From Technology Transfer to Adaptive Management

Knowledge Networks for Technological Change in Agriculture

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In studying agricultural development, we are interested in the characteristics of local contexts which enable or prevent technological change. Network theory and literature from social construction of technology provide numerous methods to make these complex processes of change more transparent. In this paper, we explore how these different approaches can inform conceptualizations of technological change in agriculture through 1) a brief synthesis of the network and social construction of technology literature; 2) a review of technological change in agricultural experiences; and 3) the proposal of a refined research methodology. Upon examining the literature, the distinction between structural and semiotic networks and the concept of technological frame are particularly valuable. Conceptualizing technological change through a social construction of technology approach, we are interested in the fundamental question of how and why a particular technological frame becomes dominant. We argue that this process unfolds through local network spaces and dynamics. In an attempt to illustrate the connection between network processes and technological frame adoption; we reinterpret two examples of technological change in agriculture. These include technology transfer in the Green Revolution and the emergence of adaptive management for the development of Conservation Agriculture production systems in the United States and Brazil. We find that the reformulation and reorganization of agricultural production networks are captured in Callon's moments of translation, where individuals take on new and even competing identities. Through deconstructing this process, we hope to provide the theoretical foundation for a more comprehensive research model to examine technological change in agriculture.

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From Technology Transfer to Adaptive Management: Knowledge Networks for Technological Change in Agriculture

Technological change enjoys a uniquely important position in the study and practice of agricultural development. Technological change in agriculture seeks to alter production behavior to improve efficiency in production processes toward an improved quality of life for those actors involved. Efficiency gains can be accomplished by a) being able to produce more product with the same resource base or b) maintaining the same level of production while consuming fewer resources (especially human labor), thus creating opportunities for these resources to be used elsewhere. Equally important, technological change reconfigures the relationships between the individuals involved in agricultural production and how production practices are integrated into individual and communal livelihood practices. Historically, various moments of technological change have made a broad and significant impact. Moreover, technological change to reduce human labor inputs in agriculture is cited as a key driver of the industrial revolution by creating the circumstances in which people could leave the countryside for the cities (Smelser, 1959). Technological change has also been a key contributor to development in the twentieth century, allowing for significant productivity gains of the Green Revolution (Borlaug, 1968). Today, technological change is anticipated to have a key role if we are to reach the second of the Millennium Development Goals: halving hunger and malnutrition by 2015 while addressing threats to agricultural productivity such as climatic variability and increased incidence of pest and disease due to climate change.

To provoke agricultural productivity gains, development agents have traditionally turned to the diffusion of innovations to farmers through mechanisms of technology transfer. It has been assumed, that improved methods must be introduced to farmers in order for productivity to increase. Recently this perspective has been challenged both with respect to its operational effectiveness and its capacity to actually characterize the processes of technological change in agriculture. The recognition of complex farming systems invoked the need for scientists and development agents to become more adaptive in their approaches and recognize the role of farmer innovation. This has led to the development of adaptive management, a range of approaches seeking productivity improvement and efficiencies through an iterative learning process at the local level. This in turn has lead to broader perspectives conceiving of the agricultural systems as networks of actors.

The notion of network has become a powerful metaphor and method for understanding the increasingly complex processes by which technological change occurs (Davies, 2003). Networks visualize social relations as a combination of nodes and ties, where a node represents an actor in the network (this can be a person, place or even an institution or object) and the various ties or linkages which connect the nodes to one another. While it has been recognized that inquiry into the linkages between members of agricultural production networks is essential for understanding and promoting technological change processes, considerable confusion remains regarding the application of the network approach to projects of technological change.

This paper presents a multidimensional framework to distinguish the various contributions of operational and analytical approaches for understanding technological change. As operational approaches to technological change in agriculture, technology transfer and adaptive management can be viewed as poles along a technological change continuum, realizing that most contemporary agricultural development projects are situated somewhere along these extremes (Moore 2009). The analysis of these technological change processes is elaborated in two ways. Shrum (2000) offers the distinction of the structural and semiotic approach to studying the networks within which technological change occurs. The purpose of this paper is to map out a framework for studying technological change which allows us to compare and contrast the insights of both approaches as they characterize particular contexts of technological change.

The paper is organized into three sections. The first two sections provide a literature review and backdrop for the subsequent analysis. We begin by introducing the operational contexts of technology transfer and adaptive management. The next section goes on to examine structural and semiotic network approaches to the study of technological change. From this foundation, the paper turns to an analysis of the administration of fertilizer subsidies as a program intended to advance technological change in agriculture and how they are understood by the different analytical approaches. The successful and less successful employment of fertilizer subsidy schemes in South and Southeast Asia and Sub-Saharan Africa inform an integrated research program to study efforts to improve soil quality through technological change in agriculture.

Technology Transfer and Adaptive Management: Differing Operational Contexts of Technological Change

Both structural and semiotic approaches have been successfully applied to the study of technological change processes. Under the technology transfer model knowledge is seen as universal, global, and subsequently transferrable. In the words of Norman Borlaug, father of the Green Revolution: “the world’s poor deserve the best science we have to offer”. The universal language of scientific knowledge in agriculture means that innovations discovered in U.S. laboratories and demonstrated effective in U.S. farmer fields can have the same effect abroad, given that there is adequate infrastructure in place to transfer both the technology and how to use it effectively.

Statements such as Borlaug’s, and the diffusion of innovations framework which technology transfer has become associated make two core assumptions (Rogers, 1983; 1995): (1) behavioral change is dependent on the decision making of autonomous individuals; and (2) scientific knowledge embodied in the technology to be transferred is directly applicable in a farmer‘s field. Given these assumptions, innovation occurs in a linear path. Experimentation to resolve a problem begins in the laboratory, and a commercial prototype is developed from those experiments which are most successful. Subsequently, firms scale up the innovation to produce a commercially available product. Early adopters pick up on the first commercially scaled version, often receiving economic rents for their entrepreneurial action. Diffusion proceeds as actors seek to acquire the profits or production gains to be made until adoption is commonplace throughout the population (Moore, 2008). Such a process of technological change divides a population into early adopters and laggards, the distribution of which in the population dictates the relative pace for the diffusion of a particular innovation (Rogers 1995; Henrich 2002).

