Abstract

This paper uses a simplified version of classical information theory to improve understanding of the dynamic potential of innovation systems in developing countries with a special focus on issues of agricultural poverty. Using examples drawn from emergent knowledge markets in industrialised countries, the paper suggests that such an analytical approach focuses attention directly on the types of institutional reforms necessary to improve the effectiveness of Third World agricultural R&D. Contrast is made with more conventional approaches that take institutional structures as given and focus more on factors such as price regimes, policy weaknesses and political will. The paper argues that so great now are the problems in this area (particularly in Sub-Saharan Africa) that there is a clear need for institutional reform to accompany relevant technological changes. In the absence of such reform innovative (and hence economic) potential is likely to be compromised.

Innovation Systems, Institutional Change and the New Knowledge Market: Implications for Third World Agricultural Development.

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I Introduction

This paper is about prospects of technological development in and for the poorest parts of the Third World. In an earlier paper in this volume Lipsey argues cogently that the rate and direction of technological change is normally quite specific to the context that obtains. He calls this property "context specificity" and uses it to rebut those who claim that technological changes occur uniformly over space and time regardless of the context. This paper takes up that theme with respect to a context that has tended to be sidelined in the standard literature dealing with innovation and technological change,[1] namely agriculture. And yet for poor developing countries it is precisely the agriculture sector that is so crucial. In the low-income countries, for example, recent data show that on average 69% of the working population continues to earn a meagre living from the land at an average per capita income of some $154.[2] And prospects for structural change in economic production will also continue to depend on agriculture insofar as downstream processing is concerned. For this reason the discussion in what follows will pay particular attention to the very poorest countries.

Clearly technological development is important, and yet as Horton and Elliott have pointed out, while “agricultural research can generate handsome returns-------- nevertheless, there is concern about the limited benefits of agricultural research for poor people, particularly in sub-Saharan Africa, where ‘Green Revolution’ technologies have not had a significant impact”[3]. This paper suggests that there may be advantage in approaching these and related issues from an innovation systems standpoint. More concretely the argument is that one important reason why agricultural innovation does proceed as effectively as it might is that the institutional context in which it is embedded often acts as inertial force. In turn an important conditioning factor is that associated innovation systems do not have the “connectivity” needed to link research adequately with economic need.

Section II provides a short summarised analysis of how technological change in LDC agriculture has evolved over the past forty or so years. To begin with differing conditions compared to those in industry gave a much greater role for public funded and executed R&D, conducted as part of national agricultural research systems (NARS). However, despite the apparent successes associated with the Green Revolution the paper charts the growing disillusionment with the role and functioning of R&D organisations at both national and international levels. In particular the paper outlines a range of relatively new approaches that collectively attempt to empower the poor farmer as a key player in the innovation process. And in so doing these approaches are consistent with recent developments in the innovation systems literature that stress the need for greater "connectivity" among the component nodes of such systems. Section III takes this insight further by couching discussion in terms of an emergent "knowledge market". Traditionally national innovation systems in and for LDCs were viewed as collections of Science and Technology [S/T] institutions that would act as the basis for technological development. Their inter-relationships were hierarchical and little attention was paid to

[1] Though there is a separate literature that deals with related issues it is remarkable how little attention it pays to the mainstream in this sense.
[2] The source for these figures is World Bank (1996), Tables 1and 4. I am grateful to Roger Sandilands for drawing this information to my attention.
[3] See Horton and Elliott (1993), p 189.

the precise mechanisms through which their "knowledge outputs" would go on to impinge on economic production.

Such a view, here labelled as the "pipeline" view,[4] has now given way to a position that stresses the need for much closer linkages between (and among) economic and technological agents. In the richer countries this has taken the form of innovative institutional arrangements that improve the efficiency of technology transfer---i.e. between those bodies that search for and validate knowledge on the one hand, and those that use such knowledge for some welfare increasing purpose on the other. Section IV goes on to stress that from a conceptual standpoint such institutional reforms are also consistent with classical informational theory in so far as this stresses the primacy of close links between the supplier and receiver of information if this is to be translated into useful knowledge. Moreover such knowledge channels are not only technological in the formal "technology transfer" sense but concern also marketing, exporting and public policy.

Section V returns to the issue of technological development for agriculture in poor countries giving examples of new institutional initiatives that are now beginning to be introduced. All of these are consistent with an "innovations systems" perspective of the policy agenda, a perspective that does not appear, however, in much of the standard policy literature. Hypothetically it is argued that major obstacles to such reform are the associated threats to vested interests and power structures. In a development context, for example, a major problem is the strength of traditional views on the importance of hierarchy. While a dynamic national innovation system requires an increasing range of horizontal linkages to ensure effectiveness, political and social structures in many low-income countries are based on the presumption of central control. The concluding Section VI speculates on what might be done to break and hopefully reverse this position.

