27] The evolutionary character of

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[27] Dosi posits a close epistemological parallel between science and technology. Although, he adds a caveat that this parallel should be construed more as an impressionistic one,

technological change is based on the assumption that the "selection"[28] of a particular technological paradigm is based on the large number of possibilities of directions of development according to the momentum generated by the problem-solving activity or technological trajectory.[29] Dosi qualifies this assumption by resorting to the operationalism called "notional possibilities."[30] Some of these selection criteria included in the notional possibilities are marketability, profit potential, potential for automation, labor-saving possibilities, and corporate strategies to remain in the markets. Technological progress is indicated by continuous changes in technological innovation along the locus of a "technological trajectory"[31] defined by a technological

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Dosi, nevertheless, moves beyond this restriction, and almost wholeheartedly adopts an isomorphic approach.

[28] The selection process is as follows. First Dosi considers the "downward" sequence "science-technology-production." Beyond pure science, many scientific theories and puzzles are passed on to the realm of applied science and technology (the boundaries between the latter two being rather fuzzy). Thus in the science-technology-production scheme, the economic forces together with the institutional factors operate as a selective device. See Dosi (1982:153).

[29] Because of this 'directedness' of the selection process, Dosi's model diverges from the randomness associated with the natural selection process in biological evolution.

[30] These "notional possibilities" may take the form of competing technological paradigms, thus contradicting the very possibility of the primacy of a reigning single paradigm in the history of technology. For more on this see van den Belt and Rip (1987:139).

[31] This is same as the "natural trajectories" of technologies developed by Nelson and Winter (1977). Natural trajectories are the paths in which technological progress

paradigm. According to him a technological paradigm is "a set of procedures, a definition of the "relevant" problems and of the specific knowledge related to their solution" (1982:148).[32] The "exclusion effects" of technological paradigms constrain the practitioners of the technology to focus on a limited range of technological possibilities (trajectories).[33]

Dosi views technological trajectory as the "direction of advance within a technological paradigm" (1982:148). Technological trajectory is the normal problem-solving activity determined by the technological paradigm.[34] Finally, a technological paradigm is selected based on several extant factors, which most notably are economic and institutional. Let us apply the Dosian model to the process of technological change in the Green Revolution. The crucial factor in this exercise is to find the technological trajectory and the technological paradigm in the Green Revolution.

Although the Kuhnian and Lakatosian models of scientific

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takes place. Nelson and Winter contend that technological innovation has a certain inner logic of its own, and technological change occurs as an inevitable process defined by a "technological regime" which may be construed as a metaproduction function.

[32] It is more of a "world-view" in a Kuhnian sense.

[33] Dosi does not elaborate why the "exclusionary effects" occur in technological change.

[34] According to Dosi, "a technological trajectory is a cluster of possible technological directions whose outer boundaries are defined by the nature of the paradigm itself" (1982:154). For an assortment of "features" of trajectories, see Dosi (1982:154-55).

change are primarily intended for comparative judgment of competing paradigms or research programmes, Dosi applies these concepts for cases of technological progress in isolation. That is, he does not discuss empirical examples of technological change in which one technological paradigm gives way to a new and supposedly successful one.[35] The Dosian method of analysis does not help us determine if the traditional agricultural system was the pre-paradigm stage for the Green Revolution. Nor does it assist us in determining if the Green Revolution was part of the whole process beginning with the traditional technology and ending with the modern technology, or a separate event with a technological trajectory and paradigm of its own. In terms of the paradigm as a world-view or model problem solutions (exemplars), the traditional and modern agricultural systems are two distinct phases of the agricultural system in India. Hence, let us apply the Dosian model to both.

The problem solution (paradigm) of traditional agricultural systems is constrained by the stipulations of traditional customs, social relations, geographic conditions, natural forces, and pre-industrial technologies. The technological trajectory in traditional agriculture may be identified as the practice of agriculture dependent on

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[35] For example, he does not go into details of technological change in the electronics industry while it was in the vacuum tube mode, but, instead, discusses the various progressive problem-shifts in the semi-conductor mode only.

complete submission to the dictates of environmental factors.[36] Lack of any significant control over natural forces, such as water, nutrients, and seeds severely curtailed the productivity of the land in traditional agriculture. Furthermore, in traditional agricultural communities it is normal for technological innovation to have reached a plateau because of minimal outside support for economic development. In traditional agricultural societies, new inventions and innovations are rarely contemplated by the peasants.[37] The technological paradigm in traditional agriculture may be put simply as subsistence farming. The rural, social, and economic relations and class and caste structures were dictated by the subsistence farming culture. The inability to substantially manipulate and gain more control over natural forces was understood to be the most important "bottleneck"[38] in improving

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[36] Of all human endeavors, agriculture is most heavily dependent on environmental factors. The progressively efficient technologies with which humans were able to control environmental factors were direct variables in increased agricultural productivity in human history.

[37] The agricultural history of India shows that, until the Green Revolution, hardly any new technology was added to the corpus of Indian traditional farming techniques for the past several centuries.

[38] Technological change resulting as a consequence of solving "bottle neck" problems in aircraft technology was cogently analyzed by Hanieski (1973) and Constant (1973). Bottle-necks in the existing technological system create a "convergence" effect to channel further innovative activities to circumvent the problems created by the bottle-necks. See Rosenberg (1976) for the application of the convergence principle in the American machine tool industry between 1840 to 1920. A close parallel can be drawn between the concept of bottle-neck and Hughes's concept of reverse salients.

traditional agriculture. The powerful "exclusion effects" of subsistence farming constrained all attempts at modernization of the existing production processes. A new outlook on agricultural practices, spearheaded by a new technology was the only way to break out of the stasis in agricultural technology in rural India. The emergence of the "New Thinking" in Indian agriculture paved the path for a new technological trajectory dictated by the new technological paradigm.

The new technological paradigm may be characterized as one in which agriculture is practiced with the aim of producing for markets.[39] The technological trajectory may be construed as the increasing ability by farmers and agricultural scientists and technologists to manipulate and control natural forces. The prime achievement in this category would be the development of the HYVs. Other important achievements included chemical fertilizers, modern irrigation systems, new agricultural equipment (tractors, pumps, threshers, weeders, etc.), and transportation systems. The necessity to increase the productivity of the land, whose area was the fixed input variable, in turn determined the nature of the new technologies. The selection criteria may be put as the political drive to attain self-sufficiency in cereals to attenuate dependency on foreign food aid and to alleviate

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[39] Besides the monetization of the rural economy, producing for markets involves a much more comprehensive change, the most important one being the transformation of peasants into farmers.

rural poverty, goodwill on the part of international donor agencies to help poor nations by transferring agricultural technology, and so forth.

According to Dosi, the development of the HYVs, for example, should be the outcome of a "mutation," that is, an ex post selection process similar to a Schumpeterian trial and error process. On this view, the HYVs became only a chance development based on the particular technological paradigm. However, the history of the HYVs shows that it was not exactly a chance invention. Although the precise nature of a new invention cannot be predicted in advance, the avenue through which the new inventive activity is being conducted and the purpose of the action are known ex ante. Similarly, in agriculture, farmers knew all along that one of the crucial factors in achieving better land productivity was using the best seeds. Thus the decision to establish research institutions primarily intended for adaptive research to develop new seeds, and the eventual development of the HYVs was not a chance occurrence. The Schumpeterian trial and error process in which entrepreneurs coming up with new technologies hardly apply to the case of the Green Revolution. Particularly the Schumpeterian stricture of "creative destruction" in which old technologies completely die out and new technologies take over rarely happens in industries, including agriculture. Old technologies do co-exist with new technologies, either in explicit forms, or in new forms after modifications and adaptations.[40] New technologies are developed based, invariably, on ideas and concepts from the old technologies they replaced. The old technology provides the problems with which new research and development activities are conducted, leading eventually to the development of the new technology. In a strict sense, technological change is a cumulative process and no technology completely dies out in societies marked by the presence of continuous civilizations.

In terms of interpreting the determinants and directions of the technological change in the Green Revolution, the Dosian model is perhaps the best among all the other models discussed so far. Its explanation of contextual factors in the selection of technological paradigms is cogent. However, there are still some problems. Dosi's primary focus of research has been on technological change in the Western market-oriented economies. Most of the determinant factors that Dosi presents can be found only in such systems. Also, in the Dosian model there is no provision to account for the process of technology transfer.