Consequently, efforts to change farming practices by way of technology transfer have focused on developing efficient avenues for communication to disseminate scientific knowledge and technologies (the technology pipeline) leading to isolated choices made by individual farm operators (Henrich, 2002). By defining such a narrow focus, the technology transfer model has limited itself to projects which solely enhance the capacity of researchers, extension agents, and farmers in support of technological change (Shrum, 2000). This has been most successful with technologies that require only limited behavioral change, have highly visible levels of short-term return, and excludable benefits (Feder and Umali, 1993). One of the most common and successful types of technology transfer is the introduction of improved locally adapted seed varieties. Not surprisingly, technology transfer of natural resource management practices, which often have a slow rate of return, can be labor intensive, and whose benefits are positive externalities have been much more difficult to encourage adoption (Mango 2002; chapter 17, Moore, 2005). Overall, technology transfer operates well under conditions where: technological change is a matter of component replacement; shared knowledge systems, trust, and uncontested reciprocal identities extend from conception to execution; and ecological and market conditions are stable and relatively homogeneous (Busch, 1978; Moore, 2009).

Nevertheless, the majority of situations in which technological change would be most advantageous do not represent the conditions which promote such a successful technology transfer. Often, there is not a stable system of reference to ensure that the knowledge transferred will be incorporated in the manner originally intended to achieve success. Often, the frames of reference held by actors in the systems, or even the systems themselves must be changed in order for technological change to occur. Sustainable agriculture and natural resource management knowledge is situated in complex adaptive systems which capture the interaction between field, farm, watershed, ecosystem, market and policy networks in a local context (Moore, 2009). Embedded within these complex adaptive systems are culture, social relations, and politics wherein even technologies themselves are not neutral (Assefa et al, 2009). Rather technologies are actors in the system as well, representative of the culture and politics of those who created them, and inherently bring their own biases to the process of effecting technological change. Often, the implications of a technology can reconfigure productive and reproductive relations and certainly will not have a uniform impact across class and gender relations (Cowan, 1983). In a complex adaptive systems context, it is recognized that innovation and behavioral change occur as knowledge constructs come into conflict with one another and are subsequently reformulated. Adaptive management is the process by which system actors interpret and engage their local contexts in processes of social learning. Under successful adaptive management, stakeholders steer their own process of technological change by integrating new ideas and processes which increase system resilience and rejecting or reformulating those that do not (Moore, 2009).

Methodological/Analytical Approaches

Structural Approach

In their purest form, structural approaches to technological change in agriculture rely upon quantitative and hypothetic deductive methods to understand technological change processes. Structural approaches operate from two key assumptions 1) that scientific knowledge is universal, and 2) that there are common characteristics of systems which facilitate or limit technological change. As a result, structural analyses produce scalable models which can shed light on the attributes of a population or relational structures in a global context. The most common structural approaches are the development of adoption models and the employment of social network analysis to understand resource and information flows in a network.

Adoption models generally use a random sample survey to collect information on different attributes of local actors likely to increase or decrease the probability of adopting a new technology. These surveys are then used to develop a binary response model for adoption in a given region (Feder and Umali 1993; Henrich 2002). Besley and Case (1993) provide an overview of the different types of modeling procedures that may be used to examine technology adoption in developing countries. Time-series data, cross sectional data, and panel-data methods can all be used to develop models of farmer decision making in technology adoption (Besley and Case, 1993). The main difference in these modeling procedures is the time period across which measurements are taken. Time-series and panel data models collect data at a minimum of two different points in time, with time-series data taking a random sample at these two time intervals to calculate adoption probability within a population and panel methods following the same individuals through time to measure adoption probability at an individual level. Both methods allow for time-constant variables to be factored out thereby isolating dynamic drivers of technology adoption. Cross-sectional methods rely on taking a one-time snapshot of the population, incorporating time constant attributes into adoption models (Besley and Case, 1993).

Structural approaches which use Social Network Analysis (SNA) are interested in relational factors, rather than the attributes of individuals which shape technology adoption. SNA approaches begin from a snowball sampling method, wherein a study is initiated from a pool of individual participants referred to as the "egos". These egos report on their social contacts to "alters" and describe the information and resources exchanged. In this manner, researchers collect data on the structure of relations between actors in a network and relate this to who adopts or fails to adopt a technology (Knoke and Yang, 2008). Like cross-sectional adoption models, structural models take a one-time snapshot of adoption patterns, which can be used to report on adoption in the network and/or as a foundation for predictive models of technology adoption.

Basic analyses of social network structures can be used to understand patterns of communication in explaining technology diffusion. Positional analyses can identify actors of greater importance in a network, in terms of their structural position as an actor who can "scale-up" a technology. For example, positional analyses of networks can identify actors who have control over the information flows between actors, referred to in the literature as high betweeness centrality (Knoke and Yang, 2008). In agricultural production networks, we often consider extension agents as the critical nodes who communicate research findings to farmers. As one can imagine, understanding on the part of the extension agent is crucial to transmitting the "right" message from researchers to the field level (Lamb et al 2010, Shrum, 2000, Kiptot et al., 2006). Other positionally important actors may have high degree centrality, meaning that they have a higher number of connections to actors (Knoke and Yang, 2008), and as such are able to reach more people in creating interest in a technology. Identifying these opinion leaders who occupy important structural positions in the network may also be an important tool to target development interventions in technological change in agriculture (Davies, 2003).

More advanced applications of social network analysis also include the development of binary choice models, much like in the adoption models described above, the most popular application being the use of a logit model (Knoke and Yang, 2008). For example, Kiptot et al (2006) explore the flow of seeds and knowledge through social networks in an agroforestry project in western Kenya through a snowball sampling procedure and the construction of a logit model which includes characteristics of network position as well as attributes such as education and kinship. The research finds that both network position and kinship are highly important. Chiefs are more likely to share both seeds and knowledge, and increased exchange of information between kin suggests that knowledge passes more easily through kinship networks. Increasingly, social network analysts have experimented with collecting panel data by following individuals over time (Knoke and Yang, 2008). However, our literature review did not find any examples of SNA in the development context using panel methods.