II Innovation in the Agricultural Sector

There has been very little work applying the national innovation system concept to agriculture but there is an important sense in which implicitly it underlies recent debates. Perhaps the best way of approaching the point is as follows. There is sometimes an unconscious predisposition amongst development analysts to regard "technology" as relating mainly to industry and by implication almost, as having little to do with agriculture. Nothing could be further from the truth. Technology, certainly in the sense used by economists (i.e. as the means by which resources are transformed into commodities that have value), is a key factor in the vitally important problems associated with poverty and sustainability in the Third World. Indeed Chambers et al.(1989) [and referring to the estimates of Wolf(1986)][5] argue that it is the technological challenges associated with the poorest of farmers working on the poorest of lands that is really the issue of paramount importance as we come to the close of the twentieth century, if only because "some 1.4 billion people, or over a quarter of the human race, are dependent on this form of agriculture for their livelihoods, comprising approximately 1 billion in Asia, 300 million in sub- Saharan Africa, and 100 million in Latin America"[6]

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[4]See Clark (1995) for a detailed exploration of this point.
[5]see Chambers, et al (1989)
[6] See op. cit. p xviii.

But if technological factors are as important in agriculture as they are in industry, it is nevertheless true that they impinge in rather different ways. There are two broad reasons for this. First, as Biggs and Clay (1981) noted in the early 1980s, agricultural production is inherently more unstable and locationally specific than is the case with industry. And that in turn is because it takes place within the context of natural (biological) systems that continuously evolve over space and time. There is thus no guarantee that a technology package that "works" in a specific location in year 1 will be equally successful 200 metres down the road in that year, or indeed in exactly the same location in year 2. Hence in terms of the production and dissemination of usable "knowledge", it is on the whole much more difficult to develop generic technology with universal applicability than is the case with industry. That is not to say that industrial technology is completely invariant across different contexts. There is, however, a clear qualitative difference compared to agriculture.

The second difference relates to the failure of the market to allocate technological resources optimally in the case of agriculture. Unless the state intervenes there will be underinvestment and everyone will suffer. Thus although the poor farmer has often a considerable fund of tacit knowledge about his environment he is in no position to invest in formal R&D to improve production possibilities. And this is not only because of cost and scale factors. It has a lot to do also with perceived risks of failure since a mistake can have devastating effects on the livelihood of himself and his family. For these reasons, therefore, the investment of resources designed to upgrade the technological level of agriculture has traditionally been seen as the business of the public sector with research being conducted in centralised institutes and its results passed to the farmer by means of a network of extension agencies. Even in rich countries with a tradition of capitalist agriculture, the same situation obtains--viz. an extensive network of publicly funded R&D institutions, financed collectively through central government revenues, which is seen as the correct means of improving productivity.

It is this mode of technology transfer that Biggs (1989) and others have labelled as the "top down" or "transfer of technology" (TOT) model.[7] In the immediate post-war period, Hall (1993) has argued, there was a widespread view that much traditional LDC agriculture was relatively primitive technologically speaking and that rapid population growth rates combined with the threat of political unrest (Anderson, 1991) meant the need for new technological practices. These would come from the transfer from the rich countries (aided by Western advisers) with diffusion taking place through community development programmes (Staatz & Eicher, 1984). Ruttan (1984) describes this as the diffusion model of agricultural development since emphasis was placed on "diffusing" technology directly from Western countries to LDCs. There was also the view of authorities like Schultz (1964) that the problem was actually not so much one of inefficient agronomic practices (farmers were actually quite efficient resource managers in Schultz' view) as one of technologies that needed to be radically upgraded to meet the exigencies of the post-war period.

The common thread running through all this thinking, however, was the perceived need to transfer "best practice" to the poorest of the poor. The way this happened very often was through the establishment of a number of research institutions based on the US land grant system initially through private and bilateral aid and later with multilateral aid

[7] See also Biggs and Farrington (1991)

(de Janvry and Dethier, 1985).[8] Bell (1979) is amongst those who have subsequently argued that although this (land grant) system may have worked well in the context of its inception in the US in the late 19th century, in Third World circumstances a hundred years later it has been found wanting. But, in the context of the time the TOT model was very much to the fore as the correct institutional mode for agricultural development. Furthermore, for the first time, plant breeders applied to crops grown in tropical countries two principles previously confined to temperate food crops---viz. hybrid vigour and dwarfing (Lipton and Longhurst, 1989). First came the maize hybrids of the 1950s with their origins in the US, but spreading to Central America and East Africa. Next, starting in the late 50s and early 60s, came the short-strawed, fertiliser-responsive varieties; rice in East Asia (Anderson, 1991), and wheat in Northern Mexico and the Punjab region of India and Pakistan. It was these so-called "high yielding varieties or HYVs" that became the bedrock of what is now known as the Green Revolution (GR), holding out the promise of solving at a stroke the world's food problems.

