Induced, Diffused or Systemic Innovation?

Technical Change in sub-Saharan Smallholder Agriculture

Mats Hårsmar, Nordic Africa Institute, Uppsala, Sweden
mats.harsmar@nai.uu.se

2011-05-10

Draft

Paper prepared for the conference

Economists of Tomorrow

13th Conference of the Association for Heterodox Economics, 6-9 July, 2011, Nottingham Trent University, UK.

Introduction

Increasingly, poor country governments in sub-Saharan Africa aim at promoting inclusive growth. Rather than infinitely trying to minimize something negative – in combating poverty – they try to situate their development challenges in a context of progress. One example is the government of Burkina Faso, which recently abandoned its "poverty reduction strategy", and replaced this with a "strategy for sustainable growth" (Palenfo, 2011). Given that the majority of the population resides in rural areas and continuously is occupied in subsistence agriculture, a major issue for the current strategy is how to raise productivity in smallholder production of food crops. Focus is increasingly given to the issue of technical change in peasant agriculture.

We will in this paper argue that technical change in peasant agriculture in sub-Saharan Africa need to be understood within the theoretical framework of innovation systems. Furthermore, this change has to be simultaneous with institutional changes, a combination we will refer to as technological change (Edquist and Edkvist, 1973). Theories about technical change emanating from neoclassical economics or from rural sociology are insufficient at explaining how technical change come about in this setting. Lacking in those theories are arguments about wider resource use, risk management and social learning, as well as about the interplay between technical, social and institutional change.

Before we arrive at that, we will dwell on some widely used theories about technical change and see where and why they fail to apply to sub-Saharan peasant agriculture.

Relevance of technical change

The importance and relevance of achieving technical change in dominating economic sectors of national economies cannot be overestimated. Seen over the last 50 years, economic differences between poor and rich countries have widened quite dramatically. Whereas a person living in an industrialized country in 1960 on average had 16 times the income of an average person in one of the poorest countries, that difference had grown to 35 times half a century later (Ocampo et al, 2007).

Neo-classical economic theory predicts that poorer countries should experience higher growth rates than richer countries, everything else being equal. This is due to the decreasing marginal productivity of capital. However, because of a negative growth on average, the group of least developed countries has fallen further behind the industrialized countries. Simultaneously, other developing countries have grown faster and caught up somewhat with the rich countries (Guillaumont, 2009: 96-103, Ocampo et al, 2007:32f).

This divergence within the group of developing countries is referred to as the twin peaks[1]. The economic growth rates for the least developed countries during the period 1970-2000 were negative (between -0,03 and -0,74 percent per annum depending on data source), whereas other developing countries grew with between 1,26 and 1,42 percent per year on average. The former group of countries slipped further behind the group of rich countries while the latter caught up somewhat (Guillaumont, 2009: 100). The two separate peaks that express the median per capita GDP of the LDCs and of other developing countries moved away from each other.

There is a vast ongoing debate on the possible reasons for such divergence in growth. This will not be discussed here, except for stating that there is little doubt that differences in technological levels have something to do with such vast economic differences.

Many of the poorest countries of the world, often found in sub-Saharan Africa, are characterized by large agricultural sectors. Part of the pattern is also that increases in agricultural productivity are lacking in many of these countries. A relevant question is why there is so little change occurring in this area?

[1] Referring to the distribution of kernel density of economic growth rates for the least developed countries relative to other developing countries during the period 1970-2000.

Neoclassical economic growth theory has usually not been very good at explaining technical change – even though technology arguably is the primary factor determining a country's income. The most widely used model to explain economic production, the Cobb-Douglas model, includes two basic production factors; human labour and physical capital. These two factors seem to explain income differences of scale factors 2,2 (labour) and 1,8 (physical capital) respectively (Hall and Jones, 1999). This is to be compared to the total income differences between poor and rich countries, which amount to factors that lie somewhere in the span of 70 to 100 (Azariadis and Stachurski, 2004:21). Since human and physical capital cannot explain more, the remainder of the prevailing income ratios between rich and poor countries has been referred to differences in technology.[2]

In order to give technical change a microeconomic foundation, and that way provide a better explanation to how the fundamental factors of production may lead to economic growth, the theory of induced innovation was introduced. Its main architects were Hicks (1932), who in his "Theory of Wages" argued that rising wages motivated labour-saving innovations, and later also Fellner (1961), Samuelson (1965), Kennedy (1966, 1967) and Ahmad (1966). Within the field of agriculture, Hayami and Ruttan (1970, 1971, 1987) as well as Binswanger and Ruttan (1978) have been the main authors promoting this theory, through empirical testing and theoretical discussions.

According to the theory of induced innovation, the innovation process takes place as certain production factors become scarce, which in turn leads to a change in relative factor prices. The fundamental force driving the process of technical change is the combination of resource scarcity and the human willingness to improve her/his situation. When certain production factors become scarce, such technologies are promoted and implemented that save on the scarce resource, be it land, labour or any other productive factor. The theory deals with rates of technical change as well as with "biases" in technical change, where one specific factor experience greater proportional savings than others. According to the theory, such innovation and technical adaptation should be automatic and come in response to changes in relative factor prices. However, in the classical outline of the position, Hayami and Ruttan (1971) allow some role for the state, at least in providing public finance for research and development of the new technologies.

Situating the theory in a development country context

The ambition in this paper is to elaborate on a theoretical framework that captures, and has the potential to explain, the main thrusts of technical change in smallholder farming in sub-Saharan Africa. For this purpose, we will start with a somewhat elaborated discussion of the theory of induced innovation, and the critique against is. This is the dominating theory in the field. By study of its strength and weaknesses we will later on proceed to alternative positions that are better positioned to explain practice on the ground.

[2] Acemoglu (2002) claims, based on his theory of "Directed Technical Change" that human capital explains a much larger share than this. However, this effect comes exactly through the mechanism of technical differences between countries and is in this way just another argument for the importance of technology in explaining differences in growth rates between countries.

Claims have been made that the theory of induced innovation is applicable also to technical change in small-holder or peasant farming (Binswanger, 1986, Binswanger and Ruttan 1987, Pingali, Bigot and Binswanger, 1987). However, the issue of how to best explain technical change in these settings has for long been contested. One of the earliest, and most influential positions it that of the Danish economist Ester Boserup (2008). There are obvious similarities between the theory of induced innovation and her argument as she presented it in the mid-1960s. She argued that increasing population pressure (land scarcity) will lead to increased agricultural intensification and improved soil management. But there is a fundamental difference between her and Ruttan and Hayami regarding the mechanism through which this will come about. Where Ruttan and Hayami see changes in relative factor prices driving the technical shift, Boserup describes a process driven by changes in the physical availability of land, due to the actual change in numbers of inhabitants on these lands. Further, she works within the framework of mainly subsistence farming where fallow is a central component. Shorter periods of fallow are in her description introduced in combination with various changes in technology. This appears to be a relevant adaptation of the theory in situations where land markets, and hence prices, generally are absent.

In her discussion on how output per man-hour changes when fallow periods are shortened and cultivating tools subsequently are changed, Boserup reaches the conclusion that labour productivity is likely to fall, not increase, with the intensification of land use. Multi-cropping with draught animals that are fed on cultivated fodder, possibly with the help of irrigation, is much more demanding in terms of work than less intense, longer fallow types of cultivation are. Further, the clearing of forest fallow with fire and axe is less labour demanding than the clearing of a bush fallow, which in turn is less labour intensive than the complete clearing of a field for permanent cultivation (Boserup, 2008, 20f). Hence, the shift towards land-saving techniques will not happen gradually, but only when the population pressure has become so high that no other options remain than to shorten the fallows, and use land more intensively.

Further, even if shorter fallow in general implies that land may carry larger human populations, there are exceptions to this. For instance, the practice of bush fallow, with up to eight year fallow periods, may have a larger carrying capacity for human populations than short fallow with animal plowing. This is because of the need for land for feeding the animals increases with the introduction of the plow. Other forms of animal feeding must be implemented simultaneously in order to increase the carrying capacity of the land (Ibid, p 27, 35ff).