The significance of the structural approach is that it allows for the examination of the quantitative impact of technological change . Through both the combination of adoption models and social network analysis, researchers can pinpoint the attributes of technologies, individuals and relational structures which contribute to or inhibit technological change. Moreover, the uniformity in methodology and research process allows researchers to develop scalable models and generalizations useful for developing strategies to replicate technological change processes in different regional and social contexts.

A drawback to both types of modeling procedures are that they impose limits on the types of relations to be included in the network. Generally, in structural approaches the only actors considered are the end-use decision makers. For example, adoption models consider attributes in the farm environment and/or technical intervention to predict adoption. Here, the relationship which influences technological change is limited to individual and/or environmental attributes that are hypothesized through economic theory to affect individual decision making. Similarly, social network analyses tend to distinguish whether they are studying relationships between scales of individual actors (farmers or extension agents), organizations or even institutions. Both cases fail to capture the more complex relations between individuals, organizations, communities, and technologies; and how these relationships change over time (Shrum, 2000).

Semiotic Approach

Semiotic approaches to understanding technological change depart from a fundamentally different core set of assumptions. Knowledge, action, and social patterns of behavior are assumed to be intrinsically connected to the context in which a person or group of persons operate. As such, a semiotic approach explains how a woman can see herself as a resource steward while continuing to engage in monocultural production (Moore, 2008). Semiotic approaches to understanding innovation in networks play a key role in developing analytical constructs by which we can begin to deconstruct complex social learning processes, such as in the case we see above. In particular, Bruno Latour, Michel Callon, and Weibe Bijker provide valuable insight into the complexity of innovation processes under the semiotic approach (Shrum, 2000). Our literature review also adds the works of Long and Van der Ploeg (1988), and Stephen Biggs and Harriet Matsaert (2004) as advocates of a contemporary actor oriented approach in agricultural development research.

Weibe Bijker's key contributions to the semiotic approach are the notion of sociotechnical ensemble and technological frame (Bijker, 1995). The term sociotechnical ensemble captures the idea that a technological process or artifact is a combination of its physical and technical attributes and the social meanings ascribed to it by its stakeholders[1]. In agricultural production, we can use the concept of the sociotechnical ensemble to understand that different approaches to agricultural production systems – such as conventional or organic agriculture – are rooted in social as well as scientific origins. Bijker's second contribution, the technological frame or frame of reference, allows us to understand the differences in production processes as inherent differences in frames of reference of what is prioritized by competing perspectives of agricultural production.

Four technological frames predominant in agricultural development today include conservation agriculture, risk-averse agriculture, organic agriculture, and conventional agriculture. To briefly characterize these systems, conservation agriculture refers to a production system in which producers are committed to preserving and improving the health of their soils while improving yields and/or profitability. This is accomplished through minimizing tillage, maintaining a permanent soil cover, and crop rotation. Alternatively, risk averse agricultural producers tend to view farming as a way of life and subsistence in their local context and community. They often engage in some form of multifunctionality or co-production by working off the farm or raising multiple crops and livestock across a dispersed area to ensure the sustainability of the farm household. Risk-averse producers classically seek autonomy and independence in agricultural production (Long and van der Ploeg, 1988), echoing a view that they would rather produce their food than purchase it in the market (Mango, 2002). Organic agriculture stresses the need for purely organic inputs which not only enhance agricultural productivity, but also improve the

[1] In Bijker's terminology relevant social group.

quality of outputs. Organic producers avoid inorganic chemical inputs and rely on manure, composting, bio-pesticides, and other bio-intensive methods. Lastly, conventional agricultural production tends to view farming as a business. Producers rely on principles of specialization and cost savings to maximize yields and profits. They advocate the usage of science and technology to improve agricultural production practice, especially by way of reduced labor inputs through intensive plowing of the land and the application of fertilizer and pesticides to the extent it is profitable and yield maximizing.

Returning to our example above, we can understand agricultural production itself as a sociotechnical ensemble and can clearly see that this woman is likely applying multiple frames of reference to her situation. Dependent upon her context, the woman may view herself as a resource steward and apply a conservation agriculture frame of reference while working with an NGO and acknowledging locally high levels of soil erosion and reporting on low soil fertility. However, in her own production practice she feels compelled to provide her family with access to the staple crop without needing to rely on the market, a marked characteristic of a risk averse frame of reference.

In the semiotic approach, the process by which multiple frames of reference are negotiated, solidified or even dissolved can be analyzed with respect to Michel Callon's (1987) moments of translation and enrollment. This four stage process begins with the invocation of actors around a certain definition of a problem, issue, constraint or need. The second moment involves a knowledge promoting actor who seeks to impose roles and identities upon other actors with a common interest in the issue. A third moment of translation and enrollment occurs when there is success in demonstrating a solution to the defined problem or a discovery of a critical piece of information which acts to link components of the network to one another. When the alliances formed allow for the discovery to become generalized consensus around the facts and this knowledge is reproduced by the members of the network, the final moment of enrollment and translation occurs (Callon, 1987). Especially in agricultural production systems, processes of enrollment and translation may take considerable amounts of time to evolve and are defined in months, and more likely, years of change in an agricultural system.

Additional contributions to the semiotic network approach include actor-oriented inquiries into technological change processes. The actor-oriented approach popularized by the late 1960s involved focusing on the agency of individual actors in technological change processes through the usage of intensive ethnographic research methods (Mitchell 1956; Burawoy 2006). However, these approaches came to be criticized for placing too much emphasis on the actor without adequate understanding of how meanings are locally constructed in networks (Long and Long, 1992). Nevertheless, this work provided a critical foundation for inquires which examine how technologies are embedded in societies (Wiskerke and Van der Ploeg, 2002). Like Bijker, these researchers hold that the success or failure of a technology isn't an inherent characteristic of the technology itself, but rather how the technology is understood and shaped by its various stakeholders (including the end users) in the development context. In a recent actor-oriented revival, Biggs and Matsaert (2004) demonstrate how using an actor-oriented approach with the vulnerable peoples of the chars in Bangladesh can improve bargaining power for such communities in formal technological change networks while maintaining and preserving local production process and techniques.