However, the initial impetus for the GR did not come from the national agricultural research systems (NARS) of the LDCs themselves, but from two international research centres that subsequently became the model for the sixteen or so centres that now comprise the Consultative Group for International Agricultural Research (CGIAR) system ---CIMMYT in Mexico for wheat and maize, and IRRI in the Philippines for rice. The CGIAR system (sometimes called the CG system) came into being (in 1971) because despite international help for the NARS, many LDC governments did not support local research sufficiently. In compensation, therefore, multilateral and bilateral aid, along with support from private foundations, was channelled to international centres of excellence that would undertake strategic research for LDCs without becoming enmeshed in the administrative and political arenas of client countries. What emerged was a two-tiered system. The CG centres developed production technologies and varieties for mandated crops (and geographical regions) that were subsequently passed on to the NARS for applied, contextual research and final transfer to the farmers. This essentially is the TOT model which became the "engine" of the Green Revolution and which has really dominated policy thinking until very recently. Its chief characteristics are a belief in the existence of scale economies in the R&D process, a faith in the scientific method as the main source of improved technological practices for the poorest of the poor and relatively little attention paid to the tacit knowledge and local preferences of the farmers themselves (Chambers & Ghildyal, 1985).[9]

But how well has the system worked? While in earlier periods it is clear that big productivity gains were achieved, particularly with respect to maize, wheat and rice, as time has gone by the evidence has become much patchier. At national level, for example, many NARS are clearly not performing well and this is so for a number of reasons.[10] *Firstly*, the NARS have often tended to become isolated from economic production, with research scientists seeing their role and function in professional rather than production terms. Research projects are often pursued as much for scientific

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[8] see p16
[9] See pp 1-30.

[10] It is hard to single out a full set of references for these points. However, interested readers are referred to the following sources: Horton and Elliot (Eds., 1993), Biggs (1989), Hall and Clark (1995). For a rather different view see Evenson et al. (1999). However, the conclusions of the authors are based upon data relating to the period 1977-87 and therefore are not inconsistent with my own view.

interest (and because of the publishability of results) as for relevance to the needs of the poor farmer. *Second*, within research bodies there are difficulties in establishing organisational structures that can focus on the broad (interdisciplinary) problems faced by the farmer. *Third*, this then becomes reflected in funding patterns since resources get allocated according to scientific criteria by funding bodies advised by professional scientists whose criteria of excellence are "scientific" rather than developmental. *Fourth*, many NARS are under-funded because of macroeconomic constraints. This is especially the case in the poorer countries such as those in Sub-Saharan agriculture[11]. *Fifth*, publicly financed extension systems have difficulty coping with the demands made on them for a variety of reasons. These range from shortages of adequately trained human resources to the sheer operational difficulties of organising and managing the complexities of new technological packages in such a way that they can reach a receptive audience of a reasonable proportion of the relevant farm population. Indeed there are a number of commentators (such as Chambers for example), who argue that as an organisational form the traditional extension system is inherently unviable and will eventually have to be replaced with something better, though there is a lot of uncertainty as to exactly what this should be.

Nor have things gone well at international levels. One problem with the CG centres is that they operate as a hierarchy. The ultimate paymasters are the donors, both bilateral and multilateral, each of which has its own aid agenda[12]. The centres are then charged with research designed to produce generic knowledge, which is supposed to be contextualised by the national agricultural research systems (the NARS) of individual countries. Finally the NARS pass applied knowledge through extension agencies and other service departments to the ultimate beneficiary--the small semi-subsistence farmer. The difficulties of this set-up are by now well known. There is no readily available means for farmer problems to communicate directly with the centres, which tend on the other hand to be driven by values of traditional scientific research. In many countries the NARS are weak and so cannot build the necessary bridges with the farmers, while the practice of employing socio-economic expertise to orient strategic research in a more direct fashion is by no means as widespread as might be expected.

It is for reasons such as these that while the CGIAR system has cost considerable resources in terms of international aid it is not easy to estimate resultant benefits. In a detailed early survey, for example, Horton (1986) argued that for a variety of reasons it is virtually impossible to calculate a meaningful rate of return to investment in the CG funded research. The "unique contribution of international programmes to agricultural development is to supply R&D technology which improves institutional performance, rather than production technology which raises productivity at the farm level. International programs play a strategic role in disseminating research findings, methodologies and institutional strategies (for the NARS--- but) the impact of (such programs) should be assessed primarily in institutional terms, not in terms of production increases at the farm level"[13]. More recently Reece (1998), in the context of a detailed

[11] See for example, Tripp (1993)

[12] The CGIAR system is suffering financial constraints to an unprecedented degree and not unrelatedly has been subject itself to a series of reviews in recent years that have been designed to facilitate appropriate re-adjustments.

[13] Horton (1986) p 465. The more general problem of the CGIAR's organisational structure has been partially addressed in the report of a recent review panel. See Ozgediz (1993)

historical case study of the Centro Internacional de Agricultura Tropica (CIAT), has argued that while the CG centres were successful in achieving their original aggregate productivity goals for well defined products, such as wheat and rice, they have become singularly unsuccessful when attempting to deal with “poorly defined problems”[14]. By these he means problems like the degradation of a natural resource base and the inadequate livelihoods provided by low-resource agriculture. The issue is really while well-defined goals are amenable to a “pipeline” research methodology, most modern issues for poor farmers need a more systemic approach. Here he echoes commentators like Eponou (1993) who develops the case for a “systems perspective” arguing that even the so-called Farming Systems Research Model “has not been very effective in testing and adapting technologies for resource poor farmers”.[15]

III National Systems of Innovation

How might a national innovation systems perspective inform this discussion? One reason for the popularity of what Biggs (1990) has called the TOT model is that it fitted very well into established views about the proper conduct of science. And since agricultural innovation has close links with scientific research this is a useful analytic starting point. A traditional way often used in setting out the general conceptual issues is to think in terms of a division of labour between "knowledge search" and "knowledge use". University departments and state funded research institutes carry out pure research according to canons of objectivity determined by the cognitive authority of peer review. The knowledge that results from this activity is then drawn upon as and when needed by a productive sector which has quite a different agenda, that of making money from the sale of goods and services. Whether it refers to the natural or the social sciences makes no real difference. The market will draw upon the technological resources it needs as and when necessary. Knowledge impinges on economic production at the end of a pipeline, which in turn represents a cognitive hierarchy of excellence. One of the great advantages of such a view is that it provides legitimacy for professional interest groups. For example economists can treat technology as exogenous to their analysis of any process, and concentrate upon explaining the "results" of technology in purely economic terms. Similarly physical scientists can justify their research in terms of the disciplinary authority of their peers, unsullied by commercial and other worldly pressures.