Furthermore, Dosi's adaptation of the Kuhnian paradigm from the realm of scientific change to technological change is amenable to the same ambiguities that paradigms suffer. Kuhn's paradigm was severely criticized for its interpretive

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[40] For a detailed critique of the Schumpeterian concept of "creative destruction," see Strassmann (1959).

ambiguity by many analysts.[41] Dosi at one point equates technological paradigm as a "world-view" a la Kuhn, arguing that there is considerable epistemological congruence between scientific and technological changes (1982:148). Dosi at another point defines technological paradigm as a "model" and a "pattern of solution of selected technological problems" (1982:152). Dosi was aware of these differing interpretations of technological paradigms. Thus, in analyzing technological change and progress, Dosi later attempts to shift his emphasis from technological paradigms to the selection criteria of technological paradigms.

3.2(b) SAHALIAN MODEL

Sahal presents a meta-evolutionary model of technological change and progress with several features similar to the Dosian model of technological change. Sahal conceives of technology in a systems framework in which the process of technological change is regarded in terms of certain "bottle-neck" factors, such as the availability of natural resources and efficiency considerations (1981b:13). He views technology in terms of functional and performance characteristics. Sahal contends that technological change is a continuous process in which several minor changes cumulate over a period of time to

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[41] Masterman (1970) catalogued some twenty-one different usages of the term paradigm in Kuhn's (1962). For additional dissent on the Kuhnian theses, consult Lakatos and Musgrave (1970), Toulmin (1972), and Shapere (1964).

bring about major changes in technology.[42] In his schema, revolutionary technological changes hardly ever take place in the history of a technology. Sahal rightly criticizes the neoclassical production-function-based and the Pythagorean[43] explanations of technological change as unrealistic and ahistorical.

According to Sahal, the processes of innovation and technological change are influenced and regulated by the boundaries set by the formation of the technological system (1981a:33). For him the dynamics of system formation is the most important factor that charts the course of long-term technological change. For example, the emergence of a particular machine design is unlikely to be the result of the instantaneous creative genius of an engineer or group of engineers, instead, it may be the cumulative synthesis of the design ideas that were available in the field for a long period of time. He argues that there is a "pattern of design" that influences the actions of the engineers long after its

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[42] This is very much the same view of technological change posited earlier by Usher (the theory of cumulative synthesis discussed earlier in this chapter). However, Sahal does not attribute this to Usher.

[43] The Pythagorean view of technological change considers technological change by the number of patents issued in one industry or technological field. Sahal argues that this view of technological change makes this process a discrete and discontinuous phenomenon, where as in real life it is just the opposite.

conception.[44] The innovations that take place in the technology in question, at any particular moment, are only a "bit-by-bit" modification of a design that remains "unchanged in its essential aspects over extended period of time" (ibid). According to him, this basic design may be characterized as the "guidepost" that charts the course of technological change.[45] In Sahal's model, technological change does not happen in a "haphazard fashion," but instead, it occurs in an "expected manner on what may be called <u>innovation avenues</u> that designate various distinct pathways of evolution" (1985:71, emphasis by author).

Technological change in the Green Revolution, according to the Sahalian model, would be an "invariant design" acting as the technological guidepost that guides technological innovations and inventions, and in turn technological change itself. Even if we accept the invariant-design concept in a broader sense as the innovation avenue or technological

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[44] Sahal is not clear about how this pattern was originally formed.

[45] In terms of examples to justify his claim, Sahal argues that the modern farm tractors were based on the design of the simple Fordson and Farmall models developed in the 1920s. Similarly, technological change in aircraft technology essentially followed the first design contained in the DC-3. He argues that despite the discontinuity following the introduction of the turbojet technology in the 1950s, there has been a "large element of continuity in technological advances" (1981a:36-37) in aircraft technology beginning with the DC-3 which was introduced in the 1930s. We may note that this view of technological change (in the case of aircraft technology) does not conform to Constant's revolutionary paradigm-oriented model of technological change.

guidepost, it is unlikely that we can find an equivalent concept in the Green Revolution. The major problem in identifying this concept in a macro-event like the Green Revolution is that Sahal's model is specifically developed for micro-case studies of already embodied technology.[46]

Although the change of agricultural technology from traditional to modern can be characterized in evolutionary terms, there is no technological guidepost that is isomorphous to both systems. As we have already seen, the dynamics of growth and change in these two cases are different. Like most other models discussed already, the Sahalian model does not take into account technology transfer as an important explanatory variable in the Green Revolution.

If we conceptualize "technological guidepost" as akin to a Dosian "technological paradigm," then we may conflate these two models. The technological paradigm of Dosi has several things in common with the technological guidepost of Sahal. Like technological paradigms guiding technological innovations in Dosi's model, technological guideposts influence and guide inventions and innovations in Sahal's. Like the technological trajectory that charts the loci of technological change in Dosi's model, innovation avenues designate the pathways of technological change in Sahal's model. Nevertheless, Dosi's

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[46] Sahal's conceptualization of technology is exclusively tool-oriented. The invariant design concept acting as the technological guidepost is constrained in its conceptualization of technology beyond embodiedness.

model is much more evocative and analytically superior than Sahal's. Dosi provides a clear heuristic of how to find the technological paradigm. Sahal does not provide a clear heuristic other than claiming that the presence of an invariant-design acts as the technological guidepost.

CHAPTER FIVE
OVERVIEW AND CONCLUSION

In Chapters Three and Four models of technological change in the literature were presented and appropriate criticisms offered. A few of the more prominent models were employed in an attempt to account for the Green Revolution. Although no consistent pattern emerged which allowed us to explain the important stages and events, each of the models, with a few exceptions, was able to account for some of the salient features. We also observed major differences according to disciplinary perspectives and prerogatives in what are regarded as the important facets of technological change. These models apparently were developed to explain and account for the same phenomenon, viz., technological change; why there was no convergence in terms of accounting for the same phenomenon encapsulated in a case study needs further scrutiny.

It was clearly demonstrated that though they were discussing the same phenomenon, the various analysts of technological change viewed it from the perspectives of their discipline-bound communities with differing emphases on the structural components of this phenomenon. Because of this, we find no uniformity in their definition of the problem, or the conceptualization of this process. Technological change has often taken the form of the proverbial elephant for most of these Aesopian analysts. As a consequence, they tend to explain the part as the whole or sometimes miss the forest for the trees. Many analysts use technological change as an omnibus term to identify a phenomenon that they more or less internalize but fail to flesh out fully in their models and theories.[1] Often these attempts materialize in the form of a model in which invention or innovation or diffusion or transfer of technology becomes the central feature. Before going any further, let me review my analysis of the models of technological change presented in this project and the way they account the process of technological change in the Green Revolution.

My claim is that technological change is primarily a process of knowledge change and artifactual change is only the physical manifestation of this process at the secondary level. The models examined conceptualize technological change in the Green Revolution as mostly artifactual change and not as knowledge change. It was shown earlier that the technological change in the Green Revolution was essentially a problem-solving activity that involved learning processes. The goal was the modification of the peasants' (subjects) knowledge of the new agricultural technology. The goal was not just

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[1] I will show later that their inability to conceptualize technological change as knowledge change is the major reason for this failure.

bringing about changes in the external state of affairs as in artifacts (objects). Thus, an internally consistent test would be to see if the models can account for the Green Revolution as a problem-solving activity intended for bringing about changes in the knowledge base of the subjects rather than as changes in external affairs of the system.

The economic models of technological change converge on the concept of production-functions as the fundamental conceptual foundation of technological change. The three prominent areas of inquiry in economics that subscribe to this concept are neoclassical, Schumpeterian, and institutionalist (induced innovation). Although these models accept the production-function representation of technological change, they diverge considerably in terms of their approaches and methodologies of explanation of technological change.

Neoclassical economists assume that technological change is responsible for increases in productive output of the economy. Technological change is manifested by the forward shift of the production-function of the aggregate economy or the production- functions of the individual industries of the economy. The major interests of neoclassical economists, however, are not in explaining technological change itself, but in its effects on the economy. Being unable to identify any economic causes for the genesis of technological change, these analysts focus their efforts on the economic consequences of technological change. Their methodology of ascertaining technological change is a technique of aggregating the residuals. That is, they account for the changes in the output due to measurable quantities like capital, labor and other factors. The increase in output due to the unmeasurable entity is the "residual" which they contend is due to technological change. Hence technological change is considered external to the process of economic dynamics itself and hence relegated to a black box. The neoclassical model assumes that the actors or the units of analysis of the economic process, which are mostly firms, opt for a new technology under the postulates of perfect competition, perfect knowledge, and the easy availability of a range of technologies for solving the same problem. Accordingly, they would argue that the peasants of India opted for the package of Green Revolution technology as the best technology available from the technology shelf in a free market situation under perfect competition and perfect knowledge. But our study of the Green Revolution show that this explanation is ahistorical and unrealistic.