In studying technological change, semiotic analyses are interested in how knowledge (1) travels through social networks and (2) is transformed in social processes. One of the most detailed research programs with a semiotic approach is presented by Masters et al (2005) in an actor-oriented tool kit which describes field activities designed to bring out the role of actors in development processes. Oral histories can be recorded through actor timelines which ask questions involving the persons involved in historic events. Constructing participatory actor linkage maps with focus groups allow producers to teach development practitioners and researchers about their production processes and can make more transparent areas where linkages might be established to improve production with locally accessible resources. For analysis, Biggs and Matsaert (2004) show how matrices can be constructed to collect data on more complex exchanges between persons as well as useful exercises for how to follow up on problem linkages in a participatory framework.

Semiotic approaches to studying technological change rely on qualitative methods wherein researchers conduct detailed interviews to understand how relationships and knowledge networks have changed over time. Like structural social network analysis approaches, semiotic network analyses also tend to begin with a snowball sampling method, following paths of knowledge exchange between different levels of system actors to study how knowledge is translated, adapted or ignored as irrelevant (Bijker,1995). In addition, semiotic approaches do not attempt to test hypotheses; rather they use qualitative methods to discover local understandings or frames of reference which actors construct to interpret events and landscapes. A classic example of such a semiotic line of inquiry comes from Nelson Mango (2002) in his examination of several technological change projects for hybrid maize and soil conservation in western Kenya, and his subsequent explanation of rejection and/or redesigning of state imposed agricultural development projects in local networks of smallholder producers. Like Mango's dissertation, semiotic analyses tend to be case study based. This is likely in part due to the in-depth nature of the methods for conducting such a qualitative analysis and the need to establish rapport with research participants. Moreover, semiotic approaches tend to be interested in questioning processes of technological change with a given region or specific technology or technological process as their unit of analysis. Contributions to understanding the larger context of technological change processes are made through demonstrating how technologies are socially constructed.

There are clear limitations of the semiotic approach to analyzing networks. Namely, it is difficult to produce scalable, generalizable recommendations from case study investigations. Moreover, such analyses are also much easier to conduct after the innovation or technological change process has occurred in order to allow the interviewed subjects to be able to provide a complete chronicle of the event in question and to have had the opportunity to interpret the events from their perspective. Semiotic analyses can also struggle in the sense that it can be difficult to define the parameters of an investigation. Social networks are dense and increasingly complicated under processes of globalization, and subsequently every semiotic researcher must encounter the question of where they will delimit the scope of their investigations. In the process of defining the most relevant social groups, the researcher is always at risk of leaving out someone and not being able to tell the "full story" of technological change.

While we have modeled operational approaches (technology transfer and adaptive management) and analytical methods (structural and semiotic) to technological change in two dimensions, unfortunately analyses have been relatively one dimensional as there is a high correlation of technology transfer projects being analyzed through structural methods and adaptive management through a case-study based and semiotic analytical process. This polarization of analytical method and operational approach is not appropriate to most commonly held beliefs about knowledge. Just as we acknowledge that contemporary technological change projects often present a mix of technology transfer and adaptive management elements, we must also adhere to a conception that knowledge is neither purely universal nor purely local, that hybridization can and must occur across such a continuum. Moreover, we see that structural and semiotic analyses of networks can both provide useful information to understanding social learning, innovation and transfer, and technological change in the development context. Research programs interested in finding locally relevant and generalizable knowledge then should seek to integrate elements of both a structural and semiotic approach as appropriate to the operational context. In the following sections, we examine cases along this continuum and track the evolution of research programs for technological change. We conclude by offering some suggestions and considerations for a research program in conservation agriculture which brings together many of our findings.

The Green Revolution, Fertilizer Subsidies, and Differing Technological Change Landscapes

The Green Revolution (GR) occurred in southern and Southeast Asia in the 1960s through the early 1980s. Commonly recognized as the most successful technology transfer of the 20th century, the GR allowed both Pakistan and India to nearly double their wheat production in only 3-4 years in the late 1960's (Borlaug 1968). While by no means do we attempt to take a comprehensive look at the GR, the vast volume of research produced regarding the GR provides a wealth of opportunity to highlight how structural and semiotic analyses can interpret an event in such different ways and reveal some of the advantages and disadvantages of each approach. This section attempts to document and tell the story of one element of the Green Revolution – the development of fertilizer subsidies and their impact on reorganizing networks in the farm landscape.

Before delving too quickly into the discussion of fertilizer subsidies, it is important to establish why they were such an important aspect of the GR package. There were two major components of the GR. The GR developed high yielding varieties (HYVs) of cereals (mainly rice and wheat, but also maize) which made more efficient use of agricultural inputs. Specifically, GR varieties were dwarf varieties bred to produce a shorter stem. As a result, increased fertilizer application allowed for a significant increase in grain yield, rather than stalk growth. GR varieties were also bred to be more or less drought tolerant or able to take advantage of the ability to water/flood fields through irrigation. For this reason, a number of analysts of the Green Revolution – structural, semiotic, or otherwise – advocated a name change from "high yielding" to "highly responsive" varieties (HRVs) to be more reflective of the additional investment that the varieties required (Shiva, 1993).

With modern or highly responsive seed varieties, the economic benefit of fertilizer application is well documented (Mengel, 1983). Even though the technology requires greater initial financial investment in the purchase of both seeds and fertilizer at the start of the production season, the benefits in terms of yield gain from the highly responsive seeds is supposed to outweigh the cost. Thus, the planting of HRVs was defined in this technological frame as the rational behavior alternative compared to the option to continue to plant local varieties – at least for those who could afford the upfront costs. HYV were not simple technology transfer substitution varieties. They were system components and the consequent outputs (short stalks) had implications for overall farm operations, decreasing the straw available for livestock, housing, and natural fertility enhancement.