Therefore, peasants would not find it profitable to shift to the more intensive systems of land use until the population density has increased above a certain level. In addition, the move towards more intensive land use initiates a complex process of varying land and labour productivity, where gains in one of them has to be weighed against losses in the other (Ibid, p 27ff). The techniques eventually applied are often both available and well-known long before they are put into practice.

To sum up Boserup's argument, population density itself is not enough to provoke this technical change. It is the combination of a high population density and a labour productivity that has fallen to an absolute minimum that leads to land-saving technical change, according to her. On this point she differs from the argument provided by the theory of induced innovation. The latter claims that it is increased factor prices alone that lead to technical change through a more gradual process. [3]

Theoretical criticism of induced innovation

Despite these differences, there is a common trait between Boserup's thesis and the theory of induced innovation. This concerns the assumption that factor scarcity through some mechanism lead to technical change, and that this technical change is of a kind that saves on the scarce production factor. The few empirical tests that have been undertaken in sub-Saharan African small-holder agriculture have all refuted the theory in this context, based on its predictions about factor bias (Carter, 2008, Goldman, 1993, Lele and Stone, 1989).

It is particularly on the point of factor bias that the theory of induced innovation has met criticism. Skarstein (2002) criticizes the theory for not being internally consistent. His argument is that a mechanism inducing technical change is lacking. Shifting factor prices would not lead to any innovations in factor saving techniques, it will merely induce a change in techniques along the prevailing substitution line, he argues. This change will take place as soon as the relative factor prices shift. When the change has taken place, there is no further incentive to move inwards to a more efficient technology.

A similar kind of critique has also been provided by Nordhaus (1973) who argues that the induced innovation theory is not different from a growth theory with exogenous technical change. If it would be, the firm would need to do two productive activities on its own: production and invention. If invention is not undertaken by the firm, invention would be exogenously given. In this case there would be some fixed costs to set up the new technology, but no further costs to the firm to utilize it. This implies that the firm would have declining average costs for its production, which is inconsistent with the assumption of perfect competition that the theory of induced innovation rests on.

Nordhaus goes on to distinguish between costless and costly shifts in technology, where the costless changes occur through movements along the existing production function (the choice between labour and capital intensity in production without any innovations), and the costly changes occur through an inward shift in the production function (introduction of new innovations). The larger the inward move is, the more costs are involved. Further, he adds that all changes in techniques in addition to being costly also carry uncertainty; you do not know exactly how the new technology functions in all respects. What he basically argues is that the progress of technology has time dependence in the sense that the possibilities for further technical change depends on what the direction of technical change has been so far.

The theory of induced innovation, contrary to this, assumes that there should be no "memory" in the innovation process. At all points only one single "isotech" (the curve along which you choose

[3] Building on Boserup, Kjaerby (1983) argued that technical change in Tanzanian agriculture, and particularly the spread of the ox plough, was explained by households' strive for high labour productivity (p 26). However, such a hypothesis has not held up empirically in other sub-Saharan contexts.

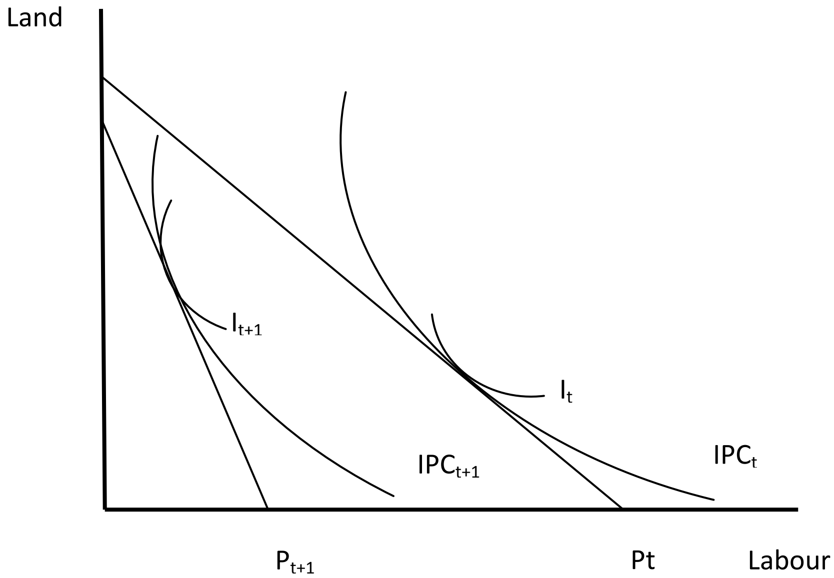
between different technologies) should be available, and this curve should be possible to attain without costs involved. These are very restrictive assumptions, Nordhaus argues before he goes on to show mathematically that such a special case is highly unlikely.

The overriding theme in the criticism of the induced innovation theory has been that technical change tends to be path dependent rather than occur in time independent ways (David, 1975). If a certain kind of technical change has been introduced, various factors, not least sunk costs, make it more likely that future technical change occurs along a path that has been initially chosen, rather than being guided by changes in relative factor prices.

In order to meet the criticism and build a more general theory, Ruttan (1996: 51ff) argues that a combination of the path dependency model of technical change and the microeconomic version of the induced innovation theory is to be preferred. He admits that the path dependent model has its merits in pointing to how important the sequence of historical events at the micro level is. But path dependency is only valid in industries with increasing returns to scale, he argues. When scale economies are exhausted and profits decline, the induced innovation will kick in again. In the longer run technical choice will be based on factor scarcity, according to Ruttan.

He further argues that the microeconomic version of the induced innovation theory should be distinguished from the growth theoretic version of the theory. Ruttan describes how the growth theoretic model of induced innovation, originally promoted by Kennedy (1961), got fundamentally criticized. In this model, the innovation possibility frontier is assumed to take on a downward sloping shape. But this, the critics pointed out, implies that labour (or capital) saving technical change should not affect the possibilities for, or the rate of, technical change that saves on the other factor. The model does not admit that there is a trade-off between labour- and capital-augmenting technical changes as the technical change progresses. Furthermore, the model has not really allowed for empirical testing, and it has remained a theoretical construct. Because of these reasons, it has more or less been abandoned.

Figure 1: Illustration of the induced innovation theory (micro economic version)



If labour becomes relatively scarce and hence the relative price of labour increases, the theory predisposes that innovations are induced by this price increase. Technical options, represented by innovation isoquants (I) are situated on an Innovation Possibility Curve (IPC) that serves as an envelope to all possible innovation isoquants – that is all possible combinations of the production factors (land and labour in this case). When the relative price of labour shifts from P_t to P_{t+1} , a new innovation isoquant is chosen (I_{t+1}), which implies that a less labour, and more land intensive technique is chosen. It is the shift in relative factor prices that induces research and diffusion of innovations along such a pattern.

As an improvement on Kennedy's version, a micro economic version of the induced innovation theory was developed by Ahmad (1966). This model works with a historically bound innovation possibility curve (IPC). This curve is made up of a large number of different isoquants, where each isoquant represents one of several possible production processes. All these production processes are determined by the current state of knowledge. However, the various techniques are not ready-made and free to choose from. Investments in research and development have to be undertaken if they are to be turned into innovations and put to productive work. When this is done, there are rather limited opportunities for substitution along the isoquants. The IPC is an envelope for all isoquants in the set of production processes that are possible to develop with a given amount of research and development costs (Ruttan, 1996: 45, 52).

Ruttan claims that there are differences in technical development and in productivity levels between countries that cannot be explained without reference to the micro economical historical events and patterns of technical choices. Further, he admits that there are differences between countries that cannot be overcome only by transfers of capital and technology. Still, he argues that the path dependent model will remain incomplete until it is integrated in the micro economic version of the induced innovation model (Ruttan, 1996:52f). A more general model will have to deal with some further challenges, according to Ruttan. It will have to integrate the factor induced with the demand induced models; and it will have to integrate induced innovation and path dependence with trade theory, he contends.