The neoclassical production-function model of technological change accounts for only the artifactual change in the Green Revolution. Primarily, the increase in output as a result of choosing the new agricultural technology would be attributed to technological change based on the concept of aggregating the residuals which are not due to tangible[2] effects like increased usage of input factors like labor and capital. It would explain the change of technologies from traditional to modern as a random process of choosing the best artifacts from a 'technology shelf' in which different vintages of new artifacts are supposed to be available for selection. This misleading and unrealistic assumption is directly related to the model's primary emphasis on artifacts. They would argue that the increase in productivity is due to a forward shift of the agricultural production-function because of a new combination of input selections based on relative factor prices. There is no provision to include other important non-tangible input variables in the function, such as the process of learning by doing, learning by using, trial and error, and the impact of institutionalized research capacity, among others.

By concentrating on artifactual change, the production-function model, in fact, became a model that explains only the impact of the change instead of the change itself. The model does not help us to explain the internal state of affairs in the Green Revolution in which the knowledge base of the system of agriculture practiced by the peasants changed dramatically. A careful evaluation of the two most important empirical works in neoclassical economics by Abramovitz (1956)

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[2] "Tangible" is used to denote that the effects are measurable in a quantitative sense.

and Solow (1957) on productivity increases attributed to a 'residual' effect reveals some interesting results. After measuring the increase in output due to increased use of input factors like capital and labor, these analysts came up with a puzzle: they could not account for the major segment of the productivity increase. This unaccounted share of increase in productivity in Solow's estimate was more than 87 per cent, which by accident became known as technological change. A year earlier Abramovitz, in fact, showed his frustration for not being able to identify this residual effect by these words: "Since we know little about the causes of productivity increase, the indicated importance of this element may be taken to be some sort of measure of our ignorance about the cause of economic growth in the United States and some sort of indication of where we need to concentrate our attention" (1956:328, emphasis added).

However, after these sobering thoughts, neoclassical economists still ventured to find the cause for technological change in artifacts. In fact, their suggestions for increasing productivity by investing in research and development for producing new technologies turned out to be another historically correct step.[3] Thus, it clearly reveals that the "measure of our ignorance" Abramovitz alluded was nothing other than an ignorance of the process of change in

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[3] It must be still emphasized that investing in R and D activities is only one important step in inducing technological change.

technological knowledge itself. That is, increase in productivity was not due to an unknown residual, but clearly attributable to change in technological knowledge. Economists' arguments that productivity can be increased by technological innovation only partly explains how technological knowledge change can be brought about.[4] Their inability to conceptualize technological change as knowledge change, instead of as artifactual change, is the reason for the inadequacy of production-function model to represent this phenomenon fully. Again, to reiterate my argument, by not being able to account for the internal goal of the problem-solving activity which was to modify and to change the knowledge base of the subjects, the production-function model only renders the external artifactual facet of the technological change.

The neoclassical institutionalist (induced innovation) model, although explicitly conceding that technological change is endogenous to the process of institutional change, contends that individuals and communities opt for technological change in a roundabout way by first opting for a profitable institutional change. That is, the new institutions act as determinants of a new set of technologies. According to this view, the peasants of India opted for the Green Revolution

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[4] I reiterate my earlier claim that although analysts of technological change more or less internalize this phenomenon they, however, fail to flesh out in their models and theories, and often their attempts materialize in the form of a model in which invention or innovation or transfer becomes the central feature.

because they sought change in their institutions. Although this model is inherently superior and more realistic than the neoclassical model, the builders of this model analyze changes only in secondary institutions like markets and bureaucracy, instead of changes in such primary institutions as social relations of production, structures of communication and political power distribution between different social groups.

The creative destruction model of technological change of Schumpeter also adheres to the postulates of production-function economics. Although Schumpeter accepts the production-function from the neoclassicists, he still adheres to the classical position of land and labor as the input factors of production. The creative destruction model assumes that old technologies completely die out and new technologies take up their positions. Technological change is spearheaded by innovator-entrepreneurs. Schumpeter dwells solely on innovation as the predominant reason for change and neglects other factors like invention. With strong empirical evidence, Strassmann has shown that old technologies do co-exist with new technologies, thus disproving Schumpeter's theoretical claim. Although Schumpeter accepted that technological change is evolutionary, the main tenet of his model does not conform to the former assumption. Applying Schumpeter's model to the Green Revolution we see no innovator-entrepreneurs of the type Schumpeter assumes in his model. Instead of peasant cultivators who should be the natural entrepreneurs, we see the government assuming that role. Also, Schumpeter does not account for technology transfer, which obviously is an important facet of technological change.

Among the models of technological change we discussed which were drawn from history are the cumulative synthesis model of A.P. Usher and the systems model of Thomas Hughes. The most versatile historical model we have seen is that of Usher. But like the economic production-function model, Usher's cumulative synthesis model also fails to pass the internal consistency test when applied to account for the technological change in the Green Revolution. Although Usher provides a four-step heuristic to explain the cumulative synthesis process of technological change, the heuristic traces only the external factors involving artifacts. For example, the four-step process of (1) perception of the problem, (2) setting the stage, (3) the act of insight, and (4) critical revision, explain the development of one important artifact, the HYV. However, the invention of this important artifact was undertaken by a few research scientists at different research centers in different parts of the world. This factor belies Usher's assertion that inventions are carried out by a few unusually gifted individuals as an act of insight that may be explained by Gestalt psychology. In a similar vein, it may explain the development of other input factors in the Green Revolution package of technologies.

The unit of analysis in Usher's model is an artifact and the cumulative synthesis concept explains its evolution. However, in a model that emphasizes problem-solving as its central explanatory feature the aim is to make problem-solving intelligible to humans and hence the unit of analysis is a social unit of individuals and communities. In the Green Revolution, the subjects are peasants and the process of changing their knowledge of agricultural technology is the central feature of the technological change. The cumulative synthesis model does not explain the learning processes and institutionalization of research systems involved in the Green Revolution. The goal of the problem-solving activity in Usher's model is external adaptation of artifacts to follow a four step-processual sequence, instead of an internally consistent act of modifying the knowledge base of the subjects and their socio-technological systems.

A careful analysis of Usher's processual explanation of cumulative synthesis concept reveals that he wanted to go beyond the artifactual level of technological change. But instead of looking at technology as knowledge, Usher uses psychological explanations to justify the inventive process. However, by adapting the four-stage heuristics for application to the people (subjects) involved in the Green Revolution, instead of the artifacts (objects), the cumulative synthesis concept may be useful as a model to explain the process of knowledge change.

The unit of analysis in Hughes's model of technological change is a system. He contends that the development and change of technologies in a historical framework can be analyzed in systemic terms. The development of a system is characterized in a sequential form: the beginning of the system dominated by inventor-entrepreneurs; the next phase of the system is dominated by transfer of the technology; the growth of the system is the next phase in which problems like reverse salients and bottle-necks dominate the problem-solving activities; the fourth stage is system momentum and the determination of its direction; and the final stage is system maturity. The final phase is dominated by financiers and consulting engineers instead of inventor-entrepreneurs.

Although a few of the above five stages can be seen in the Green Revolution, major problems crop up in defining a system. The systems model can be applied to the case study only if we take extreme liberty with what constitutes the boundary conditions. The major focusing devise for the reverse salient in the Green Revolution was the low productivity of land and lack of new knowledge on new seeds and scientific farming techniques. Having developed for industrial technologies, Hughes's model does not fit well most other cases of technological change. The theory of the evolution of socio-technological systems that Hughes delineates is amenable to technological change in advanced industrialized countries, but does not transfer very well to pre-industrial or pre-capitalist societies. Finally, having no heuristic based on a universal concept like knowledge change, the model limits its application.

The sociological models are the constructivist model of Pinch and Bijker and the actor-network-heterogeneous engineering models of Callon and Law. The social-constructivist model claims that technological development can be explained entirely by sociological factors. They argue that factors like technical efficiency and economic feasibility do not determine technological change. That is, technological change is underdetermined by technical and natural factors and determined by social factors only. The construction of technological artifacts, according to this model, is explained with respect to culture of the community in which the development of the artifacts takes place. The "closure" of problems or the solution to technological problems, in this line of argument, is achieved by finding appropriate solutions based on the "interests" of the technology-developing communities.