In the early implementation of the GR, fertilizer subsidies played a key role in facilitating this change process (Feder, 1993). Immediately reaching out to the large population of subsistence farmers with individualized policies such as training and rural credit was viewed by policy makers as infeasible, at least in the short term. Whereas individual farmers were exceptionally difficult to reach, subsidies could easily be delivered to fertilizer companies through the mandated fertilizer prices to ensure that companies would pass on their cost savings to farmers. Lowering the price of fertilizer to a level below its cost of production was seen as a way to increase the incentive for farmers to adopt the HYV package. This was an intervention to route benefits to smallholders through the subsidized development of a domestic fertilizer sector. In social network terms, the state fertilizer subsidy to private sector fertilizer dealers created actors with high betweeness centrality and consolidated control over the distribution of fertility inputs. This effort was motivated by the desire to reach a higher number of small farmers than through individualized outreach to provide fertilizer resources and education. Meanwhile extension agents continued to promote the new varieties with field demonstrations, etc.

The operation and success of fertilizer subsidies is explained with different terminology and credited with varying levels of importance across structural and semiotic analytical approaches. Structural adoption analyses define categories for technologies and develop separate and complimentary adoption models. Structural analyses of the GR focused on the divisibility of both seed and fertilizer technologies as key to the success of such programs in influencing adoption (Feder and Umali, 1993). For example, Feder (1982) models complimentarity between "lumpy" irrigation technologies and divisible technologies such as fertilizer and seeds. The argument is that adoption decisions are informed at different scales by characteristics such as risk aversion, credit availability, and farm size; with adoption of the divisible technologies precipitating that of packaged technologies and overall adoption increasing over time as risk aversion declines relative to rising income and other factors (Feder, 1982). Extensions of individual adoption models explore the role of prices, how and why spontaneous adoption occurs, and simultaneous decision making, while aggregate models examine macro level factors influencing adoption such as climate or infrastructure (Feder and Umali, 1993).

Alternatively, the semiotic approach views the GR as an attempt to replace the existing risk averse technological frame with the conventional agricultural production frame. The fertilizer subsidy regime understands the fertilizer subsidy policy as a way of subtly reorganizing the rural landscape in accordance with this new frame of reference. In India, fertilizer plants cropped up around the countryside (Anand, 2010; Shah 1974; Sharma and Thaker 2009). These fertilizer manufacturers created opportunity for off farm employment and as a result some farmers began to move out of agriculture to work in these factories. This entailed a reconfiguration of the identity of some subsistence farmers toward becoming a service providers or small businesses dependent upon having a market requiring their services. Transitioning from agricultural production practice which isolated communities towards practices which encouraged specialization and external linkages for the rural economy enabled more people to work off the farm or migrate to the city. The subsequent expansion of farm plot sizes lead to increased productivity and improved incomes for the remaining farmers. Technological change was sustained because the fertilizer subsidy not only incentivized adoption at the individual farmer level, but because it opened a process of enrollment and translation which reconfigured identity and social relations of a significant interconnected segment of rural actors throughout the network . As some members of the rural community moved out of agriculture to work selling fertilizer, they also moved from being net or subsistence food producers to net consumers. Alternatively, other farmers used the opportunity to bring more land into production and move from subsistence to net producers. With both parties now relying on income from sales of their goods to sustain a livelihood, rural actors experienced a true change in mindset regarding their individual and communal roles in the local society.

From these examples, we can see that the structural approach tends to place more weight in the nature of the technologies themselves, whereas the semiotic approach emphasizes the importance of the reorganization of rural networks in facilitating and sustaining processes of change in attempting to understand why particular interventions for technological change are successful. In both cases, we see that there is a transition from risk aversion to commercialization. In the structural case, this is documented as a dynamic relationship between household income and technology adoption. The semiotic case explains how technological change is sustained through the reorganization of rural social networks. Interestingly, the respective approaches are equally useful for unpacking why the fertilizer subsidy scheme under the GR was less successful in at least some contexts.

Fertilizer Subsidies Problematic in the Sub-Saharan African Context

While it is well documented that improving soil fertility will be crucial to improving agricultural productivity and food security in Sub-Saharan Africa; there is less consensus regarding the best way to accomplish this goal. Increasing usage of inorganic fertilizer must have a significant role, but fertilizer subsidy schemes in Sub-Saharan Africa have been considerably less successful than in the Asian context. In this section, we compare both structural and semiotic analyses of fertilizer usage to better understand this aspect of technological change in Sub-Saharan Africa. We will begin by comparing a structural and semiotic approach to examining why fertilizer subsidies have been less effective in Western Kenya.

The structural approach has been particularly challenged to explain why the GR and accompanying fertilizer regimes have not worked in Sub-Saharan Africa. A recent analysis which has captured a lot of attention is by Esther Duflo et al (2009), and suggests that behavioral economics can explain why farmers fail to apply adequate amounts of fertilizer at the appropriate moments in the production process. In other words, continued farmer resistance to fertilizer use is a function of poorly functioning formal and informal networks which influence production behavior. Here the terms formal and informal networks refer to those market relations formally regulated and promoted by the state, such as the extension and fertilizer subsidy programs, and non-market relations often based on kinship and/or social capital. On the one hand, behavioral economics suggests that the reason farmers often fail to use fertilizer is that they wait too long to purchase the fertilizer, and when they seek out fertilizer for purchase in the following spring, prices have risen to high for profitability. This is described as farmers over-estimating their ability to save income from the previous harvest profits to purchase fertilizer for the coming season (Duflo et al 2009). This is diagnosed as a failure of formal input markets to: 1) make locally informed recommendations for fertilizer application from the extension level; and 2) for market traders to deliver fertilizer of consistent quality at times of peak demand. Informal markets are also diagnosed as failing in this case by placing social pressure on farmers to spend what income they earn from agricultural production activities on customary events such as weddings, etc. These informal network pressures limit the ability of farmers to purchase fertilizer shortly after the growing season when prices are low.