While arguing this, he admits that the major weakness of the microeconomic version of the induced innovation theory is that its internal mechanism in terms of learning, search and formal research and development processes remain unknown ("...inside a black box"). Further, he retains that the path-dependence model applies only in the presence of increasing returns to scale. This way, he goes on to argue that it is "…hard to believe that in a competitive environment technical competition would not result in a 'bending' of the path of technical change in the direction implied by changing factor endowments." He also argues that: "…a shift in relative factor prices can be expected to induce an intensified search for technologies along a ray that is more consistent with contemporary factor prices" (Ibid, p 53).

More recent works, building on the findings of the endogenous growth literature, have managed to provide a stronger micro-economic basis for the induced innovation theory (Acemoglu 2001, 2002 and Funk, 2002). The most important addition emerges when technical change is made endogenous to the model. This shift results in a new effect emerging: the effect of a growing market. While the price effect, as we have seen, induces technical change to be directed at raising the productivity of the scarcer factor of production, the growing market effect induces technical change to be geared towards raising the productivity of the more abundant factor of production. Hence, the two effects work in opposite directions. Whichever of these two effects that ultimately dominates depends on how high the elasticity of substitution is between the two factors of production is.

We have chosen not to dwell on this particular version of the induced innovation, for two reasons. The first is that, however elegant, mathematically and logically robust this version of the theory may be, it is very difficult to empirically test. In each different situation, any technical bias can be explained by referring to different values of the elasticity of factor substitution. The theory is not possible to refute, as long as we cannot independently find out the elasticity of factor substitution. Our level of ignorance is shifted from the question of technical bias, to the question of what drives the elasticity on factor substitution. As shown by Acemoglu himself, the theory lends itself to explanations of a lot of events and tendencies. However, as long as the theory is not possible to refute through empirical tests, we cannot use it as a scientific theory (Popper 1972:44f).

Furthermore, when trying to explain the elasticity of factor substitution, we will end up in the same deliberations on the relevance of path dependency for technical change and the roots of this path dependency as we do when discussing the original version of the induced innovation theory.

The other reason to disregard this version of the theory of induced technical change is that in the context where we will discuss it – smallholder agriculture in sub-Saharan Africa – it is hard to find any historical factor market expansions that would be able to explain an innovation bias towards the more abundant factor, be it land or labour. In most of the countries in this region factor markets have rather been characterized by mal-functioning or fractured market mechanisms, badly functioning or limited market institutions or missing infrastructures. Further, the technical options available to smallholder agricultural producers tend to be highly complementary in character. Hence, we would expect the price effect to dominate over the market effect.[4] That implies that it is the induced theory of innovation in its more original form that ought to be analysed and discussed.

An institutional approach to technical change

To what extent does Ruttan manage to save the theory of induced innovation? Actually, he provides no empirically based arguments to support his position, only reasoning and assessments of probabilities. He does this, even though he earlier referred to how Salter (1960) had criticized Hicks' hypothesis of induced technical change. Salter had argued that in a competitive equilibrium, all the different factors would be used to the extent that their marginal value products equal out. Hence, in such situations, it does not matter which factor is saved through technical change, since all changes would be equally profitable. Ruttan counters by claiming that if either the capital- or the labour share is larger in the prevailing technology, entrepreneurs will choose technical change that save on the factor with the larger share, until a balance with equal shares of the productive factors is established. The reason for this is that the savings achieved would be proportionally larger as long as one factor represents a larger share in the production process (Ruttan, 1996:44).

We have referred to two positions claiming that the factor bias of technical change is an open empirical question (Acemoglu, 2002 and Salter, 1960). Still, the biggest challenge to the induced innovation theory comes from the path dependence model. Ruttan admits that the path dependence approach has merit, especially when it comes to the micro economic foundation, which the induced innovation theory has had so many problems with. Even so, Ruttan holds that path dependency is only applicable in cases of economies of scale. When these decline, and over the long run, factor scarcity will steer the direction of technical change.

When Ruttan discusses path dependency he refers to David (1975) who outlined a few central concepts and processes underlying path dependency: a) linear fixed-coefficient processes; b) a limitation in the number of potential processes that could be designed with the existing state of knowledge; c) localized learning that directs technical change toward the origin along a specific process-ray and d) a probabilistic learning process bounded by the firms' initial level of technology. These concepts make for a search process in which the firm's initial myopic selection of a technical process that at least over some time will influence the future course of development (Ruttan 1996: 47).

A closer look at just one of these elements – the localized learning process – points to factors that make the path dependency theory more thorough than it appears in Ruttan's description. There might be indivisibilities not only in goods, but also in terms of social processes, and in particular in the build-up of knowledge. In the perspective of Veblen (1921: 28) production depends on a "joint stock of knowledge derived from past experience". The knowledge needed for innovations cannot be individually owned or controlled, since it necessarily involves the practices of a whole industrial community, and constitute "the immaterial residue of the community's experience" (Veblen 1908:

[4] In the notation of Acemoglu the elasticity of factor substitution, $\sigma < 1$, indicating that technologies are complementary to each other, rather than substitutes.

539f). Of course, technologies and technical knowledge are transferred from one place to another, and may as well be captured by single individuals. But technologies still constitute a common stock of knowledge, which is held and carried forward by the community. Innovations are done as additions to, or alterations of, existing processes of production, rather than as completely new sets of production systems. Learning is potentially a process of positive feedback between the individual and society (Hodgson 2008:30). Seen more widely, such a more collective perspective on knowledge and innovation opens up for the importance of institutions in relation to technical change – what are the formal and informal rules that guide research and innovation processes and the allocation of resources to such processes? We will return to this discussion later.

Even Ruttan discusses the importance of institutions and institutional change for technical change to come about. Not least, if actors within the research sector shall be able to react and to adjust their research and development activities based on relative factor price signals, functioning institutional structures would be needed. On this point, Ruttan admits that there is a challenge. We may as well note that his way of phrasing it indicates that he has a very instrumental view on institutional change:

"Incentive compatible institutional design – the design of institutions capable of achieving compatibility among individual, organizational, and social objectives – remains at this point an imperfect art. The incentive compatibility problem has not yet been solved even at the most abstract theoretical level. It represents, however, a missing link in the effort to harness induced technical change and path-dependent technical change theories…" (Ruttan 1996:56).

How a process of institutional change comes about is highly contested. What position one takes may partly depends on how one defines institutions. However, there is general agreement among social scientists that institutions defined as some form of "rules of the game" tend to be sticky, and change only slowly. This is one of the remaining challenges for Ruttan and others working in the framework of the induced innovation theory.

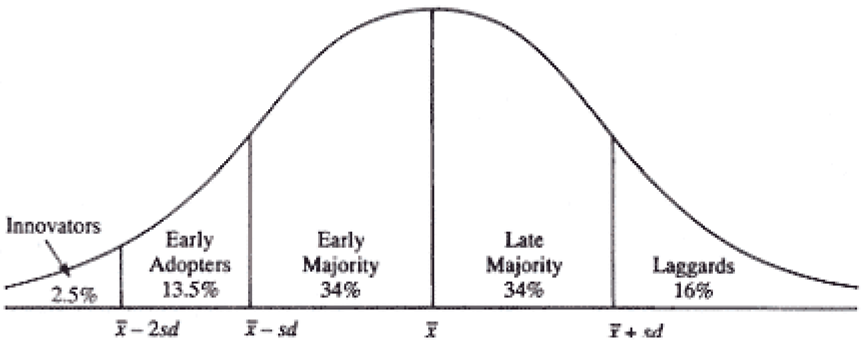
To sum up so far, some essential challenges have emerged from this discussion. These include the more precise character of the mechanism that translates relative scarcity of specific production factors into innovations; The more precise role of institutions in relation to technical change; And the ways path dependency is created in technical change. We will bring these challenges with us into a continued discussion about innovation in sub-Saharan small scale agriculture.