The social-constructivist model explains "construction" in compartmentalized micro-events. There is no provision for inter-phasing macro- and micro-events. The model fails to capture such macro events as technology transfer and institution development. As we have shown, a careful evaluation of the changes reveals that social factors were only a few among several other factors. The problems that cropped up for inducing technological change are sociological, economic, political and environmental. Although the impact of change can be explained using sociological tools and methods, the internal dynamics of the change are determined by changes in the knowledge content of agricultural technology itself.

The social-constructivist model, unlike the economic and historical models discussed above, admits that its primary emphasis is on the construction of artifacts and their change. It has been already explained in Chapter Four that the social-constructivist model explains only the artifactual change in the Green Revolution. The model would explain the development of individual artifacts in the Green Revolution, such as HYVs, chemical fertilizers, electric pumps, tractors, irrigation systems, etc., but would fail to explain technological change itself as a process of knowledge change. The social constructivist's model of technological change does not look at technology as knowledge. Although this model claims to transcend the subject-object and micro-macro dichotomies, its primary concern still is to explain the construction of artifacts as individually isolated events in the history of a technology.

It was clearly shown that the social-constructivist model did not explain the transformation of peasants into farmers and the development and dissemination of new technological knowledge among the peasant-farmers. It conceived of the problem-solving as an external event to transform the artifacts, instead of modifying and changing the knowledge base of agriculture itself practiced by the peasants. The reason for this important omission was due to the model's assumption that once a particular technology is constructed and chosen, it in turn takes care of the internal issues concerning the subjects. The model further assumes that social factors are frozen in a given technology and technological change occurs independently of social factors. This determinist trap in which the social-constructivist model falls can be avoided only by a reversal of its unit of analysis from artifacts (objects) to the actors (peasants and farmers).

The "actor network" model of Callon and the "heterogeneous engineering" model of Law have several factors in common and are conceptually closer. Both models are based on the premise of building a system in which both animate and inanimate elements that constitute the system are joined together in the form of a network. Like the social-constructivists, the actor-network builders emphasize that there should be no division between the social and the technological worlds. They oppose all other methods of analyses of technological change than the ones that directly impinge on the surroundings of the technology. They are joined together in such a way as to eliminate problems ("closure") and create stability. While the protagonists of Law's model are "heterogeneous" engineers, engineer-sociologists are the protagonists in Callon's model. Law and Callon adhere to the concept of symmetry in explaining sociological and non-sociological factors. These models put strong emphasis on explaining micro-level events, and assume that macro-level changes can be accounted for by explaining the constituent parts.

In addition to the problems just noted, there are no heuristics to help us to string the elements together nor a methodology or rule for inclusion and exclusion of elements or actors. Although contingent factors did play important roles, the Green Revolution shows that careful planning and development were the major reasons for the change. The actor-network and heterogeneous engineering models are good explanatory tools at a micro-level, but fail to explain events that transcend the immediate micro-worlds of the actors.

The evolutionary models of technological change of Dosi and Sahal are not part of any particular discipline but rather of a new area of inquiry known as neo-Schumpeterian-evolutionary-systems models of technological change. Dosi believes that technological change is conceptually similar to scientific change, but differs in the way paradigms are selected. He contends that the selection of a technological paradigm is based on notional possibilities, such as marketability, profit potential, potential for automation, labor-saving strategies, management decisions, etc. Technological change is indicated by continuous changes in technological innovation along a technological trajectory defined by a technological paradigm.

The technological paradigm in traditional agriculture may be construed as subsistence farming. The problem solution is constrained by the stipulations of traditional customs, social relations, geographic conditions, and pre-industrial technologies. These constraints and bottlenecks have to be solved, or overcome in order to facilitate the emergence of a new paradigm. The technological paradigm of the new system is one in which agriculture is undertaken with the aim of producing for markets.[5] The technological trajectory may be construed as the increasing ability of new technological knowledge to manipulate and control natural forces. HYVs, chemical fertilizers, mechanically-powered tools and implements became part of the new agricultural system. So far, Dosi's model is the best and most comprehensive model of technological change, notwithstanding the fact that it was developed for advanced market-oriented economic systems.

Having developed his model for analysis and judgment of technological paradigms in isolation and not for their comparative judgment, it becomes difficult to trace the pre-paradigm and the post-paradigm stages of the technological change in agriculture. The application of Dosian heuristic to the case study reveals that the technological paradigm of traditional agriculture is one in which agriculture was based on subsistence farming. In the Green Revolution the

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[5] The monetization of transactions is the most visible and lasting change, in place of a commodity-exchange system.

technological paradigm is practicing agriculture for a market transaction-oriented economic system.

However, we have seen in Chapter Four that the Dosian heuristic applied to the Green Revolution explains only the selection of new artifacts, such as HYVs, tractors, pumps, fertilizers, and irrigation systems. Dosi's model explains the evolution of these artifacts as chance occurrences and not as a consequence of planning. This model also does not explain how the farmers learned the new technology, or the development of research institutions intended for adaptive research to develop new seeds and agricultural equipment which were location-specific. The model still falls short of providing a comprehensive account of knowledge change in the case of the Green Revolution because of its primary concern with artifactual change.

Sahal's meta-evolutionary model of technological change has several things in common with Dosi's. Sahal conceives of technological change as a process necessitated by bottleneck factors. Sahal like Usher argues that technological change is a continuous process in which several minor factors cumulate over a period of time to bring about a major change. However, Sahal's major theoretical position is that technological change follows the course of an "invariant design." According to him, a basic design acts as a guidepost on an innovation avenue.

The invariant-design metaphor, however, is a poor concept to apply to the case of the Green Revolution. But if we take the technological guidepost as conceptually similar to Dosian technological paradigm, Sahal's model can be rescued for limited application. Lacking heuristic power, Sahal's model does not help us to find out how the technological guidepost and the innovation avenue can be ascertained in a particular case of technological change. Also, it has deterministic overtones which limits its analytical potential.

The reason why the models did not converge is because, barring certain structural similarities, most of these analyses did not consider technological change as inherently cognitive change in technological knowledge. These analyses confined their concerns with technological change mostly to the artifactual level. What constitutes artifactual change can vary according to the perception of what an artifact is in each of these models. Because of this, the models cater mostly to the structural factors (components or forces) of technological change. Their creators molded the models to explain different components of technological change, like invention, innovation, development, transfer and diffusion, instead of the process of the change and development of technological knowledge in its entirety.

As we have seen, a model based on artifactual change does not completely account for the Green Revolution because technological change is more than artifactual change alone, and it is both cumulative and temporal in nature. However, there are a few exceptions to this complaint among the models discussed earlier. Hughes's systems model, Ruttan et al.'s induced innovation model, and Constant's and Dosi's technological paradigm models do, in fact, attempt to go beyond artifacts in accounting for technological change. However, they study technological change not from the point of view of "technology as knowledge," but, instead, from the point of view of technology as artifacts. One of the most important limitations of confining their analyses to the artifactual level is that technological change is not viewed as a continuous and cumulative process.[6]

Although the exact nature of the outcome of technological change cannot be predicted accurately in advance, the history of technological change shows one important feature, that is, change follows an evolutionary course. (And it is possible to steer the course of development of technology in a desirable way by influencing the selection environment,[7] about which more later.) History further reveals that technological change

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[6] This is a major difference between the predominant models of scientific change (for example Kuhn who conceptualizes it as a sudden or catastrophic change) and that of models of technological change which view it as evolutionary and non-catastrophic. The limitations of using scientific change models to explain technological change is obvious from this major difference.

[7] For an innovative approach to influencing the development of cleaner and safer technologies using the methodology of "constructive technology assessment," see Schot (1989).

is a continuous, and, largely, an irreversible process.[8] Technological change is both evolutionary and cumulative. By cumulative, it is meant that ideas, practices, laws and theories from the past do pass on to the development of newer technologies.[9] The reasons why this aspect tends to be neglected or does not seem apparent is due to the tacit nature of technological knowledge. Many technological traditions and practices are not committed to writing.[10] They are transmitted through succeeding generations either in informal settings like shop floors, apprenticeship programs, or in family craft practices. These sources do not exhaust the whole of technological knowledge. With the integration of engineering and organized research and development activities along with journals and books on technological development do, in fact, take up a large segment of modern technological knowledge in organized settings.