Duflo et al (2009) contrast these findings with surveys in which farmers report on their intent to utilize more fertilizer in the following growing season, only to continue in the same cycle of under and often late application. In order to resolve this predicament, an alternative regime is proposed in which a subsidy is offered to purchase fertilizer when prices are low at the end of the production season. It is argued that the subsidy should also be accompanied by an alternative reduced fertilizer recommendation where fertilizer is only directly applied in each individual hole with the seed during planting.

What is interesting here is that Duflo et al have attempted to step back from traditional structural approaches (which focus on either the structure of relations or characteristics of the adoption environment) by creatively applying behavioral economic theory to provide an alternative voice that may be more empowering for farmers. Yet, how fertilizer is actually being utilized if it is being incorporated into production systems by methods alternative to the extension recommendation remains undocumented. Not surprisingly, the analysis ends up placing the blame on the extension service and the farmers themselves for their inability to adhere to a logic which aligns with the conventional agricultural production frame of reference. In theorizing about farmer ability to save, Duflo assumes the voice of the farmers without taking their values and priorities into account.

Attempts to approach analysis of fertilizer subsidies from a semiotic perspective seek to address these key shortcomings. Mango (2002) explores the perceptions of farmers regarding artificial fertilizer usage in Siaya District in Western Kenya. Mango begins by framing the issue of smallholder fertilizer use in light of Kenya's larger agricultural production system. Like in the Duflo case, Mango reports that smallholders lacked the means to purchase the same amount of fertilizer as larger holders. Even one bag of DAP fertilizer, available for approximately 1800 Kenyan shillings was greater than the income of many families from a harvest (Mango, 2002). Thus, in order to reach smallholders, fertilizer had to be repackaged into smaller bags for purchase by individual farmers. While on the one hand this repackaging made purchasing fertilizer more affordable, repackaging fertilizer also introduced the opportunity for traders to mix in additional fillers such as litter, etc. As farmers have a difficult time discerning the quality of the fertilizer until they apply it on the land, they have no way of assuring themselves that they are purchasing quality fertilizer and exposing themselves to considerable risk in investing in a fertilizer intensive production regime. Unlike in India where fertilizer subsidies encouraged the development of fertilizer production in rural communities, fertilizer manufacturing in Kenya was limited to the most productive areas of the country and Kenya remains a net importer of fertilizer. This implies that most traders of fertilizer are not directly invested in the production and quality of their goods. As a result, these traders have less incentive to assure that they are providing a consistent quality product.

Moreover, older farmers in the region reported seeing a decline in fertilizer quality from the time that it first became available in Siaya district to the present. Farmers report that the fertilizer they buy today does not build organic matter in the soil and degrades the texture of the soil over time. With this information, farmers perceive organic and inorganic fertilization methods as comparable and even interchangeable despite their considerably different properties. Even though smallholders acknowledge that there is not enough organic fertilizer to adequately enhance soil fertility, the fact that the quality of what fertilizer is available is consistent and knowable because it is acquired locally is important to their input decision making process (Mango, 2002).

To reduce some of these vulnerabilities, extension agents have attempted to work with farmers to build partnerships to allow for demand for larger quantities of fertilizer purchase, both to reduce opportunity for cheating by traders and reduce trader costs in being able to bring larger quantities of fertilizer for sale to low fertility areas. However, as farmers already held a widespread perception of the increasingly negative impact of fertilizer upon the soil, whether due to the declining quality of purchased fertilizer or soil mining, these efforts have only had limited success. As such, little local resilience is built into a fertilizer regime for agricultural production in less suitable areas. As a result of feeling cheated by the market in fertilizer, risk averse behavior in farmers is supported and enhanced. Mango calls this process "distancing" from the state imposed technological regime (Mango, 2002).

While these examples from Western Kenya use structural and semiotic approaches to document and provide competing explanations for low fertilizer usage in Western Kenya, the structural and semiotic approaches have also been used in a more active research framework to more directly interpret how farmers learn from one another. Specifically, structural approaches have begun to challenge an underlying assumption of the technology transfer operation of promoting technological change – that farmers make decisions in accordance with a desire to maximize utility. While utility might be different from farmer to farmer, with individual farmers placing more weight on food security for the household or earning an income off the farm, etc. the underlying premise is that farmer decision making will align with the farmer's perceived needs and priorities.

However, a structural analysis from Ghana suggests that farmer proximity in social networks likely has a more direct contribution to changing farmer behavior regarding fertilizer application. Conley and Udry (2001, 2010) investigate how farmers learn through social networks. Working with a project on pineapple production for European markets, Conely and Udry (2010) surveyed farmers to see how and why farmers were redesigning the technological package with specific regard to fertilizer use. It was discovered that farmers only communicated about fertilizer usage with a very small number of contacts as opposed to widespread sharing of experiences at the village level. For instance, when one farmer in the group applied significantly high amounts of fertilizer and experienced a vast yield gain, those individuals in that farmers "close" network were significantly more likely to increase their fertilizer application in the following growing season (Conely and Udry, 2010). Thus, production behavior was highly influenced in these small social networks. As such, farmers do not receive perfect information in agricultural markets as suggested by the technology transfer operational approach. These findings are especially intriguing in light of the fact that the study addresses a cash rather than staple crop production regime. In working with cash crops, farmers are already, to some extent, applying a conventional frame of reference in that they are practicing farming as a business. In the technology transfer operation, this should be significant to promotion of successful and widespread adoption.

Additional extensions of the structural approach to understanding innovation in social networks has led to further questioning of the assumptions made by the diffusion of innovations framework regarding technology adoption. Henrich (2002) demonstrates that farmers are more likely to also imitate particularly influential actors in the local network in demonstrating behavioral change. For example, smallholders are more likely to adopt a technology when a person of power adopts that technology successfully (Kiptot et al., 2006). Thus, adoption processes are not individualized rational choice decisions, but rather processes of imitation of other actors in the system. Both Conley and Urdy (2010) and Henrich (2002) suggest then, that what you know is not nearly as important as who you know in the attempt to shape efforts which facilitate farmer learning for technological change. Network relationships are important.