As industrialisation proceeded in the post-war years, however, it became increasingly difficult to see innovation in such stark terms. The shortage of governmental capacity to continue to fund pure research, disciplinary rigidities within academic and quasi-academic bodies, changing technological demands in the productive sector and expansion of activity within the knowledge-producing sector itself, each contributed to the blurring of the boundaries that demarcated these traditional knowledge categories. To begin with the notion of state funding of applied science began to break down because countries could not afford to continue to support the apparently ever-increasing demands of science in the face of severe economic constraints. In Britain, for example, the recommendations of the Rothschild Report (Rothschild, 1971) in the early 1970s represented probably the first real attempt to introduce market criteria into science funding---in this case by suggesting the notion of a "customer-contractor" principle as a means of determining the research needs of government departments. They included

[14]See Chapter 6, p 225.
[15]See op. cit. p 309.

also however, changes to traditional patterns of resource allocation within the research council system---in this case by alienating a proportion of funding, held to be "applied", to the relevant department. Essentially the Rothschild reforms were an attempt to separate off the funding of "basic" research from that having practical uses and in this way to introduce some kind of economic discipline into what was rapidly becoming an expensive drain on national resources.

From that point on in the UK (and similar trends have obtained in other countries) a range of new institutional forms have emerged to improve the efficiency of this emergent knowledge market. Examples include the increased use of directorates, such as the UK Biotechnology Directorate, designed to focus the combined strengths of industry, research, university and government on a key generic technology: interdisciplinary research programmes; and schemes like the UK "teaching company" scheme that introduce joint academic/industry PhD supervision of students that are also employees of companies. The net effect of all these initiatives has been to blur the distinction between knowledge search and knowledge use and hence to make the notion of a knowledge pipeline (or shelf) increasingly untenable. Instead attention is now placed on more complex ideas like that of the national innovation system. Defined as the "network of economic agents together with the institutions and policies that influence their innovative behaviour and performance",[16] emphasis is placed on how such a system should be organised to improve the dynamics of economic production.

Here the key factor is the need to understand much better than we do at present why innovation and technical change can be so influential in economic development in some countries but so much less so in others. Modern literature emphasis factors such as the increasing knowledge base of economic production, the tacitness of much of this knowledge (i.e. the importance of non-codified knowledge), the role of "learning interactions" amongst different techno-economic agents and associated networking arrangements, the non-linear properties of relevant knowledge flows, the significance of user/supplier contact, specially designed public policy regimes, and other factors which do not *in and of themselves* relate directly to components of the science/technology (S/T) system as conventionally defined.

It was largely to take account of these dynamic properties that the idea of a national innovation ***system*** was given its “systemic” title although unfortunately very little of the *national system of innovation* literature engages directly with the concept of a "system" independently of its use. Instead the word "system" is employed as a kind of loose metaphor to describe broad relationships among relevant stakeholders whose activities affect innovation. Very probably this tends to weaken related policy analysis simply because it is hard for the analyst to use the underlying ideas in a rigorous way. And all too often, we find, there is a tendency for policy analysis to retreat back to the single discipline with the inevitable result that such analysis often fails to capture the holistic nature of problems and solutions.[17] For analytical purposes, therefore, it is useful to

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[16] See Lundvall (1992) and Edquist (1999) for detailed discussion of this concept. There is actually a burgeoning literature on the topic but these two sources provide a comprehensive review.

[17] There is in fact a substantial literature on systems analysis dating back fifty years and more. For example, Lotka and von Bertalanffy began to develop an open systems perspective on all science in the 1920s and 1930s, while more recently Emery, Beer, Ashby and many others have done a great deal of valuable work in applying systemic ideas to a wide range of disciplines. For a useful collection of some of the classic papers in this tradition see Emery (1970) that includes a paper by von Bertalanffy referencing some of his

begin with a broad description of what precisely is the nature of such a system, what does it consist of, how may it be identified, how may it be classified, how does it behave, and so forth?

A system may be defined as something that is made up of interconnected elements (or nodes), and has a boundary that separates the inside from the environment. Often a distinction is drawn between a *closed* system and an *open* system, based upon the extent to which the analyst wishes to consider the degree of interaction with the system's environment. When the system is open, both matter and energy can enter and leave the system. When the system is closed, in general energy, but not matter, can cross its boundary. Sometimes a distinction is also made between an *isolated* and a *closed* system such that in the former case neither matter nor energy can cross its boundary. In the human or life sciences, however, in addition to these broad distinctions (which often actually help to define a system in the physical sciences as a closed one), we have three additional requirements. Firstly, the interacting elements, which make up living systems, are connected in an *organised* manner. Secondly, the participating components are *affected by their participation, and are modified* when they leave the system. Thirdly, the system as a whole *behaves*. It does something while turning its inputs into outputs, or depending on the point of view, it may do something in order to turn its inputs into outputs.