The concept of technological evolution is structurally and practically different from that of biological evolution.[11]

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[8] De Bresson argues that these facets of technological change embolden us to quip that "One needn't reinvent the wheel" (1987:752). As part of his thirty-five social principles of invention, Gilfillan (1970/1935) postulated that few inventions are ever lost.

[9] For further elaboration, see Layton (1974).

[10] This factor prompted Price (1965:561) to identify technology as "papyrophobic" and science as "papyrocentric."

[11] The selection process is characterized by instruction, understanding, experience of learning by doing, and, finally, cognitive change. For an excellent treatment of evolutionary analogy to technology, see Basalla (1988) and Medawar (1975).

'Evolution' is used here as an explanatory metaphor or a meta-model. Technological evolution is not isomorphic or analogous to biological evolution. Technological change is construed as a selective-retention process which is adapted to a sequential process of variation and selection.[12] Within the milieu of sociocultural evolution, adaptive learning and perception lead to the accumulation and change of technological knowledge. Fundamentally, technological knowledge is gained, in general, by trial and error, learning by doing, learning by imitating, and learning from our mistakes.[13] (The Green Revolution explicitly proves this facet of technological change, about which more later.) The evolutionary concept is important in explaining technological change because it captures the temporal nature of this phenomenon.

The cumulative nature of technological change, on the other hand, explains that technological change is irreversible. By cumulative, we do not mean a uniformitarian theory of accretion of everything past from the history of a technology. The major idea here is that the functional

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[12] The intellectual foundation for this evolutionary epistemology was first presented in Campbell (1974) essentially expanding on the pioneering works of Popper on the evolutionary nature of knowledge creation and change processes. Works that implicitly or explicitly follow an evolutionary epistemology of technological change are De Bresson (1987), Dosi (1982), Nelson and Winter (1977), Clark and Juma (1988), Basalla (1988), and Bijker and Pinch (1987).

[13] Popper (1963) in his Conjectures and Refutations delineates the essential epistemological problems associated with the acquisition and growth of knowledge, particularly of scientific knowledge.

attributes and the basic principles of design and operation of a technological system, to a large extent, remain invariant. Unlike in the natural sciences where paradigmatic changes may occur due to new experimental discoveries and theories, in technology the fundamental functional attributes are invariant. The end-use of a wooden plough or a mechanical tiller is the same. The latter does the work faster using mechanical power, and the former does it slower using human and animal power. The functional attributes of the technology remain invariant in both cases.[14] Technological change is fundamentally influenced by its antecedents. The idea of technological improvement as a means for efficient action remains the same in all societies. That is, more out of less. Improved efficiency, increased productivity, less cost, less human intervention, better medicines, and so forth are achieved by improving on the existing technologies. Thus it is imperative that all models of technological change should account for both the evolutionary and cumulative nature of this phenomenon.[15]

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[14] Mostly the operating procedures, materials for constructing the artifacts, and the energy sources for operating the artifacts are changed.

[15] This does not mean that there are no "revolutions" in technological development, like the so called "transistor revolution" or the "jet revolution." The word "revolution" is more apt to indicate the impact of these new technological developments on the society and on scientific and technological knowledge production in general. Although revolutionary in nature, the development of the transistor was clearly an evolutionary process. It was related to earlier developments in solid-state physics which, in turn, emerged

A model that does not recognize the pattern of the historical development of technology, not only its temporal form but its cumulative form as well, will not serve for studying technological change. A model's primary purpose is to provide the framework for interpreting historical events in a contextual fashion. It serves as a model if it works as a heuristic device in understanding other historical events in the same field. Thus a model of technological change should be deemed useful if it can help us to understand better the development and change of that technology and in the process help us interpret and understand cases of similar nature. Thus models without heuristic potential may end up a poorer representation of an event. A simplistic representation of a complex event does not necessarily become a good model, although it may be argued that the primary purpose of models is to understand complex events by representing such events in an easily understandable way.

The conclusions that we can draw from this project are the following. It may not be possible to develop a universal model of technological change along the lines of existing disciplinary-based models because of its complex and

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from quantum physics. The search for a better switching transistor, to replace the slow thermionic valves, in telecommunications was a problem that had been vexing scientists and technologists for nearly three decades until the point-contact transistor was developed at Bell Labs in 1948. Charles Weiner (1973) argues that the transistor was not "invented" but "emerged" from a "complex interaction of individuals, ideas, and institutions."

multidimensional nature. Although our conceptualization of technological change has been enriched by this comparative research study, questions still remain. Models of technological change developed from disciplinary perspectives tend to emphasize different aspects of the same phenomenon. These models do not clearly delineate and reveal the objectives by which technological change is driven.[16] (This should be qualified, though, because many of these objectives can be specific to individual cases.) Nevertheless, broad themes can be easily drawn.

Similarly, most models do not adequately portray the development and transfer component forces of technological change. The only model that explicitly dealt with the transfer component was the institutionalist model of Ruttan et al. One of the major reasons for the failure of the models to adequately represent the technology transfer component of technological change is the failure of the model builders to conceptualize the tacit nature of technological knowledge.[17] Another major drawback was the non-recognition of technological change as knowledge change as well as,

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[16] Weingart (1984:116-121) identifies a few of the driving forces as "orientation complexes." According to Weingart there are technical and non-technical orientation complexes. While economic, political, and cultural orientation complexes identify with the latter, the technical orienting complex is based on the premise of technology as a cognitive system.

[17] Pavitt (1987) argues that this may be so because there is no way of accounting some of the tacit nature of technology.

concurrently, in most cases with artifactual change.

The above models and theories of technological change are valuable sources for understanding several aspects of this phenomenon, but we have shown that no single model by itself successfully represented technological change. Thus a major research problem in STS is to develop a comprehensive theory of technological change in order to develop a model that can act as a powerful heuristic to account this phenomenon. The models discussed, however, are an important resources for achieving this goal. A STS model would strive to integrate the pertinent ideas and findings from these models toward building such a meta-model or meta-theory.

Notwithstanding their many shortcomings Dosi's and to some extent Usher's and Hughes's models, do what the other models discussed in this project do not, i.e., provide a heuristic of how to account for technological change in different cases. Hence a meta-model of technological change should adopt the main tenets of these three models. That is, technological change should be conceptualized as occurring in a systemic framework and following a trajectory in an evolutionary course. Insights from all the other models can be useful in a STS-metamodel. Usher's cumulative synthesis principle, institutional factors as an important facet of technology selection from institutionalist models, the idea of closure as an important problem-solving tool from the social-constructivist model, the concept of invariant-design acting as innovation avenues from Sahal's models, and the concept of actors creating an actor world to create a network are useful ideas.

A model of technological change from a STS perspective should be truly interdisciplinary, and it should try to integrate useful disciplinary viewpoints.[18] Its major strength would be its heuristic power and flexibility in adapting to situations involving various cases of technological change pertaining to different technologies. Technological change is characterized essentially as a problem-solving activity. Although it is a problem-solving activity conducted in need-based or need-induced circumstances, the solutions do not simply pop out of a pipeline of a concatenation of technologies. Extant social, political-economic and institutional factors, including government policies, do organize the problem-solving activity, but they by themselves do not provide the solutions. The technological problems vary from case to case and the problem-solutions vary according to the degree of complexity of the technological system. Some of the technological problems are low efficiency, adverse environmental problems, functional failures,[19] imbalances

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[18] For a brief but excellent treatment of problems related to achieving interdisciplinarity and if STS (science, technology and society) has achieved this state, see Bauer (1990).

[19] For more on the concept of functional failures, see Constant (1980).

between technologies[20] of different vintages, inadequate or non-existent organizational structures. These problems can be the direct or indirect result of climatic and geographic constraints and limitations, natural disasters, social and cultural demands for change, simple economic wants, military demands, and varying resource positions of countries and regions.

In the Green Revolution, we have seen that, all of the above, except military demands, were the focusing devices that influenced or molded the alternation and variation processes for the selection of the new (agricultural) technology. The selection environment was created by the combined efforts of the international donor agencies, the government of India and its various departments, and the international and national research institutions. The transfer, creation, and local adaptation of the new technological knowledge ultimately transformed the existing traditionally-based knowledge system. The case clearly delineates an active selective-retention process at the three distinct stages of the Green Revolution. The third stage (1965-75) during which a distinct pattern of change in the practice of agriculture as a result of the introduction of HYVs and other new inputs vindicates this claim.