Theories of innovation diffusion and systems

Situating social learning and the "joint stock of knowledge derived from past experience" in a sub-Saharan context implies that indigenous institutions and social relations come to the fore. One theoretical approach that resonates with path dependence perspectives is the "diffusion of innovation"-theory. This theory was first developed by Ryan and Gross (1943) based on a study of hybrid corn seed diffusion in Iowa, USA. From the mid 1960s onwards the theory was developed and adopted to research in developing countries. Rural sociologists based in the US were instrumental, and particularly important was Everett Rogers from the University of New Mexico. After a peak in the late 1960s, the theory spread to other scientific areas, and turned into more of an interdisciplinary field (Valente and Rogers, 1995).

The theory builds on the observation that innovations generally are not widely adopted at first – even if their advantages may be quite convincing. Adoption rather forms S-shaped curves over time, and at the heart of innovation diffusion is exchange of information and communication about the new idea. This puts relations at the core of the theory. Different communication channels are used at various stages of the process. The theory distinguishes between different groups of adopters based on their personal characteristics: innovators, opinion leaders, early adopters, early and late majority as well as laggards. Innovators tend to travel and read widely and to have a cosmopolite orientation. These people are the ones that first adopt new ideas and innovations. However, the most innovative members of a society are often perceived as somewhat odd, and often have low credibility in the eyes of others. Therefore, information and advice on the innovation is brought to the majority by opinion leaders and change agents. Opinion leaders are characterized by being more exposed to external communication, having somewhat higher social status and being more innovative than the average member of society. The degree to which leaders can influence change depends on societal norms. If they bring changes too far, they will lose status. Change agents are external actors that try to influence social practices in a particular direction. These agents are often professionals who promote or try to hinder the adoption of innovations. The change agents rely on the opinion leaders to help them in these processes (Rogers, 1962:23-28).

Figure 2: Various categories of adopters in the innovation diffusion process



Because of the characteristics of involved agents, processes of innovation diffusion tend to follow path dependent patterns. A social system, for instance a village, tends to adopt the technology that has been introduced through the initiative of opinion leaders and change agents. Once the adoption process takes off to reach early and then late adopters, a particular technology tends to dominate in that particular village. This technical change may, or may not, save on the scarce production factor. Factor scarcity is not the reason why it is introduced and adopted. It is adopted as a result of a communication process, which is conditioned on the characteristics of the involved actors.

The innovation diffusion theory has been criticized for being too focused on the relations, and for not understanding the importance of cultural linkages. The criticism is based on empirical findings of more rapid and unstructured diffusion than predicted by this theory (Strang and Meyer, 1993:489, Ikenberry, 1989). The explanation provided is that some concepts and ideas have been institutionalized in globally, or at least widely, spread cultural categories (Strang and Meyer, 1993:493). But this argument can also be seen from another angle: in cultural categories where localized concepts and ideas have been institutionalized, we might even see a slower diffusion than predicted by the innovation diffusion theory.

The innovation diffusion theory has been expanded with the help of the innovation system approach (Lundwall, 1985, Freeman, 1987, Nelson, 1988, Edquist, 1997). The latter approach refers to “system” as “a set of interrelated components working toward a common objective” (Carlsson et al, 2002:234). Central entities in an innovation system are actors, relations between these actors and institutions. Improved feedback between the components makes the innovation system more dynamic, and better able to generate, diffuse and utilize technologies (Sumberg, 2005:24). Whereas the communication process, and thereby relations, drives technical change according to the innovation diffusion model, it is rather the wider institutional context that is in focus in the innovation system model. The innovation system approach brings all relevant pieces together, including the actors, but focuses in particular on the institutional aspects of innovation – an area where the theory of induced innovation has less to offer, as we saw above. The innovation system may be described as a neo-Schumpeterian approach (Spielman 2005:8f, 17, 43) and as such, distinct from the factor induced approach to technical change, which focuses on the link between allocative and dynamic efficiency.

From the innovation system approach we may conclude that it is the interplay (feedback) between institutional change and technical change that drives technical change. It will not occur unless institutional change of some kind occurs; institutional change may be provoked and enabled by technical change (however, it may occur for other reasons as well). It is this interplay between technical and institutional change that may be referred to as the process of innovation.

When the innovation system first was developed, it emerged as an extension of Friedrich List’s concept of “national production system”. List wrote in criticism of Adam Smith’s idea of the “invisible hand” promoting economic growth, and where free trade was assumed to be beneficial for both strong and weak economies. In contrast, List’s project was a government initiated build-up of infrastructure and institutions needed for promoting economic growth and development, as a strategy for a “catching-up” economy in the early 19th century Germany (Lundvall, 2007:113). When the innovation system theory was developed by Freeman (1982), it emerged in the spirit of List, and the first concept used was “national system of innovation”.

The approach has mainly been applied to rich countries, and more often as an ex post concept than ex ante (Lundvall, 2007:112). However, in the context of poorer countries it may be more relevant to study the building up of innovation systems, since many of its constituting elements and their interrelations are beset with weaknesses and defaults. Further, when innovation system approaches are discussed or applied in developing country contexts a common argument emerging is that further studies on the institutions that condition the frame and condition the behavior of agents involved (Spielman, 2005:44, Lundvall, 2007:117, Sumberg, 2005).

This analysis concurs with the analysis emerging from the induced innovation theory (Ruttan, 1996), albeit differing in central aspects. Whereas Ruttan is preoccupied with how to reconcile diverging incentive structures (which stems from the institutional structure), authors within the innovation systems tradition are more preoccupied with how the innovation process is embedded in an institutional environment. While Ruttan argues that the incentives derived from the relative factor prices in most cases eventually will dominate the process of technical change, the proponents of the innovation system approach argue that this will depend on the institutional setting.

Lines of division concern the level and persistence of technical stickiness. This in turn depends on how the origin and endurance of path dependency is explained.

From the descriptions above, we have seen that path dependency is explained in various different ways. Ruttan ascribes path dependency to economies of scale, and argues that in the longer run, and under the influence of competition, path dependency will be overcome.

Paul David (2007:102), who is the main architect behind the path dependency model, claims that this statement simply is wrong. The presence of irreversibility at the micro level is on its own sufficient to create path dependency. Therefore, there is no necessary connection between path dependency and indivisibilities of goods produced or exchanged. Hence, no connection between increasing returns and path dependency is necessary, since path dependency may appear anyhow. The irreversibility that David is referring to may be “sunk costs”, which are costs that are not possible to recover. These may for instance be investments in physical structures, in human capabilities or in knowledge assets. But the irreversibilities may also concern coordination failures and externalities affecting non-market interaction (Ibid, p 101, 104).

More systematically, David classifies the roots of path dependency into three groups (1994: 208f):

a) The importance of history in forming mutually consistent expectations that in turn enable coordination between agents (collective action) without depending on centralized orders. The establishment of socially established conventions (norms) aligns the expectations of individuals and makes it possible to select one out of many solutions to a coordination game.

b) The importance of history in establishing resemblance between different information channels and behavioral codes, which are essential for efficiency in all kinds of organizations. An organization needs to filter and compress information into usable formats. This is done through the use of established codes;

c) The importance of history in creating interrelatedness among central elements of complex organizations. Functions are much better performed if fitted together in a particular way, where one function may help another. This may be seen as economies of functional interaction.

All three of these groups provide explanations on a micro level to why path dependency emerges and tend to persist. It is further obvious that these roots of path dependency are situated in the institutional context of economic actors – an argument which fits squarely with the innovation systems approach.

Analysis of theoretical positions

To understand the possible stickiness of technology use in sub-Saharan African agriculture, we need to dwell on how these roots of path dependency actually play out in local contexts. In doing so, we simultaneously put various theoretical approaches to technical change to test. But before doing that there is a need to clarify what the main lines of distinction are between the theoretical approaches. We do this by way of an illustrating table:

Figure 3: Major theoretical dividing lines in technical change

		Forms of innovation dynamics	
		Linear	**Interactive**
Sources of technological path dependency	**Economies of scale**	Induced Innovation; E. Boserup	Innovation Systems (?)
	Mechanisms for collective coordination	Diffused Innovation; P. David	Innovation Systems

Most of these concepts are self explanatory, or have been described already. However, some need to be commented on. In figure 3 a number of different arguments are lumped together under the label "mechanisms for collective coordination". David's three groups of arguments are all in some way related to mechanisms for achieving collective action or coordination: shared expectations, shared information channels and norms, as well as the interrelatedness of central elements of complex organizations. The latter may were referred to as "economies of functional interaction", which may clearly be contrasted to "economies of scale". It is possible that yet other arguments about the sources of technical path dependency might be placed under this label.