Central to the notion of a national system of innovation is therefore the degree of substantive interconnection among the "nodes" of that system. This paper argues that this interconnectedness is both informational and institutional. What do I mean by this? Basically the idea is that as society becomes more technologically sophisticated its component organs generate increasing volumes of information. And it is how to cope with this that becomes the key question. In other words, there is so much information (potential knowledge) in most economic systems that the scarce resource is how to identify what is relevant to any specific activity and organise it in a productive way. In turn this requires system-wide skills [including the capacity to achieve interaction between agents] that have also to be created.

In this way the concept of a national innovation system is now used as a kind of shorthand for the network of inter-institutional linkages that apparently successful countries have built up as a support system for economic production across the board. In this sense it has been explicitly recognised that economic creativity is actually about the quality of "technology linkages" and "knowledge flows" amongst and between economic agents. Where the interactions are dynamic and progressive great innovative strides are often made. Conversely where systemic components are compartmentalised and isolated from each other, the result is often that relevant research bodies are not at all productive. In extreme cases they have ceased to provide any innovative output at all. Put another way the key property of a national system of innovation is therefore not so much its component parts, or nodes, but rather how it performs as a dynamic whole. As one recent paper argues: "Even if single elements of such systems are strong, the system as a whole may be weak. The capability to learn and build new competencies will depend on how well the parts fit together and on the strength of these connections."[18] It also adds four other key properties of successful national system of innovation, viz.:

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own early ones. For a more complete discussion of the general issue see also Clark, Allen and Perez-Trejo (1995), especially Chapters 1 & 2.

[18] See UNCTAD (1996), pp 5 & 6. See also Mytelka and Tesfachew (1998).

- The implications of this perspective for public policy (e.g. it has begun to be used as an explicit policy tool, such as in "foresight" exercises)

- The need to focus on entrepreneurship in its broadest sense

- The importance of organisational/institutional innovations as an integral part a dynamic national system of innovation

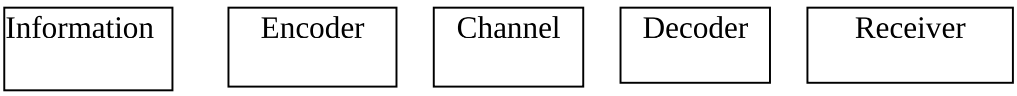
- The need to integrate the national system of innovation with foreign knowledge sources

IV Information Theory

In order to shed more light on the topic it is useful to make a distinction between 'information' and 'knowledge'. In fact conventional economic analysis does not do this but on the whole uses both concepts interchangeably to describe a category of boundary conditions that prevent economic actors from behaving, as they ought to (to achieve some putative optimum in terms of the allocation of resources).[19] What the formal theory of information does is to define the concept in a way that is logically independent of 'meaning' and in so doing provides the basis for a more general theory of systemic communication. In particular, it allows us to relate the flow of information to that of energy/entropy and thence to develop a model of the technical change process that has the property of systemic generality[20]. Information theory conceptualises 'information' in terms of a flow of 'messages' that have 'news value'; that is, they cause surprise to recipients. In the words of Singh (1966) for the 'communications engineer's purification of the term, the stress is on the quantitative aspects of the *flow* in a *network* of an *intangible* attribute called *information*'.[21] Such a network consists of three main parts:

- a transmitter;
- a receiver;
- a communications channel

Figure 1



Since the medium of communication is not in general similar to that of the transmitter or receiver, there needs to be a means of translating signals at the beginning and at the end of the process, so that any typical communication system may be represented as shown in Figure 1. For example, a traditional radio system operates by converting sequences of voice production into electromagnetic waves that are beamed through the atmosphere to be received and understood by listeners. Thus 'information' turns out to be closely related to energy. Its flows are conventionally quantified in statistical terms,

[19] There is a long history of the conflation of information with knowledge going back to Machlup in the 1950s at least. See Machlup (1962).
[20] For a detailed discussion of this point see Clark and Juma (1992)
[21] See op cit. p 9.

that is by means of a multiplicand of probabilities attached to 'bits' of information where the total information content of any message, in a given 'ensemble' of possible messages, may be measured by the logarithm of the probability of its occurrence. Logarithms are used to convert combination of discrete probability measures to a summation. Hence the information content in any complex of messages is then simply the sum of its individual components.

Singh (1966) shows that no information system has this freedom of information content because of practical limitations. The English language, for example, is such that not all of its letters are equally likely to be chosen. It has the property of 'redundancy' and it is this redundancy that gives it 'intelligibility'. It may easily be seen also that redundancy is closely related to organisation. This is because as soon as constraints are placed on a system (in this example, to give language intelligibility), to that extent the system exhibits a degree of organisation that it would not have had in the absence of such constraints. Notice, finally however, that the above definition is completely independent of semantic meaning. It is merely 'a measure of one's freedom of choice when one selects a message from the available set, many of which may well be devoid of meaning'. It is thus used logically in computer science.[22] Thus the greater the amount of raw information in any given system the more chaotic that system will become and the greater the need for internal organisation to give its component parts meaning. It is in this very fundamental sense that organisation is so central to the idea of an innovation system. Unless the institutional context is such that information flows have meaning to the separate nodes of that system, it will not function as a dynamical system and will not in consequence contribute significantly to economic growth and development.