These three stages in the history of the Green Revolution

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[20] The concept of technological imbalances as a technological problem was suggested by R. Laudan (1984b).

include understanding the new techniques and problems, learning new ways of doing things by trial and error, and the organization of a new research system. It is important to note also that this learning process was mediated by socio-cultural background of the participants. The technological change involved here follows a clear heuristic in which the development[21] part and the diffusion[22] part joined together and interactively brought about the change. There evolved a technological algorithm of how the new knowledge can be transformed into material outputs -- in the form of technological artifacts and productive outputs.

The technological algorithm evolved as a means for simplifying the complex knowledge of a new agricultural system into a simplified form that the farmers and peasants could easily absorb in order to produce the desired results (outputs). In simple terms, it can be equated to a decision-rule-making process by the actors. The process of change was clearly a conceptual-cum-cognitive change. The peasants learned the new agricultural practices by trial and error, by observing how the new technology was practiced, and by learning from the experts sent by the government. For them the new agricultural technology became meaningful only after internalizing new ways of doing things. Technological change

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[21] Invention, innovation and the development of new technologies are included in this part.

[22] Transfer of the new technology and the adoption of it by the recipients are included in this part.

here involved not just the introduction of a few new artifacts, but essentially the change in their knowledge related to agricultural technology itself. After they acquired the new technological knowledge, they in turn provided valuable feedback to the experts who were able to accommodate their suggestions and complaints. Unless we understand how the change in knowledge actually takes place, technological change cannot be conceptualized fully. Without such a perspective, models of technological change become only models of one technological artifact replacing another.

The role of the government and international agencies was to create a proper selection environment for the technology users and developers - in this case peasants and farmers, and local extension workers, and research and development personnel. Unlike in natural selection where chance occurrences are the norm, in technological selection, persuasion and the perception of the need for the new knowledge decide the outcome. The possibilities for variation are limited and fixed to a large extent ex ante. So, the public agencies can guide the path of selection in a desired fashion. (This must be qualified because usually the after effects of the technology cannot be fully predicted.) Adverse and unexpected effects of the new technology might create the need of a new selection environment,[23] which might change the

[23] The selection environment may be construed as a sort of meta-market.

direction of the technological trajectory. Thus, it is within the control of humans of how technological change are directed and molded.

It is obvious that since the actors who make the decisions regarding technological selection are particular groups of people in the society, and the creators of the selection environment are motivated by political and economic reasons, technological change is both socially constructed and political-economic in nature. The former may appear to be a tautology. It is always the case that since we are all members of a society, all our actions, beliefs and decisions are social constructions. Because of this self-referencing of our actions, social construction arguments cannot be used as analytical categories for developing models of technological change. They always, thus, remain explanatory devices rather than predictive ones. As opposed to this, political economic arguments are powerful analytical categories for aiding model building. For example, we can develop a model of technological change based on the findings from the Green Revolution. In this model we would concentrate on the policy decisions and the design and development of carefully planned institutions; the government was able to steer the course of change in the knowledge of agricultural practices of the peasants. The selection environment was ultimately determined by the political economic agenda of the government. These claims become more clear when we take a brief look at the history of technological change.

It used to be widely believed that technological change was caused largely by the works of individual inventors who tinker with technologies and the rest of the society accepted new technologies whenever they were offered to the public. The rise of organized production based on factory systems in the nineteenth century necessitated the need for improving upon the technology for increasing productivity, reducing the power of workers who could strike for redressing grievances, substituting for alternative input materials and methods of production, and market competition to reduce cost, among other factors. The decline of feudalism and the rise of industrial capitalism marked this change in social labor and social production first in Western Europe. The search for improved technology became a profession now of the technologists and scientists employed by the firms. The first organized research and development laboratory was opened in the German dyestuffs industry in the second half of the nineteenth century (Beer, 1958). Thus the role of invention and new technology development moved from the realm of individual inventors to the hands of organized R&D efforts of firms and businesses.

Governmental regulations, market forces, consumer preferences and environmental factors also influence the course of technological development. With governments actively involving themselves through science and technology policy instruments, the course of scientific and technological change began to take a different form since the First World War. This process took on a frenetic pace during the Second World War because of massive governmental investments in scientific and technological development activities. During the post-war era the role of governments in formulating and implementing science and technology policy became more visible. Thus it becomes clear that technological change now is shaped by the active social, political and economic agenda of the government and its allies.

While the political-economic and social interests set the stage for technological change and determine its trajectory, the actual process of learning and the cognitive processes required for that change are dictated by cultural and cognitive attributes of the members of the particular social groups involved. Through premeditated and consciously thought-out actions humans try to change nature to satisfy their needs. Consciousness alone does not change the world to satisfy their needs, action is required to change the world.[24]

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[24] Marx's strong criticism of idealism and metaphysically based philosophy--that it is not just enough to understand the world but to change it must be the role of philosophy-- was based on this. He postulated that it is with technology that humans can manipulate nature to transform their world. Marx's unusually candid tribute to capitalism under the captainship of the bourgeoisie in these words is noteworthy: "The bourgeoisie, by the rapid improvement of all instruments of production, by the immensely facilitated means of communication, draws all nations, ...into civilization. ...It compels all nations, on pain of extinction, to adopt the bourgeois mode of production. ... Subjection of nature's forces to man, machinery, application of chemistry to industry and agriculture, steam-navigation, railways, electric telegraphs,... what earlier century had even a presentiment

While the social, political, economic and other factors set the stage for change, the internal dynamics of the actual change are determined by the functional attributes of the technology: the requirements of energy substitution, the possibilities for diminishing human intervention, the possibilities of automation for avoiding hazardous actions and increasing productivity, the ability for invariant reproduction of products and services based on same ideas, the sustainability of action through methods of communication and control, and finally the decision-rules humans establish to decide between alternative courses of actions.[25]

To reiterate, technological change should be conceptualized as essentially a form of knowledge change. Instead of putting primary emphasis on the change in artifacts, models of technological change should take into consideration how the knowledge content of technology itself changes, and hence primary emphasis should be put on the actors involved and their social and institutional structures. The appearance of newer artifacts should be incorporated as the manifestations of the phenomenon and not the phenomenon itself. Technological change should be modeled within the framework of an evolutionary epistemology of technological

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that such productive forces slumbered in the lap of social labour?"(1952/1848:421).

[25] Daniel Bell (1975) cogently analyzes how a few of these dimensions of technology transform culture and social structure.

knowledge.

Thus a complete model of technological change ought to have the following features: (Wherever appropriate, these categories are explained using the Green Revolution as the empirical basis.)

<u>(1) It should be conceptualized under the premise of "technology as knowledge."</u>

The Green Revolution illustrates a rich social history of a technological change. It is more than a chronicle of the development, transfer, and diffusion of artifacts and "techniques." The case study demonstrates that technology entails a sound know-how of ways and means of doing things to solve a problem. The Green Revolution package of technology is a system of knowledge intended to circumvent the constraints of low productivity of the land. It cannot be de-coupled from knowledge because what essentially took place after the technological change was the change of an old knowledge system to a new one designed to solve a problem which the old system failed to solve.

The creation of this new technological system was achieved by transferring a successful and sound knowledge developed in the West to India. This included the development of a research system to adapt that knowledge to the specific needs and conditions of the recipient, and its transmission to the peasants and farmers who ultimately learned the new knowledge through trial and error, learning by doing, learning by using, and other learning processes. These internal factors demonstrate that the technological system entailed ideas and thoughts at one end and techniques and things at the other. Although these processes involved artifacts and techniques, they were only part of the technological system. It was the knowledge content of these artifacts and techniques that mattered. If the recipients failed to understand how these artifacts worked, and how to reproduce them, and failed to adapt them to the recipient's specific circumstances, the transferred technology would have become extinct once the artifacts had worn out or were used up. The concept of technology as knowledge is affirmed by the success of the technology transfer component of the Green Revolution.

The idea behind the creation of hybrid-rice varieties was known to the Chinese thousands of years before the high-yielding varieties (HYVs) were developed. Cross-breeding techniques for developing short-strawed rice and wheat varieties were used by Japanese farmers who obtained this knowledge from their colonies in Asia. United States scientists transferred many hybrid varieties of wheat from Japan in late-nineteenth century. The development of the HYVs was partly made possible by the knowledge already existed in the form of genetic manipulation of cross-breeding.