The "interactive innovative dynamics" we refer to concern the interplay between technical diffusion and social norms and institutions, which is characteristic of the innovation systems approach. It may be argued that also the innovation diffusion approach should be placed in this box, since there is some form of interaction between the various kinds of agents in that approach. However, seen over longer terms, it is a matter of whether innovations get spread or not, rather than a matter of social transformation in the process. This is an important difference between the innovation diffusion and the innovation systems approaches.

The innovation systems approach is placed in both of the right-hand boxes in order to indicate that both these are possible positions within that approach, whereas most of the proponents probably would place themselves in the lower box.

A difference between the linear and interactive innovation dynamics positions is that linear models assume that an independent driver of change exists, and eventually will be able to implement technical changes regardless of context. What constitutes the driver is not always clear, but it is related to the human will to improve her situation. Interactive models compromise the driver of change in the sense that the outcome is also dependent on transformations of human interaction in the context and environment where technical changes are introduced.[5]

When opening up for the possibility that technical change is not necessarily driven only by external "drivers", but may be the result of interplay between social entities, the innovation system approach needs to study factors like the following;

- The importance of resource access for technical change;
- The influence of risks and uncertainty on technical change;
- The role of knowledge and social learning for technical change.

All these three may potentially hinder technical change. If they do, this would be most probable in settings where these three are in short supply, such as in small-holder agriculture in sub-Saharan Africa.

The sub-Saharan Africa small-holder context

What could a typical local situation look like in a sub-Saharan agricultural small-holder setting? There would of course be substantive differences between various countries, geographical regions, agro-ecological zones and societal types. Still, there might be commonalities between agricultural systems that to large degrees are of subsistence type and only partly market oriented; where land is distributed through customary tenure systems; where women and men tend to have distinct roles in production and reproduction and where most of the cultivation is rain-fed.

A widespread characteristic of small-holder agriculture in sub-Saharan Africa is that the household is the basic production unit, but at the same time subject to specific interrelationships between household members. Crop cultivation takes place through various forms of labour division and – mobilization within the family. Clearly defined roles and responsibilities are generally given to women, men, young and elderly. However, these roles form a pattern, which makes it possible to regard the household as a basic production unit.

Another fairly common pattern in African farming systems is to cultivate relatively small plots of land. Cultivation on some of these plots – the household fields – is the responsibility of household heads, which implies that these plots are cultivated through common family efforts. In addition, individual plots are cultivated – often with complementary crops, which could be cash crops. The degree of integration of such individual fields into the household economy may vary, but certain kinds of labour division follows from this way of organizing production.

With the possible exception of parts of settler economies, such as Kenya (with its system of individual land titling), land markets are uncommon or weakly developed in sub-Saharan Africa. Most land is distributed through customary tenure systems, where communal control over land is a common

[5] This is the reason why price as a mechanism should not be interpreted as "interactive". Hence, the induced innovation approach is to be placed in the left hand box.

element, where rights to land may come in various forms, and may be distributed to more than one agent for the same plot of land. It is furthermore common that religious and metaphysical ideas influence the relationship between people and their lands (Jacoby, 1971).

Due to the fragility of food production in systems that are rain fed, the levels of risk in food production, and in agricultural production in general, are very high. At times, it may even be relevant to use the concept of uncertainty, since volatility is so high and combinations of events so unpredictable that it is impossible to ascribe probabilities to them occurring. In situations where risk and uncertainty is predominant, insurance systems based on social relations and diversified livelihoods are common and widespread (Berry, 1993). An emerging literature points to major economic inefficiencies stemming from high levels of risk in production and livelihoods. In the presence of high production risk, investments in social relations are undertaken as security measures. This implies sub-optimal allocation of resources, and foregone income opportunities of important dimensions (Elbers et. al., 2007, 2009, de Laiglesia, 2006, Christiansen and Sarris, 2007).

In situations with these characteristics it would be expected that there is substantive interplay between factors such as internal household relationships, the size of cultivated plots and technical solutions. Changes in technology would impact on household relations, as well as on land distribution patterns and land rights. To give a very simple example: if a technical change leads to increased production on household fields with the same amount of work, that would imply shifts in the relative allocation of worked hours on household versus individual fields, and therefore in intra-family economic relations. That such interplay may be a general characteristic of agriculture in sub-Saharan settings is made probable by Hall and Clark (2010).

It would furthermore be expected in the typical situation described that much effort is geared towards establishing collective security systems. African societies are often described as being collectively oriented, and characterized by egalitarian norms (Fafchamps, 1999, Platteau, 2000, 2009, de Laiglesia, 2006). Upholding of social relations, and of social structures are important elements of livelihoods and security systems. The establishment of institutions that serve the function of enabling collective action seems evident. Hence, we would expect institutions to be established, and become sticky, because of their ability to contribute to collective action (de Laiglesia, 2006). It is due their stickiness that institutions enable collective action. This in turn implies that path dependency emerges.

The descriptions of peasant agriculture in sub-Sahara given above are very general in character. This is due to the high level of diversity in prevailing farming systems. If there is anything truly general to these farming systems, it is that they need to be understood in their institutional and wider societal context. Still, we have pointed at some common patterns that already provide a basis for theoretical inferences.

What would such societal contexts that we mention here look like in practice? What are the concrete and tangible examples of situations and institutions that are relevant in the context of technical change? Based on data from the Ethiopian Rural Household Surveys from the first half of the 1990s, Dercon and Christiansen (2005, 2008) found that peasants use significantly lower rates of fertilizer when faced with ex-post risk of lower consumption. Applying fertilizer lead to higher yields given good rains. However, if the rains fail, so will the harvests, and the end result is that money spent on fertilizers are spent in vain. When peasants live on a really minimal budget, they tend to avoid buying such risky inputs. They thereby forego the increased yields that would follow in times of good rains. Dercon and Christiansen found this effect significant even after testing for current levels of liquid assets, and for the seasonal unavailability of credits.

Elbers and Gunning (2003, 2007, 2009) use econometric methods based on simulations applied to panel data from rural Zimbabwe. They find that risk substantially reduces growth, which in this particular case imply that the capital stock is reduced by more than 40 percent when households apply measures to deal with risk. Hence, even in this case, the effect comes about through ex-ante strategies applied by households to minimize the impact of risk. Elbers and Gunning conclude that households invest in various indigenous institutions to cope with risk, and that such investments implies significantly reduced growth.

These latter studies deal with the issue of long term effects from risks on growth, and not directly with technical change and innovations. However, their findings have direct relevance also for technical change. The *combination* of minimal resources, the lack of credit and insurance, and the presence of high risks create situations where peasants avoid risky agricultural inputs. Instead they hang on to institutions that may provide some basic insurance – often through the upholding of personal relations – but at the same time imply foregone opportunities.

What has been discussed may be described in terms of poverty traps. But this combination of factors is also highly relevant for technical change. Most technical changes involve the introduction of new inputs into production, and when there are costs involved, this also increases risk, as seen in the case of fertilizer in Ethiopia. Under different circumstances technical change is actually possible in similar situations. This is indicated by studies on khat cultivation in Ethiopia. Khat is a drug and a cash crop with high levels of profitability, and where well functioning market structures are in place. In order to increase the productivity and profitability in khat cultivation, peasants willingly, and without outside support, introduce new techniques and increase the use of fertilizer – in sharp contrast to the areas that Dercon and Christiansen studied. Such changes are also introduced despite having substantial negative effects on the prevailing culture, on certain social relations and on the cultivation of other crops (Dessie and Kinlund, 2008, Dessie, personal communication, 2010).