In addition to the challenges to technology transfer from its legitimizing base in the structural approach, frustration and inefficiency of technology transfer to improve soil fertility in Sub-Saharan Africa has stimulated more active research frameworks from a semiotic and actor-oriented analytical perspective. A prime example of this is the Ethiopian experience of moving from an aggressive technology transfer approach which pushed a comprehensive package of hybrid seeds, fertilizer and credit in the late 1980s and early 1990s (Borlaug and Dowswell, 1994) towards the more recent and widespread and gradual progress made by the Integrated Nutrient Management Program (Corbeels et al 2000).

Under the aggressive technology transfer regime, much as in the GR case in India, the obstacle of providing credit to purchase inputs for the hybrid regime was a major constraint to technology adoption. The Ethiopian government opted to address this problem by making extension agents creditors. However, many naturally complained that this compromised their educational function both in placing significant demands on their time and in making farmers less willing to listen to their advice after pressuring them to repay their loans (Belay, 2003). Moreover, as in the Kenyan case, extension activities were biased toward wealthier producers with the ability to afford such risks. The additional burden on extension is symptomatic of the larger failure to promote the development of intermediate markets for the realization of yield benefits in the intensified technology transfer approach. Not surprisingly, the program had extremely uneven levels of success through the countryside.

What is exciting about the Ethiopian case is that the revised Integrated Nutrition Management Program and its farmer field school network have become a platform for facilitating the process of finding common ground for local and scientific knowledge. The farmer field school approach has been particularly helpful in allowing for local agro-ecological problem solving and legitimizing farmer knowledge of soils and their properties for producing differing agricultural commodities. Moreover, encouraging farmers to experiment and share their findings with others to make farmer led choices about technology development and adoption decisions mobilizes farmers' own frames of reference. This has allowed for increased farmer empowerment and the ability to reach smallholders more effectively than previous extension efforts. Farmers also observe and compare ecological outcomes of different methods to improve soil fertility. For example, farmer trials demonstrated that organic manure keeps the soil softer and is better for retaining moisture while artificial fertilizer produces a darker colored leaf and improved grain yield. With such results, many farmers opted for a 50/50 organic and artificial fertilizer regime, an outcome that allowed farmers to improve their yield, manage their short term risk, and invest in the long range productivity of their soils (Kebebe et al 2007).

Semiotic and Structural Approaches: What do they suggest for a research framework for soil fertility in SSA?

It is well established that enhancing soil fertility will be key to technological change efforts to improve the quality and quantity of agricultural production in Sub-Saharan Africa. Equally, as we can take from our example of fertilizer subsidies, approaches to improving soil fertility must come from a network based approach. Structural and semiotic analyses both have a great deal to bring to the table in designing research programs to improve soil fertility in SSA.

From the semiotic, we can see that there are many technological frames already in existence trying to address the problem of soil fertility, and developing a respect for how these may shape farmer behavior will be crucial to negotiating a workable solution. As we can see in the Ethiopian case in the blending of a 50/50 organic and artificial fertilizer, being a purist in one approach may not be enough for farmers to act meaningfully within their technological frame in order to realize the best outcomes. Semiotic frameworks provide the ability to catalog the knowledge opportunities available in the system and how they can best be brought to realization through cooperation between actors. Moreover, in investigating the story of where the actors have been and situating current technological change projects in light of their predecessors, semiotic approaches in active research decrease the likelihood for repeating past mistakes.

We also have much to learn from structural analyses. The reality is that there are only limited resources to address issues of soil fertility. As we have seen, imitation of fellow farmer behavior is highly influential towards the spread of a technological package. Structural social network analyses can pinpoint who opinion leaders are in a farming community. An exciting extension of this would be to also use social network analysis to find opinion leaders in the research and extension communities and how to utilize these actors for the advancement of the technological change project. We have also noted that these analyses can be very powerful to verify the accomplishments of a technological change projects. Policy analysts want to see a return on their investment to see the quantitative substantiation of who and how many people were helped in the project.

While we have used this paper to compare structural and semiotic network approaches, the truly exciting element of this study is that the two can be made to work together to optimize our ability to conduct, document and explain technological change processes. Possibilities for bringing together structural and semiotic approaches include using focus groups to bring out some of the defining characteristics of local technological frames and to allow researchers and development agents to get a sense for the perspectives that currently govern production systems. This can be an empowering process for building trust between these two groups in allowing the farmers the opportunity to teach researchers or development agents about what they do. Such activities can also assist in the design of network level surveys by making important suggestions as to the scale and scope of production actors that would need to be surveyed to provide a comprehensive picture. Further, a broad network survey can be used to identify opinion leaders and researchers could follow up with these actors to gain insight into existing knowledge and current technological frames applied to production practice.

In both cases, researchers have the opportunity to present a much richer analysis of how networks for technological change operate in the development context. Quantitative documentation can be given a human face and meaning through insights gathered during semiotic interviews or focus group sessions. In this way the value of qualitative methods can be substantiated and the insights of quantitative analyses enriched.

The growing recognition of the importance of adaptive management to solve soil fertility problems in SSA enhances the need to combine structural and semiotic research methods. This is because adaptive management requires an increasing awareness of the diversity of actors and production systems involved in technological change. The socio-ecological networks of rural communities most in need of assistance are rapidly changing. However, projects need to continue to be made accountable from above and below. This presents challenges to both network approaches. Structural approaches need to be able to take into account change in system dynamics through the increased development of methods to document change across time through panel methods. Meanwhile, semiotic approaches will be challenged to find ways to demonstrate their ability to provide insight as to how change occurs. The best way for network researchers to continue to meet this demand is to increasingly combine methods and use alternating research approaches so that methods can continually be altered and improved in tandem with one another.