The HYVs once transferred to India had to have their genetic quality renewed to sustain the high-yielding potential. They had to be genetically altered to suit the climatic conditions and the new pests. They had to be made suitable to accommodate the tastes and cultural mores of the recipients. These actions were made possible by the institutionalization of the new knowledge system through the creation of research and development facilities and institutions of higher learning. We have seen that the Green Revolution entails a rich array of information transfer, creation, and diffusion. It involves new ideas, new ways of doing things. It amply illustrates that technology cannot be de-linked from knowledge, and that technological change should be conceptualized under the premise of "technology as knowledge."

(2) It should be conceptualized in systemic terms, such that technology is defined as an instrumental ordering of human experiences and ideas with efficient means as the interpretive variation of human action.

The case study reveals that the technological change evolved as the traditional agricultural system gave way to a new system. In the old system, the boundary of the socio-technological system did not stretch beyond the villages. With the new system, it stretched far beyond the villages. As a result of the flow of the new knowledge of agriculture through increased communication facilities, the socio-technological system expanded to include markets, rural co-operatives, roads, irrigation systems, extension networks, national and regional research and educational institutions, international agencies, governments, and several other related tangible and non-tangible entities.

In both the traditional and the modern agricultural systems, the technologies reflect the ideas and experiences of the actors involved. Both systems were efficient, when looked at from their own perspectives. In terms of energy efficiency, the traditional system was more efficient than the modern. But in terms of productivity, the modern system was more efficient. As the rate of population increase outstripped the rate of food production, the efficient means available for increasing food production was to increase the productivity of the land. The most efficient means for achieving that was to develop better seeds and energy-intensive agricultural practice.

The HYV technology clearly reveals that it is a product of a knowledge system evolved out of rich human experiences dating back thousands of years. The basic idea behind its development was energy efficiency. A smaller stalk meant less energy wasted in the stalk. But its full potential began to emerge only in the late nineteenth and twentieth centuries when chemical fertilizer was invented. The new package of agricultural technology associated with the HYVs are clearly the result of an instrumental ordering of human experiences and ideas with efficient means as the fundamental principle of human action.

<u>(3) It should specify that artifactual change is (only) the manifestation of the process of technological change.</u>

A complete model of technological change should specify that artifacts are the physical manifestation of the knowledge change at the secondary level. While technological change is an irreversible phenomenon, artifacts may be temporary entities. The reason why the former does not disappear even when the latter does is due to the fact that the former involves something fundamentally different from the latter. This facet is directly linked to the notion of "technology as knowledge," as explained earlier. [See item (1) above].

<u>(4) It should recognize that invention, innovation, and transfer of technology are (only the) component forces of technological change, and that these component forces act interactively and do not follow a law-like sequence.</u>

The Green Revolution shows that all the component forces of technological change are present in it. The HYV is an invention. Making it location-specific involved detailed adaptive research, which may be identified as an innovation. The new agricultural technology was largely transferred to India from different parts of the world, most specifically from the United States, Mexico and the Philippines. Extensive diffusion of the new technology was achieved through extension work. There was no clear pattern of a law-like sequence involving these forces. We have seen that feed-back from peasants on problems related to HYVs were relayed back to the researchers through extension agents. New seeds were in turn developed at research stations in India, after taking into consideration these feed-back.

A network of causal linkages in the Green Revolution can be put as: invention (hybrid seeds, HYVs, seed-fertilizer-irrigation agriculture) --> transfer (of the new technology to India) --> innovation (further adaptive research in India to make HYVs location-specific) --> development (establishment of research capability, development of several other new varieties) --> diffusion (the transmission of the new knowledge to the peasants through extension agents) --> feedback (problems and new ideas relayed back to the researchers through extension workers) --> innovation (further research and development) --> transfer (of the new technology to other parts of India, and lately to a few other Third World countries.) This is an open-ended network. These entities acted interactively without any hierarchical structure.

Thus models that emphasize just one or more aspects of technological change may not give a complete picture of this dynamic process. A model that is developed with the Green Revolution as an empirical basis would recognize that these forces act interactively and do not follow any particular sequence.

<u>(5) It should recognize that technological change is an evolutionary process operating within reversible social factors.</u>

The evolutionary nature of technological change in the Green Revolution shows that this metaphor is not isomorphic with biological evolution. It is used to indicate that technological change is a continuous, as opposed to a discontinuous and discrete process. Although the very phrase "Green Revolution" is incongruous with the notion of an evolutionary change, a review of the literature (Chapter Two) shows that this phrase was coined to indicate the impact of the technological change, rather than the change itself.

The evolutionary nature of this change is amply manifested by the history of the HYVs. Randolph Barker (1971) delineates the historical process of the development of high-yielding rice varieties as an evolutionary process that took thousands of years. The genetic manipulation of seeds was facilitated by the development of new instruments, and new scientific theories in molecular biology. Although the new varieties were brought to India in the 1960s, they were available in the West several decades earlier. And, the concept of developing short-strawed rice varieties was known to the Chinese a thousand years earlier.

Similarly, the process of technology transfer and the establishment of an agricultural research system involved several years and decades. Lele and Goldsmith (1989) argue that one of the crucial reasons for the success of the newly-transferred research system in India was because there was already an educated elite in India which learned the new technology and later administered the research facilities, compared to most African countries where none of these factors are present to make the transfer of technology successful.

The peasants and farmers learned the new technology through different learning processes. It involved model demonstration programs, trial and error, formal and informal training programs, and training and visit of the extension agents, among other activities. The change from the old system to the new was not discontinuous. The change over from old seeds to the HYVs was gradual. The peasants experimented with the HYVs by first devoting only a small fraction of their land for it. The farmers accepted the new seeds, and new methods of farming only after they were convinced of the high productivity gains from the new technology.

(6) It should recognize that technological change is a cumulative process.

As we have seen earlier, the idea that technological change is cumulative is closely linked to its evolutionary nature. By cumulative, it is not necessarily the case that everything past from the technological system is cumulated and that technological development take place by accretion. It is argued that the basic ideas and functional attributes of the technology, to a large extent, remain invariant. Models of technological change ought to affirm the cumulative nature of this phenomenon because it is influenced by its antecedents.

The driving force behind technological change is the limitations of the technology itself or the constraints imposed on it by its surroundings. Increased productivity, improved efficiency, less cost, less human intervention, and other such technological improvement measures are normally achieved by improving on the existing technologies. The Green Revolution shows this facet of technological change. The knowledge change involved new and better ways of doing things. However, the fundamental nature of agricultural practice did not change. The changes were concerned with using new seeds and new seed-preparation, weeding, watering, and other activities and techniques.

The Green Revolution also shows that the most important component of the change, viz., the development of the HYVs was based on the concept of technological improvement. The basic principles of the HYVs was known earlier. The new HYVs were only improved versions of the old hybrid seeds. The mechanized tiller is nothing more than a traditional plough with a motor. These claims do not discount the fact that totally new artifacts do evolve as a result of technological change.

<u>(7) It should specify that technological change undergoes a</u>

<u>variation and selection according to the rules set by a selection environment, or a meta-market.</u>

In the case study, we saw that natural disasters, inadequate organizational structures, pre-industrial technologies, social and cultural demands for change, simple economic wants, and resource positions of countries and regions were the problems that influenced the variation processes for the selection of the new technology. The selection environment was created by the joint efforts of the government of India, various international donor agencies, and different national and international research institutions. We saw that the creation, transfer, and local adaptation of the new technology ultimately transformed the existing traditionally-based knowledge system. The case clearly delineates an active selective-retention process at the three distinct stages of the Green Revolution.

The first stage (1952-65) was the development of a national research system. The second stage (1962-67) was the transfer and diffusion of the HYVs. The third stage (1965-75) was the change in agricultural practice as a result of the introduction of the HYVs. These three stages in the Green Revolution include understanding the new techniques and problems, the organization of a new research system, and learning new ways of doing things by trial and error. The new selection environment (meta-market) was created by the government and its allies during the third stage.

The government created the scientific and technological infrastructure as part of this selection environment. It acted as the sole supplier of all the necessary inputs for the meta-market. As part of its campaign to attract the peasants and farmers to adopt the new technology, the government ran educational programs on its radio stations, introduced massive demonstration programs, provided free and subsidized seeds, and constructed roads and irrigation systems.

(8) It should specify that the selection environment is created by the political economic and social agenda of the government and other public institutions.