We conclude that it is the *combination* of factors – resource access, measures to deal with risk, the institutional setup, as well as availability of improved techniques – that matter. This is an important reason why the innovation system approach is the most fruitful theoretical approach to apply to technical change in sub-Saharan agriculture. Since the approach is interactive, it enables the inclusion of not only a number of different factors, but also to deal with the institutional changes that are necessary for technical change to occur.

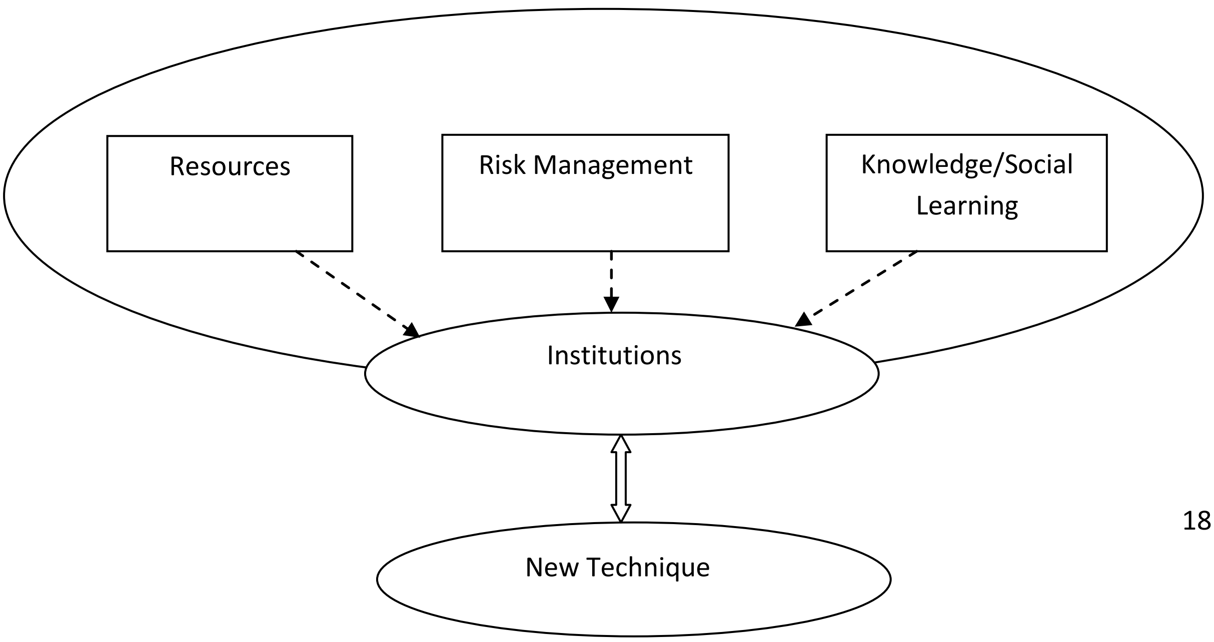
Another important factor to include in the scheme is knowledge and knowledge transfers. In particular, we should focus on social learning, given Veblen's insight (1921) that technical changes always builds on societies' cumulative knowledge. Social learning is in itself a very vast field of research, which is impossible to fully grasp in this context. Still, it seems to be a necessary element to any innovation system approach. Lacking, or improper, knowledge has been observed as a hindrance to adoption of techniques, as well as a hindrance to the use of their full potential (Foster and Rosenzweig, 1995, Ellison and Frudenberg, 1995).

Ellison and Frudenberg (1993) theoretically show that in settings that are not overly complex, but where information about technologies and their outcomes is too intricate to process, simple “rules of thumb” may result in fairly efficient long-term outcomes. Even selection based on the popularity of a technique may serve as a basis for such outcomes, since popularity may serve as a proxy for the historical performance of the technology (Ibid: 613f). So when people look at what technique their neighbours use, and when they don’t have too narrow outlooks geographically and conceptually, (“window width” in the E&F terminology) efficient techniques will eventually spread and be adopted. However, this would not be the case in more complex settings, such as in sub-Saharan small-holder agriculture, following the argument of Munshi (2004). Based on a comparison of wheat and rice farmers in India, Munshi argues that wherever growing conditions for a crop are more heterogeneous – as in rice cultivation compared to wheat – there is less learning from neighbours taking place.

In a sub-Saharan small-holder agricultural setting, what is needed is wider understanding of the concept of social learning. Rather than learning by doing (Arrow, 1962) or learning by using (Rosenberg, 1982), it is learning by interaction (Andersen and Lundvall, 1988) that we should look at. The latter encapsulates the necessary interaction between designers of techniques, diffusion agents and users. There is a need for functional feedback mechanisms between these. There is also need to see the synthesis of innovation and diffusion when things are implemented, when the technique eventually will be put to work, “innofusion” as Fleck (1988) has phrased it. Users have to transform techniques to put it to use in their particular environment, their culture. The technique, the artefact, needs to be *translated* into a new setting (Latour, 1987, Sörensen, 1997). This is where social learning comes in as an interactive process both in terms of interaction between agents, and in terms of interaction between the technique and the social environment. The main reason why interaction is of such importance in this particular setting is the diversity of conditions – agro-ecological, topographical and not least institutional – that characterize African small-holder farming systems. Relevant social learning will not take place without dense feed-back loops.

We may now summarize the central elements within an innovation system for sub-Saharan agriculture. The following factors need to be considered within the framework of a system:

Figure 4: Central components of innovation systems in sub-Saharan small-holder agriculture



What the figure describes is that resources, risk management and knowledge need to be simultaneously catered for in the sub-Saharan small-holder agriculture setting, where these are in particular short supply or complicated. Furthermore, it is institutions, in the form of rules, norms and standards, which organize solutions to the collective action problems that consist of providing these factors in a coherent way. There would certainly be interaction between the factors themselves. However, this is not what we focus on here. The figure illustrates that these institutions exist that solve coordination problems especially around these three factors in some combination.

The institutions we are dealing with take the form of particular intra-village and –household relationships, including gendered and other social castings; or it may take the form of localized risk sharing through for instance intermarriages, patron-client relationships, customary land tenure systems, or the adherence to certain crops or cultivation patterns. Such institutions are mostly non-official and may be characterized by their tendencies to share information through hierarchic structures and to be underpinned by egalitarian norms (de Laiglesia, 2006:32, Hårsmar 2004). These institutions are not necessarily established with the primary purpose of solving the above mentioned coordination problems. Institutions should not be explained functionally. However, since they are proven effective in solving coordination problems as well, this strongly contributes to their stickiness.

In the study of introduction of new techniques, the interplay of primary interest concerns the new technique and institutions, rather than the new technique and the factors as such (risk, resources and social learning). When new technical solutions are introduced, these have to interact with the institutional set-up that solves collective action problems. Strang and Meyer's argument about theorizing of general models (1993: 492f, 506) claims that diffusion is greatly enhanced by commonly shared concepts and ideas. What they also find, and what is more relevant here, is that diffusion is halting when practices are to spread across communities of specialized theorists (Ibid: 494). When commonly shared concepts and ideas are localized rather than global, diffusion becomes more difficult. The introduction of a new technique becomes possible as long as it fits the prevailing indigenous institutional set-up. Otherwise its adoption would demand that a change in institutional set-up occurs through interaction between these two entities. This is the fundamental reason why we see path dependency and inertia in the adoption of new techniques.

To sum up, we retain from the theory of induced innovation, and Boserup's thesis that central driving forces behind technical change is a combination of resource scarcity and the human willingness to improve her/his situation. But the mechanism translating factor resource scarcity into innovation is not the straightforward one that this theory has assumed. A more complex interplay takes place. From the theory of innovation diffusion, we retain the centrality of relations. But without the insights from the innovation systems approach that the interplay between indigenous institutions and technical solutions is absolutely essential, we would not be able to explain processes of technical change in sub-Saharan African smallholder agriculture. In addition, the roots of the prevailing path dependency are to be sought in functions related to collective action and economies of functional interaction around central challenges.