Two properties immediately follow from this discussion. The *first* is that information only becomes useful knowledge if the receiver perceives it to be so. In a sense the receiver, whether an individual or an organisation, needs to understand information as economically productive. To the extent that understanding is not there, then the information loses value. From an organisational standpoint the capacity to convert information into useful knowledge, and thence technical change, is therefore contingent on internal organisational conditions. Put differently, unlike economic commodity flows, information flows only take on value where there is a deep and shared understanding of what that information means on the part of *both the sender and the recipient*.[23] And it is this peculiar property that renders the market for knowledge so hard to function efficiently. For example, it is one important reason why centralised public sector laboratories often find it hard to interest the private sector in their research findings. The *second* property is that productive information flows are also therefore a function of related actions on the part of recipients. This is because the capacity to understand the full potential of externally acquired knowledge is governed to a large degree by recipient

[22] It has the additional property of being similar to an energetic measure, because since this measure of information is statistical it is therefore directly analogous to the statistical mechanics of molecular systems. Here the degree of freedom of any closed system (its entropy), or its *thermodynamic probability*, is a measure of the deviation of molecular (or micro) 'states' from the average (or macro) 'state' of the whole system. See op. cit. p 9.

[23] There is of course an informational content in any normal economic transaction but outside the case of very complex goods we can probably treat this as fairly trivial. For those who cannot accept such treatment, a more general position could be to define pure "economic" transactions as having no informational uncertainty but where they do, to stress the contingent nature of such transactions in a purely informational sense.

knowledge investment. Paradoxically technology transfer in general only works well where the recipient carries out its own related R&D programme.

Nor are these relationships only technical but are also ideological since in a fundamental sense, organisations only hear what they want to hear.[24] For example, contemporary philosophy of science now accepts that that all knowledge is contingent knowledge in the sense that it its results are theory dependent. The idea of the "paradigm" popularised by Toulmin, Kuhn, Lakatos and others in the 1960s[25] was originally developed to show how scientific progress is strongly influenced by institutional views about the true underlying nature of reality. And it was not long before Constant, Aitken, Hughes, Rosenberg, Dosi and many others extended this argument to technological progress.[26] Here the idea of the "technological paradigm" was used to an established technology that guides production.[27] The "paradigm" was defined as a set of shared views among the stakeholders about the correct knowledge base for production. In effect it supplies the ***informational*** coherence that provides for the knowledge market what the product itself provides for the product market. And in the absence of such shared informational coherence, it would really be impossible for production to take place at all. Notice also that the paradigm crosses established institutional boundaries. No longer is it justifiable to argue that "basic science" should somehow proceed in the absence of any consideration of the needs and aspirations of development or economic production. Nowadays the science-based nature of much economic production renders this inadvisable from a policy standpoint.

There is one additional point that should be stressed about this analysis of information theory. That is it illustrates by implication the need for well-organised and co-operative knowledge markets. Nowadays (and partly also because of technological changes in information handling) there is so much information that ***could*** be relevant to economic agents that new ways have to be found of minimising the costs of information search and maximising the “receptivity” of those who are able to use the information. It is this essentially ***interactive*** feature that ultimately lies behind the notion of an innovation system and distinguishes an effective one from an ineffective one. A system which permits information interchange among otherwise independent organisations, where management hierarchies do not intrude excessively and where encouragement is provided to individual agents to try out new and possibly risky approaches (and even to make mistakes), stands every chance of contributing greatly to innovation and change.

Conversely, a system that is formal and rule-bound, where individual agents are constrained by their own hierarchies and where co-operation between organisations is viewed with resentment and suspicion, is unlikely to make that sort of positive socio-economic impact. It is with this disjunction in mind that many industrialised countries, driven to some extent also by the recent success of Japan and the East Asian NICs,

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[24] As Duysters (1996) has pointed out in a recent detailed study of major IT sectors, even if a firm fully appreciates the necessity for a specific course of action in a techno-economic sense, attempts to put this into practice may fail if significant organisational stakeholders simply cannot bring themselves to believe in it. And though this is sometimes related to threatened vested interests, often it is simply that the measure contradicts some deeply (and widely) held belief system.

[25] See, for example, Lakatos I & A Musgrave (Eds.) (1972). These points are discussed in detail in Clark & Juma (1992).

[26] Probably the first to do this in a substantive way, to my knowledge, was Constant. See Constant (1980). See also Clark (1987) and Clark and Juma (1992) Chapters 4 & 5.

[27] See Clark (1987)

have begun to experiment with new and innovative institutional forms of the emergent knowledge market. Notice finally that such knowledge channels are not simply those associated directly with the transfer of a given technology *per se*. A recent UNCTAD document maintains that what is equally needed are channels of communication that build awareness of alternative technology sources, public policy regimes that can help or hinder transfer processes and incentive structures that permit co-operative arrangements among organisations that currently treat each other as rivals rather than as potential sources of new knowledge[28].