Bibliography:

Anand, G. 2010. Green revolution wilts as fertilizer subsidies backfire. 22 February 2010. *The Wall Street Journal—India.*

Assefa, A. Waters-Beyer, R. Fincham and M. Mudhara. 2009. Comparison of frameworks for studying grassroots innovation: Agricultural Innovation systems and Agricultural Knowledge and Innovation Systems. In: *Innovation Africa: Enriching Farmers Livelihoods*. P. C. Sanginga, A. Waters-Bayer and S. Kaaria (eds.) London: Earthscan

Belay, K. 2003 Agricultural extension in Ethiopia: the case of participatory demonstration and training extension system. *Journal of Social Development in Africa*: 2003(1): 49-84

Besley, T. and A. Case. 1993. Modeling technology adoption in developing countries. *The American Economic Review* 83(2): 396-402.

Biggs, S. and H. Matsaert. 2004. Strengthening poverty reduction programs using an actor-oriented approach: Examples from natural resource innovation systems. *Agricultural Research and Extension Network,* Network paper No. 134.

Bijker, W. E. 1995. *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change.* Cambridge, MA.: Massachusetts Institute of Technology Press.

Borlaug, N.E. 1968. Wheat breeding and its impact on world food supply. *In* K.W. Finlay & K.W. Shephard, eds. *Proceedings of the 3rd International Wheat Genetics Symposium*, p. 1-36. Canberra, Australia, Australian Academy of Sciences.

Borlaug, N.E. and Dowswell, 1994. Feeding a Human Population that Increasingly Crowds a Fragile Planet, CR 9-1994 Wageningen, ISSS.

Burawoy, M. 2006. The extended case method. *Sociological Theory* 16(1): 4-33

Busch, L. 1978. On understanding understanding: Two views of communication. *Rural Sociology* 43: 450-73.

Callon, M. 1987. Society in the Making: The Study of Technology as a Tool for Sociological Analysis, In: W. E. Bijker, T. P. Hughes and T. J. Pinch (eds), *The Social Construction of Technological Systems.* Cambridge & London: M.I.T. Press: 83-103.

Conely T. and C. Udry. 2010. Learning about a new technology: Pineapple in Ghana. *The Amercian Economic Review* 100(1): 35-69

Conley, T., and Udry, C. 2001. Social Learning Through Networks: The Adoption of New Agricultural Technologies in Ghana. *American Journal of Agricultural Economics* 83(3): 668-73.

Corbeels, M. A. Shiferaw, and M. Haile. 2000. Farmers' knowledge of soil fertility and local management strategies in Tigray, Ethiopia. Managing Africa's Soils No. 10

Cowan, R.S. 1983. More work for mother: The ironies of household technologies from the open hearth to the microwave. U.S.: Basic Books Inc.

Davies, R. Network Perspectives in the Evaluation of Development Interventions: More than a Metaphor. Paper presented at the EDAIS conference, 24-25 November 2003

Duflo, E., M. Kremer, and J. Robinson. 2009. Nudging farmers to use fertilizer: Theory and experimental evidence from Western Kenya. NBER Working Paper No. 15131

Feder, G. 1982. Adoption of interrelated agricultural innovations: Complimentarity and impact of risk, scale and credit. *American Journal of Agricultural Economics* 64: 94-101

Feder, G. and. D. Umali. 1993. The Adoption of agricultural innovation: A review. *Technological forecasting and social change.* 43: 215-239.

Henrich, J. 2002. Cultural transmission and the diffusion of innovations: Adoption dynamics indicate that biased cultural transmission is the predominant force in behavioral change. *American Anthropologist* 103(4):992-1013

Kebebe, E., B.Sheleme and W. Wondimu. 2007. Learning experiences of farmers field school on Integrated Nutrient Management: Evidence from Wolaita in southern Ethiopia. *Journal of Agronomy* 6(4): 560-565

Kiptot, E., S. Franzel, P. Hebinck and P. Richards. 2006. Sharing seed and knowledge: Farmer to farmer dissemination of agroforestry technologies in western Kenya. *Agroforestry Systems* 68(3): 167-179.

Knoke, D. and S. Yang. 2008. *Social Network Analysis: Second Edition.*. SAGE Publications.

Long N. and J.D. van der Ploeg. 1988. New challenges in the sociology of rural development. *Sociology Ruralis* 29(1): 30-42

Long, N. and A. Long. 1992. *Battlefield of Knowledge: The interlocking theory and practice in social science research and development.* London: Routledge.

Mango, N. 2002. Husbanding the land: Agricultural development and socio-technical change in Luoland, Kenya. PhD Dissertation, Wangingen University.

Matsaert, H., Z. Ahmed, N. Islam and F. Hussain. 2005. Using actor oriented tools to analyze innovation systems in Bangladesh. *Participatory Learning and Action* 51(4): 100-110.

Mengel, K. 1983. Responses of various crop species and cultivars to fertilizer application. *Plant and Soil* 72:305-319

Mitchell, Clyde. 1956. *The Kalela Dance*. Manchester: Manchester University Press for Rhodes-Livingstone Institute.

Moore, K.M. 2008. Network framing of pest management knowledge and practice. *Rural Sociology* 73(3) Pp. 414-439.

Moore, K.M. 2009. Systems Integration and Innovation. In: Moore, K.M. (ed) *The Sciences and Art of Adaptive Management.* Ankeny, IA: Soil and Water Conservation Society.

Moore, K.M., C. Brewster, and M. Bertelsen. 2005. What we have learned. In: *Conflict, Social Capital and Natural Resource Management: A West African Case Study.* Cambridge: CABI Publishing

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

Rogers, E.M.1983. *Diffusion of Innovations,* 3rd ed. New York: The Free Press.

Shah. S.M. 1974. Growth centers as a strategy for rural development: Indian experience. *Economic Development and Cultural Change* 22(2): 215-228

Sharma, V.P. and H. Thaker. 2009. Fertilizer subsidy in India: Who are the beneficiaries? Indian Institute of Management Working Paper Series No. 2009-07-01

Shiva, V. 1993. *Monocultures of the Mind: Perspectives on Biodiversity and Biotechnology*. London: Zed Books.

Shrum, W. 2000. Science and story in development: The emergence of non-governmental organizations in agricultural research. Social Studies of Science: 30(1): 95-124.

Smelser, N.J. 1959. Social Change in the Industrial Revolution. Chicago: University of Chicago Press.