Conclusion

The essential issue of what drives technical change, and how the innovation process unfolds, has been discussed during decades. A number of theoretical approaches have been proposed and developed, most of which have been developed and tested in industrialized societies. It has been proposed that such theories may be able to explain technical change in agriculture in poor countries, such as those in sub-Saharan Africa, as well.

Our discussion has shown that the theory of induced technical change, with its focus on relative factor prices, has little merit in sub-Saharan Africa when it comes to small-holder agriculture. However, what it contributes is an understanding of the central driving forces behind technical change. The theory of innovation diffusion may be somewhat more relevant by focusing on the importance of relations for the diffusion of new ideas and technique. Nevertheless, it fails to capture essential characteristics of the relationships that enable innovation diffusion. It is rather the innovation systems approach that has a greater potential in explaining how processes of technical change unfold in sub-Saharan small-holder agriculture. In particular, it is the emphasis on feedback loops, and the interplay between societal institutions and technical change that is important. Furthermore, prevailing path dependency in technical change ought to be explained by sticky institutions. The stickiness of such institutions emanate to a large degree from their capacity to enable collective action. In particular, it is in the nexus of lacking resources, high production and market risk and complex social learning where indigenous institutions manage to coordinate solutions. This has led to the longevity and stickiness of institutions that in many ways limit the scope for technical change.

This leads us to focus on intensified studies of the role of indigenous institutions in explaining the degree of technical change in sub-Saharan African small-holder agriculture. If such institutions are sticky and slow to change, so would also the rate of technological change be. Efforts to raise agricultural productivity would thus be more effective if the institutional set-up is taken into due consideration. Alternative solutions to risk management under scarce resource and complex social learning conditions should be sought. Generalized and simple to understand programmes for social protection may be one option that might have effects on the rate of innovation in small holder farming in sub-Saharan Africa.

References

Acemoglu, D., 2001; "Factor Prices and Technical Change: From Induced Innovation to Recent Debates", *Working Paper* 01-39, MIT, Department of Economics, Cambridge.

- , 2002: "Directed Technical Change", *Review of Economic Studies*, Vol 69: 781-809.

Ahmad, S., 1966: "On the Theory of Induced Investment", *The Economic Journal*, LXXVI (June 1966), 344-357.

Andersen, E.S. and B-Å. Lundwall, 1988: "Small national systems of innovation facing technological revolutions: an analytical framework", in C. Freeman and B-Å. Lundwall (eds): *Small countries facing the technological revolution*, Pinter, London.

Arrow, K., 1962: "The economic implications of learning by doing", *Review of economic studies*, 29, 155-173.

Azariadis, C. and J. Stachurski, 2004: "Poverty Traps", *Research Paper No 913*, University of Melbourne.

Barrett, C.B., M.R. Carter and M. Ikegami, 2008: "Poverty Traps and Social Protection", Working Paper, Social Science Research Network.

Berry, S. 1993: "No Condition is Permanent – The Social Dynamics of Agrarian Change in Sub-Saharan Africa", Wisconsin Press, Madison.

Binswanger, H.P., 1986: "Evaluating Research System Performance and Targeting Research in Land-Abundant Areas of sub-Saharan Africa", *World Development*, Vol 14, No 4.

Binswanger, H. and P. Pingali, 1988: "Technological Priorities for Farming in sub-Saharan Africa", *The World Bank Research Observer*, Vol 3,No 1:81-98.

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

Boserup, E., 2008 (1965): *The Conditions of Agricultural Growth – The Economics of Agrarian Change under Population Pressure*, Aldine Transaction, New Brunswick, USA and London, UK.

Carlsson, B., S. Jacobsson, M. Holmén and A. Rickne, 2002: "Innovation Systems: Analytical and methodological issues", *Research Policy*, Vol 31, pp 233-245.

Carter, M.R., 1997: "Environment, Technology, and the Social Articulation of Risk in West African Agriculture", *Economic Development and Cultural Change*, pp 557-590.

- , 2008: "Inducing Innovation: Risk Instruments for Solving the Conundrum of Rural Finance", Paper presented at 6th AFD/EUDN Conference, Paris.

Christiaensen, L. and Sarris, A. 2007: "Rural household vulnerability and insurance against commodity risks – Evidence from the United Republic of Tanzania", FAO, Trade and Markets Division, Rome, Italy.

David, P.A., 2000: "Path dependence, its critics and the quest for 'historical economics'", in Garrouste, P. and S. Ioannides (eds): *Evolution and Path Dependence in Economic Ideas: Past and Present*, Edvar Elgar, Cheltenham, England.

- ,2007: "Path dependence: a foundational concept for historical social science", *Cliometrica*, Vol 1:91-114.

De Laiglesia, J.R. 2006: "Institutional Bottlenecks for Agricultural Development", *Working Paper 248*, OECD Development Centre, Paris.

Dessie, G. and P. Kinlund, 2008 : "Khat Expansion and Forest Decline in Wondo Genet, Ethiopia", *Geografiska Annaler, Series B, Human Geography*, Vol 90:2, pp 187-203.

Dupré, G. and D. Guillaud, 1988: "L'agriculture de l'Aribinda (Burkina Faso) de 1875 à 1983 – Les dimensions du changement" in *Cahier Science Humanitaire*, Vol 24:1, pp 51-71.

Edquist, C and O. Edqvist, 1973: "Social Carriers of Techniques for Development", *Journal of Peace Research*, Vol 16:4, pp 313-331.

Edquist, C., 1997: *Systems of Innovation Approaches : Technologies, Institutions and Organizations*, Pinter, London.

Elster, J., 1983: *Explaining Technical Change- Studies in Rationality and Social Change*, Cambridge University Press, Cambridge, UK.

Elbers, C. Gunning, J-W and Pan, L. 2009: "Growing out of Poverty under Risk: Evidence from Rural Ethiopia", Department of Economics, VU University, Amsterdam and Tinbergen Institute, Amsterdam.

Elbers, C. Gunning, J-W, and Kinsey, B. 2007: "Growth and Risk: Methodology and Micro Evidence", *The World Bank Economic Review*, Vol 21, pp 1-20.

Ellison, G. and D. Frudenberg, 1993: "Rules of Thumb for Social Learning", *Journal of Political Economy*, Vol 101:4, pp 612-643.

Ellison, G. and D. Frudenberg, 1995: "Word-of-Mouth Communication and Social Learning", The Quarterly Journal of Economics, Vol. 110, No. 1 (Feb., 1995), pp. 93-125.

Fafchamps, M., 1999: "Rural Poverty, Risk and Development", FAO Economic and Social Development Paper 144, FAO, Rome, Italy.

Faure, G., 1994: "Mécanisation, productivité du travail et risques: le cas du Burkina Faso", *Economie rurale*, No 219, pp 3-11.

Fellner, W., 1971: “Empirical Support for the Theory of Induced Innovation”, *Quarterly Journal of Economics*, Vol. LXXXV, pp 580-604.

Fleck, J., 1988: "Innofusion or diffusation? The nature of technological development in robotics", *Edinburgh PICT Working Paper*, No. 4.

Foster, A.D. and M.R: Rosenzweig, 1995: “Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture”, *Journal of Political Economy*, Vol 103:6, 1176-1209.

Freeman, C., 1982: “Technological Infrastructure and Infrastructure Competitiveness“, (mimeo) Draft paper to the OECD ad hoc group on Science, Technology and Competitiveness, OECD, Paris.

- ,1987: *Technology Policy and Economic Performance: Lessons from Japan*, Pinter, London, U.K.

Funk, P. 2002: “Induced Innovation Revisited”, *Economica*, Vol 69, pp 155-171.

Goldman, A., 1993: “Agricultural Innovation in Three Areas of Kenya: Neo-Boserupian Theories and Regional Characterization”, *Economic Geography*, 69,1: pp. 44-71.

Guillaumont, P., 2009: “Caught in a Trap – Identifying the Least Developed Countries”, *Economica*, Paris.