The worsening food situation in India as a result of the introduction of misguided development policies which put priority on industry by neglecting agriculture, prompted the government to create a "New Agricultural Policy." We saw that massive importation of food grains from the United States staved off the food shortages only temporarily. The reasons cited for the creation of the new agricultural policy was to attain self-sufficiency in food production and to regain political independence. The selection environment created by the government reflected its political-economic and social agenda.

The government's intention was to influence the technology users and developers. They were peasants and farmers, extension agents, and research and development personnel. By persuasion and perception, and by the creation of a planned institutional structure, the government was able to steer the course of change in agricultural knowledge. By molding the science and technology policy instruments to reflect its own agenda, the government successfully implemented its new agricultural policy through the selection environment.

(9) It should recognize that the variation and selection process is carried out with the understanding that technological change is a problem-solving activity.

The Green Revolution corroborates the assumption that technological change is a problem-solving activity. The actions undertaken were a clear response to a specific problem that was recognized, identified, and for which a specific plan of action was implemented. As described earlier, the problems faced by the government and its citizens was solved by the transfer, innovation, and diffusion of a new knowledge system. It makes it easy to conceptualize the technological change, by looking at it as a problem-solving activity. The political-economic and institutional factors organized the problem-solving activity. The technological change described in the Green Revolution proves that it occurred as the outcome of a specific set of concrete actions and learning experiences of a wide array of human and social actors. It elucidates how the problems were defined and solutions were sought.

<u>(10) It should recognize that the focusing devices for the problem-solving activity are provided by the functional problems of the technology.</u>

The inability to increase productivity beyond the subsistence level using the old technology was a direct correlate of its functional problems. The constraints of the old system provided the problems. The old technological system provided the problems with which new research and development activities were conducted. The solution was to come up with concrete measures to circumvent the constraints. It started with the seed. The old seeds were replaced by hybrid-high-yielding varieties. The problems associated with using these varieties further necessitated new approaches to agricultural practice. Constant renewal of seeds, increased usage of fertilizers, water, and other inputs were mandated by the change of seeds.

Thus, we see that the learning processes involved actions which necessitated substituting mechanical power for human and animal power, chemical fertilizers for manure, HYVs for traditional seeds, and irrigated water for rain water. The Green Revolution proves the case that human actions and learning experiences were responsible for the increase in cereal productivity rather than some <u>deus ex machina</u> from which these material benefits were made to emanate.

<u>(11) It should specify that technological change is</u>

characterized by an algorithm of decision rules based on such concepts as efficient action, least amounts of risk in adopting the new technology, etc., made by the actors.

The Green Revolution reveals the evolution of a technological algorithm of how new knowledge can be transformed into material output in the form of food. The algorithm was a means for simplifying complex knowledge into a simplified form of information that the peasant-farmers could understand. The peasants learned the new technology by trial and error, by observing how the new technology was practiced, and by learning from the extension workers. For them the new agricultural technology became meaningful only after learning new ways of doing things. The claim that technological change is knowledge change is clearly manifested by the fact that their cognition of agricultural practice changed. This was not attributable to the introduction of a few new artifacts, but to a systemic change in the knowledge related to agriculture.

(12) It should recognize that technological change is molded and directed entirely by human interests and hence it is not a process out of societal control.

The Green Revolution reinforces the claim that technological change is not an autonomous process out of societal control. It belies the technics-out-of-control theory. It was not the dictates of the technology itself that directed its change. The problem-solving activity was entirely within social and institutional control. The policies were chalked out by policy-makers, both in India and aborad. The particular technological selection choices were made by particular groups of people in the society. The creators of the selection environment were motivated by political and economic reasons. It was shown that the technological change in agriculture was directed by distinct social groups.

(13) It should recognize that models of scientific change are poor models for technological change.

It was argued at the outset that technology and science are molded by different cognitive and social systems requiring radically different analytical means to study them, notwithstanding the fact that they relate interactively and enrich their knowledge content from each other. There are several differences between technological and scientific knowledge, as shown in Chapter One. The former is more tacit, procedural and less amenable to writing than the latter. Technology is both a private and public good. Science, on the other hand, is always a public good.

The reasons why models of scientific change do not help to account for technological change are directly related to the differing social processes that organize these two activities, in addition to the differing driving forces that direct them. Technological change is driven by political-economic factors. Technological change is driven by a form of action-oriented functional logic. Scientific change, on the other hand, is driven by explanation-oriented naturalistic logic. While technological knowledge is created for doing things and getting things done, scientific knowledge is created for explaining and understanding nature. Although these two phenomena can be conceptualized as problem-solving activities, they cannot, obviously, be represented by the same analytical tools or models.

It may be possible to find analogous situations in these phenomena, and they may reflect common constraints, but may not reflect common causes. Individual resemblances of entities, like a paradigm, are not enough to look for isomorphism in causal relationships between a model and a theory of scientific or technological change.

(14) It should offer a clear heuristic as to how it can be applied to all cases and categories of technological change.

The success of a model of technological change is its heuristic potential. Its universality is reflected by its flexibility and adaptability to various cases of technological change. It should provide general ground rules for allowing how different component forces of technological change can be represented, and show how they interact to bring about the change. This is a general category that cannot be tested by a single case study.

It is hoped that from this comparative research study that we have gained considerable insight into the process of technological change. The above check list could be a useful guide to the development of a comprehensive theoretical model of this phenomenon. Needless to say, the most useful knowledge that we have of technological change is that it is a cognitive process. It is characterized by knowledge change, and change in the physical structure of the technological system should be treated as the outcome of this process. Artifacts are only the physical realization of technological knowledge. The production of technological knowledge and the pattern of its change should be the central concerns of a model with which we can conceptualize technological change.

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EDUCATION

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MS Science and Technology Studies, Rensselaer Polytechnic Institute, May 1983
BSc Electrical Engineering, University of Calicut, January 1978

PROFESSIONAL HISTORY

Graduate Teaching Assistant: Graduate Program in Science and Technology Studies, Virginia Tech. 1987-90.

Researcher: Econometric Research Inc., Washington, D.C. Database development, econometric modeling, and research. 1986-87.

Graduate Teaching Assistant: Department of Economics, American University. 1984-86.

Graduate Assistant: Department of Science & Technology Studies, and Electrical, Systems and Computer Engineering, Rensselaer Polytechnic Institute. 1982-84.

Engineer/Expert: University of Sulaimania, Sulaimania, Kurdistan, Iraq. Trained Kurdish engineers and technicians in power station operation and maintenance practice. Helped to plan and establish research and laboratory facilities for the College of Engineering of the University of Sulaimania. 1979-81.

Electrical Engineer: Office of the City Engineer, Bombay. Worked as a supervising engineer at a 220 kV substation construction project which was part of a World Bank-aided drinking water purification plant for the City. 1979.

Electrical Engineer: Engineer-in-charge of an electrical product testing laboratory of Maharashtra State Electricity Board in Thana, Bombay. Tested and certified electrical power and energy meters and equipment. 1978-79.

PUBLICATIONS

Book Review: The Process of Technological Change: New Technology and Social Choice in the Workplace by John Clark, Ian McLoughlin, Howard Rose, and Robin King in Science, Technology, & Human Values Vol. 15(1), Winter 1990.

"Science for social revolution: Science and culture in Kerala," Impact of science on society (UNESCO) Vol. 39(3), 1990.

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PRESENTATIONS

"Mobilizing the Public in Technology Policy Debates: The Case of Kerala Sastra Sahitya Parishad in India," paper presented at the Fourteenth Annual Conference of Society for Social Studies of Science, November 18, 1989, Irvine, California.

"Appropriate Technology: A Review of the Movement and Its Conceptualization of Contemporary Technology," Faculty research seminar in the Center for the Study of Science in Society, September 6, 1989, Virginia Tech.

UNDER REVIEW

A Normative Appraisal of Development Economics: An Application of the Methodology of Scientific Research Programmes.

Schumpeter on Invention, Innovation, and Technological Change.

The Conceptualization of Contemporary Technology in Appropriate Technology Literature: A Critique.

Democratic Control of Technology and Environmental Conservation: A Case Study of an Indigenous Citizens' Movement in The Third World. (Grant Proposal Submitted to the MacArthur Foundation.)

HONORS AND AWARDS

Graduate assistantship/tuition scholarship from Virginia Tech; Teaching Assistantships from Rensselaer Polytechnic Institute, and The American University.

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