V Prospects for the Future

How then does this type of analysis relate to the LDC agricultural context? We saw from the earlier discussion in Section II that a major issue in agricultural R&D is the top-down nature of the institutional context in which it tends to occur. Because so much of research is conducted within the public sector[29] the prevailing trend has always been one in which the rules and norms of professional science have governed events. And inevitably as Biggs and many others have pointed out, "pipeline" thinking has applied. And even where strenuous efforts are made to develop closer linkages (with user sectors, for example) such is the inertia of prevailing institutional forms that it is actually quite hard to get these changes to work.

This is not to say that changes are not beginning to happen. For example, Ethiopia has radically transformed its agricultural extension system over the past five years following a period under the Derg during which agriculture as a whole stagnated dramatically.[30] In fact there was practically no extension to speak of in the period 1974-1983. In 1983 the then Government introduced a food self-sufficiency programme based on the Training and Visit [T&V] type of extension system, but this also met with limited success. Accordingly upon the advent of the new regime the Government instituted a new philosophy based on farmer participation. This was prompted by the "Sasakawa Global 2000" initiative[31] although initially there was little response on the part of the farmers. There followed the Participatory Demonstration and Training Extension scheme [PADETES]. Starting in that year with 167 farmers, by 1994 there were 1600 farmers reached. In 1995 a national programme had got underway (35,000) and livestock forage had been introduced. By 1996 the scheme had reached around 360,000 farmers and dry land zones were included. By 1997 a range of new packages had been developed and some 650,000 farmers had been reached. In 1998 the authorities estimate a figure of 2.5 million.

Essentially the new system is oriented mainly towards assessing farmer need and hence advising on R&D priorities, but with a strong participatory and human resource development dimension. For example in one regional research centre near Lake Tana there is a dedicated Research & Extension section mainly concerned with fulfilling the PADETES strategy of setting up on-farm demonstrations. In addition the agricultural economics section has as its primary role, advising on priorities on the basis of

[28]See UNCTAD (1999).

[29]According to Eyzaguirre and Okello (1993) who conducted a detailed survey of NARS in 50 of the poorest countries public research bodies employ over 90% of the total. See page 239.

[30] See UNCTAD (2000), Chapter 4.

[31]Discussed in Tripp (1993)

assessing farmer need.[32] The chosen farmer supplies only labour for cultivation of the demonstration plot and is allowed to keep the proceeds, which often amount to a yield 50% greater than normal. Advertising is done by extension workers who announce the existence of the trials and periodic field days that are well attended. According to the general manager of the research centre the results have been very successful with significant rates of adoption of the recommended technologies.[33]

Another general area where significant developments appear to be taking place is in contract farming. By this is meant the practice of a central node establishing purchase contracts with farmers. These usually involve the central node supplying the technology, markets and credits for inputs such as fertiliser. The farmer supplies land, labour and tools in growing the crop, which is then sent to the central node for finishing, grading, packaging and sale, often to an export market. Although such schemes are not without their problems (see, for example, Porter and Phillips-Howard, 1997) they are an increasingly important mechanism for technological development in many parts of the Third World. The central node is often a multinational company. An example here is the firm Arbor International that sources fresh food from countries like Zimbabwe and then supplies to big retailing firms such as Marks and Spencer. In this case the intermediary provides technology, other key information, cold storage and airfreight facilities, and direct access to a high value market.[34]

In other cases the node is a parastatal company like the Magwa Tea Corporation in the Transkei (Porter and Phillips-Howard, 1997), or a co-operative like the Vijaya Vegetable and Fruit Growers Association in India (Hall et al, 1998). The latter purchases grapes and mangoes from small Indian farmers and sells to centralised markets in big Indian cities, the Middle East and Europe. Paradoxically in this case one of the problems faced is access to necessary technological inputs. Public sector bodies seem unable to deal with the systemic nature of the technological changes needed to penetrate successfully these high value markets. And according to Hall et al. (1998) this is at least partially due to the “pipeline” attitudes of research centre staff. Their research shows that the central node was forced to access technology from another private sector firm and a research facility in Europe.

Yet another institutional development is the potential role of growers associations in providing greater coherence to NARS in a Third World context. A good example here can be found in the recent UNCTAD (1999) science and technology review of Colombia, with cases drawn from three sectors—Cut Flowers, Coffee and Sugar. In each sector the growers association (or gremio) provides a range of technological services at a level of quality that the corresponding public sector institutions seem incapable of matching. Indeed in some cases the gremios undertake investment functions (such as road building/repair) that are normally the preserve of the state. Porter and Phillips-Howard (1993) also recommend the establishment and/or improvements of growers associations as a mechanism to improve some of the problematic side effects of contract farming schemes.

[32]This contrasts with arguably the more commonly observed practice whereby agricultural economists spend the bulk of their time researching for publishable material.
[33] The "Sasakawa Global 2000" initiative, however, is not a straightforward panacea. See Tripp (1993) for an interesting evaluation of its impact on maize production in Ghana.
[34]See UNCTAD (2000), Chapter 1.