Hall R.E. and C.I. Jones, 1999 “Why do Some Countries Produce so Much More Output per Worker than Others?”, *Quarterly Journal of Economics*, Vol 114, No 1:83-116.

Hayami, Y. and V.W. Ruttan, 1970: “Agricultural Productivity: Differences Among Countries”, *American Economic Review*, Vol 60, No 5: 895-911.

- ,1971: *Agricultural Development: An International Perspective*, Johns Hopkins University Press, Baltimore.
- ,1987: “Population Growth and Agricultural Productivity” in Johnson, D.G and R.D. Lee (eds) *Population Growth and Economic Development: Issues and Evidence*, University of Wisconsin Press, Madison.

Hicks, J., 1932: *The Theory of Wages*, McMillan, London 1st ed., 2nd ed. 1963.

Hodgson, G.M. 2008: “The Emergence of the Idea of Institutions as Repositories of Knowledge” in Ebner, A and N. Beck (eds) *The Institutions of the Market: Organizations, Social Systems and Governance*, Oxford University Press, Oxford, UK, pp 23-39.

Ikenberry, J., 1989: “Explaining the Diffusion of State Norms: Coercion, Competition, and Learning in the International System”, paper presented at International Studies Association, London, UK.

Jacoby, E.H, 1971: “Man and Land – the Fundamental Issue in Development”, André Deutsch, London, UK.

Kaboré, D. and C. Reij, 2004:”The Emergence and Spreading of an Improved Traditional Soil and Water Conservation Practice in Burkina Faso”, *EPTD Discussion Paper* No 114, IFPRI, Washington D.C.

Kennedy, C., 1964: “Induced Bias in Innovation and the Theory of Distribution”, *The Economic Journal*, LXXIV (Sept 1964), 541-547.

- , 1966: “Samuelson on Induced Innovation”, *Review of Economics and Statistics*, XLVII (Nov 1966), 442-444.

Kjaerby, F. 1983: “Problems and Contradictions in the Development of Ox-cultivation in Tanzania”, *Research Report No. 66*, The Nordic Africa Institute, Uppsala, Sweden.

Latour, B., 1987: *Science in action*, Milton Keynes: Open University Press.

Lele. U. and S.W. Stone, 1989: “Population pressure, the environment and agricultural intensification – variations on the Boserup hypothesis”, *MADIA Discussion Paper 4*, World Bank, Washington D.C.

Lundwall, B-Å. 1985: “Product Innovation and User-Producer Interaction“, Aalborg University Press, Aalborg, Denmark.

- ,2007: “National Innovation Systems – Analytical Concepts and Development Tool “, *Industry and Innovation*, Vol 14:1, pp 95-119.

Marchal, J.Y., 1982: “L’option pour l’”extensif”. L’évolution de l’agriculture mossi (Haute Volta)” in *Economie rurale*, No 147-148, pp 63-67.

Munchi, K., 2004: “Social learning in a heterogeneous population: technology diffusion in the Indian Green Revolution”, *Journal of Development Economics,* Vol. 73, pp. 185–213.

Nordhaus, W.D. , 1973: “Some Sceptical Thougts on the Theory of Induced Innovation”, *Quarterly Journal of Economics*, Vol. LXXXVII, pp 208-219.

- , 2002: “Modeling Induced Innovation in Climate Change Policy”, in Grubler, A., N. Nakicenovic and W.D. Nordhaus (eds): *Modeling Induced Innovation in Climate Change Policy*, Resources for the Future Press.

Nelson, R.R., 1988: “National Systems of Innovation : Institutions supporting technical change in the the United States“ in Dosi, G., C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds): *Technical Change and Economic Theory*, pp 309 – 329, Pinter, London.

Ocampo, J. A., K.S. Jomo and R.Vos, 2007: *Growth Divergencies – Explaining Differences in Economic Performance*, Zed Books/Orient Longman/ Third World Network/United Nations, London/Hyderabad/Penang and New York.

Ouédraogo, R.S., 2009: “Adoption et intensité d’utilisation de la culture attelée, des engrais et des semences améliorées dans le centre nord du Burkina Faso”, in Kouassi, B. (ed) *Innovations technologiques et productions agricoles en Afrique de l’Ouest – Example du Burkina Faso, du Ghana et du Togo*, Karthala, Paris.

Palenfo, Philippe, Direction de la coopération décentralisée du Ministère de l’Économie et des Finances, personal communication.

Pingali, P. Bigot and H. Binswanger, 1988: “Technological Priorities for Farming in sub-Saharan Africa”, *The World Bank Research Observer*, Vol 3, No 1:81-98.

Platteau, J-P., 2000: “Insitutions, Social Norms and Economic Development”, *Fundamentals of Development Economics*, Vol 1, Harwood Academic, Reading, UK.

- ,2009: “Institutional obstacles to African economic development: State, ethnicity and custom”, *Journal of Economic Behavior & Organization*, Vol 71, Issue 3, pp 669-689.

Popper, K., 1972: *Objective Knowledge – An Evolutionary Approach*, Oxford University Press, Oxford.

Rogers, E.M., 1995: *Diffusion of Innovations* (4th edition), The Free Press, New York.

Rosenberg, N, 1982: *Inside the black box: Technology and economics*, Cambridge: Cambridge University Press, Cambridge, UK.

Ruttan, V.W., 1996: ”Induced Innovation and Path Dependence: A Reassessment with Respect to Agricultural Development and the Environment”, *Technological Forecasting and Social Change*, 53: 41-59.

- , 2002: “Productivity Growth in World Agriculture: Sources and Constraints”, *Journal of Economic Perspectives*, 16:4 pp 161-184.

Ryan, B. and N.C. Gross (1943), “The Diffusion of Hybrid Seed Corn in Two Iowa Communities, ” *Rural Sociology 8* (March): 15-24.

Salter, W.E.G., 1960: *Productivity and Technical Change*, Cambridge University Press, Cambrige, UK.

Samuelson, P.A., 1965: “A Theory of Induced Innovation along Kennedy-Weizacker Lines”, *Review of Economics and Statistics*, XLVII, 343-356.

Skarstein, R. 2002: “Induced Innovation and Agricultural Productivity – A Critical Note”, (mimeo), Department of Economy, NTNU, Trondheim, Norway.

Slingerland, M.A. and V.E. Stork, 2000: “Determinants of the Practice of Zaï and Mulching in North Burkina Faso”, *Journal of Sustainable Agriculture*, Vol 16, No 2:53-76.

Spielman, D.J. 2005: “Innovation Systems Perspectives on Developing-Country Agriculture: A Critical Review”, *ISNAR Discussion Paper 2*, IFPRI, Washington D.C.

Strang, D. and J.W. Meyer, 1993: “Institutional Conditions for Diffusion”, *Theory and Society*, Vol 22, pp. 487-511.

Sørensen, K.H., 1997: “Learning Technology, Constructing Culture – Socio-technical change as social learning”, (mimeo), Centre for Technology and Society, Norwegian University of Science and Technology, Dragvoll, Norway.

Sumberg, J. 2005: “Systems of innovation theory and the changing architecture of agricultural research in Africa”, *Food Policy*, Vol 30:1, pp. 21-41.

Tabo, R., A. Bationo, B. Gerard, J. Ndjeunga, D. Marchal, B. Amadou, M.G. Annou, D. Sogodogo, J.-B. S. Taonda, O. Hassane, M.K. Diallo and S. Koala, 2007: "Improving Cereal Productivity and Farmers' Income Using a Strategic Application of Fertilizers in West Africa" in Bationo, A., B. Waswa, J. Kihara and J. Kimetu (eds): *Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities*, Springer, Dordrecht, the Netherlands.

Tauxier,L., 1917: *Le Noir du Yatênga*, Larose, Paris.

Valente, T.W. and E.M. Rogers, 1995: "The Origins and Development of the Diffusion of Innovations Paradigm as an Example of Scientific Growth", *Science Communication*, Vol 16, No 3:242-273.

Veblen, T., 1921: *The Engineers and the Price System*, Harcourt, Brace and World, New York, NY.