A final type of development that is increasingly common in many parts of the Third World is the use of NGOs to supplement public sector R&D activity. In a recent survey of agricultural R&D relevant to the small farmer in Latin America, for example, Kaimowitz (1993) shows how much of the green revolution success of the 1950-80 period has either by-passed the small farmer or has created new problems for him that the public research sector seems unable to deal with. Again (though the author does not use this terminology) at least some of the reason for this is the "pipeline" nature of institutional structures. Kaimowitz goes on to argue that much greater use should be made of NGOs to contextualise public sector R&D and to provide the necessary connections to the real problems (and knowledge) of the poor farmer.

What all these developments have in common is that they are examples of a more systemic approach to technological development in and for Third World agriculture. They also add substantially to a debate that has tended really to avoid many of the important institutional questions. Thus we still see many examples of analysis that while pessimistic about the level of resource allocation to agricultural research, do not directly engage with these systemic institutional issues. Good examples of this can be found in Lipton (1988) and Pardey et al (1997). In the latter the authors provide a detailed account of the decline in African agricultural research spending but there is virtually no analysis of why this has happened. Consequently the final conclusion focusing on the need to increase finance is unconvincing. The Lipton paper goes further in linking declining research expenditures to falling economic rates of return but the analysis virtually ignores institutional questions, concentrating instead on poor policy frameworks, below optimum size of research stations and product relevance.

Tripp (1993) seems to get much closer to the institutional issues in his penetrating analysis of Ghanaian maize research. His position is that international support for public research in agriculture has certainly declined significantly and this is strongly connected to the "disappointing track record of many government agricultural research organisations"[35]. But the remedies suggested reflect too simplistic an analysis that often results in premature abandonment of public sector R&D.

> "Rather than trying to carefully define a role for public sector research, donors and governments have shifted to an uncritical reliance on alternatives. The two principal candidates are the private sector and the NGO community, both of which clearly offer important contributions. Few would dispute that public sector agricultural research deserves a housecleaning, but there is a real danger that both external donors and national governments will use the new alternatives as an excuse to abandon rather than to reshape the public sector contribution to agricultural development"[36]

The paper goes on to analyse a number of the suggested "alternatives" concluding that none of them are by themselves sufficient to remedy the situation and that a re-vitalised

[35]See Tripp (1993) p 2003.
[36] Ibid. pp 2003-2004.

public R&D sector has an important part to play. Although he does not put it in so many words, it is clear that Tripp is implicitly arguing for a more systemic approach to the analysis of agricultural research, an approach that has the potential to integrate the different contributions that a wide range of actors can make.

VI Conclusions

The nub of this paper has been to stress the essential complementarity between institutional and technological changes, at least in the context of Third World agriculture. While there is no question that public sector R&D is an essential component of an effective NARS, it is also clear that its activities need to be supplemented by other mechanisms designed to ensure productivity improvements, especially for the poor farmer. The decline in formal public sector R&D investment noticed by many commentators over the past twenty years may well be due to these complementary shortfalls rather than problems with the R&D as such. But from an innovations system standpoint the diagnosis appears self-evident, viz. the necessary linkages to ensure healthy technological development often do not exist and have therefore to be fostered. Not that this is easy to bring about since in many poor countries top-down power structures are common. In Africa, for example, Juma and Clark (1995) point out that many institutions were copied from ex-colonial powers at the time of independence but then cloned to social structures that favoured traditionally hierarchical systems of administration. The result has been that attempts to create the kinds of "horizontal" connectivity necessary for healthy innovation systems are often resisted for cultural reasons or because of perceived loss of control on the part of vested interests. Tribal ethnocentricity then exaggerates an already unproductive situation. Under these conditions the resultant haemorrhaging of NARS throughout much of Sub-Saharan Africa has inevitably been hard to remedy.

And yet there are indications that institutional change is certainly possibly. For example, CGIAR centres have begun increasingly to associate their work with private sector bodies, illustrated by recent developments in India. Thus Pray and Kelley (1997) report the way breeding lines from the International Agricultural Research Centres have been used by the private sector seed industry in India (specifically maize lines from CIMMYT in Mexico, and sorghum, pearl millet and pigeon pea lines from ICRISAT). More recently a consortium of five Indian seed sector companies has contracted ICRISAT to develop a bold grained sorghum genotype over the next five years. The findings of Pray and Kelley (1997)[37] suggest that in the Indian seed industry, R&D managers feel that India's seed industry would benefit by innovative experiments in research funding as well as contractual agreements and partnerships involving private and public institutions. While the private sector is expressing a strong desire, however, progress so far is limited.

Section V of this paper has given other examples of the types of institutional innovation that show considerable promise in this regard. If allowed space to develop and with the help of supportive administrations, they could begin to transform possibilities for poverty reduction in precisely those parts of the Third World that appear to most in need. Indeed far from being a threat, such institutional reforms could end up by giving much greater legitimacy to political leaderships who could then claim, with some justification, that their wise interventions had been a necessary ingredient. The basic point, however, is that the lack of technological development in Third World agriculture is not something

[37] See also Pray and Umali-Deininger (1998)

reducible to simple solutions such as lack of finance. Nor is it due solely to lack of research skills since much more could be made of existing capacities. What are really needed are institutional structures that permit the symbiosis of knowledge search with knowledge use. Only when that is successfully achieved will the problem begin to reduce.

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