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Network Framing of Pest Management Knowledge and Practice*

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ABSTRACT Conventional technology transfer is based on the assumption that autonomous individuals independently make behavioral decisions. In contrast, Actor-Network Theory (ANT) suggests that people and technologies are interconnected in ways that reinforce and reproduce some types of knowledge and consequent behavioral practices, but not others. Research on pest management in Mali shows the extent to which farm-level decisions are shaped off-farm through contracts that communicate commercial and regulatory decision-making information. Findings from the analysis of Ukrainian farmer pest management decision-making demonstrate the exercise of power of commercial interests. In light of these findings, evidence from Farmer Field School experiences in Indonesia is reinterpreted. This paper concludes that knowledge networks are not monolithic and, furthermore, there is competition between network segments to define appropriate knowledge and practice. It also recommends that agricultural scientists pay more attention to the negotiations framing legitimate knowledge about the networks in which their producer clienteles are embedded.

We are faced with a dilemma. On one hand, pesticide use in developing countries has increased dramatically over the past decade creating conditions for a human and environmental catastrophe. On the other, pesticides are playing an increasingly important role in economic development. Indeed, increased investment in crop protection tech-

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nologies and crop enhancement techniques has led to increased agricultural production and incomes, providing a potentially viable means for reducing poverty in developing countries (Sumberg and Okali 2006). The problem is that increased pesticide use has not been accompanied by an equally important increase in farmer knowledge, skills, and practices that would assure the safe use and handling of pesticides.

Safer and more profitable production knowledge and practices do exist. Integrated pest management (IPM) based on enhancing natural processes and limiting artificial inputs offers the knowledge, skills, and practices to ensure more profitable, healthy, and environmentally safe food production. This scientifically generated knowledge has been promoted globally through an adapted training method called Farmer Field Schools (FFS). Sustained farmer adoption of IPM, however, has not met expectations (Feder, Murgai, and Quizon 2004; Norton, Rajotte, and Luther 2005). Analysis of contemporary agricultural production in developing countries demonstrates that farm-level decision making is becoming universalized in one dimension after another. Seed technology is increasingly controlled by transnational corporations (Mulvaney 2005). The global food system is being standardized by private quality control standards emanating from the retail sector (Busch and Bain 2004). Reardon and Timmer (2005) speak of the ''supermarket revolution'' determining the structure of developing country agriculture. Indeed, without external support indigenous knowledge appears to be disappearing (Agrawal 1995). In sum, off-farm entities are playing increasingly significant roles in shaping on-farm decisions. Zilberman et al. (1994) identified two types of off-farm agents affecting the range of IPM decisions: (1) those determining pest management options/strategies (chemical companies, research and extension); and (2) those who affect actual application methods (creditors, dealers, shippers, processors, etc.). To these, one can add a third type, those concerned with end product consumption (consumers, retailers, regulators, etc.).

Despite these universalizing processes, improved methods for promoting IPM and increasing numbers of extra-local actors, unsafe pest management decisions are still being made by smallholders in developing countries. Why is excessive and uneconomic pesticide use maintained in the face of scientific evidence of superior methods of pest management? How is it that with increasing globalization and disappearance of indigenous knowledge systems scientifically based best management practices are not universally being implemented? Focusing on the constitution of and competition between scientific and

commercial knowledge networks, the objective of this paper is to demonstrate why and how this occurs.

The knowledge networks perspective presented here builds on and adapts the insights of Actor-Network Theory (ANT). Three major points will be made. First, ANT suggests that people and technologies are interconnected in ways that negotiate the reproduction of some types of knowledge and behavioral practices and not others (Busch and Juska 1997; Clark and Murdock 1997; Latour 1987; and Röling and Jiggins 1998). This means that the factors shaping adoption of pest management practices are not simply a matter of autonomous decision making and behavioral change by individual farmers at the farm level. Pest management decisions are structured by actor-networks extending beyond the farm gate and sharing a common terminology and perspective concerning appropriate pest management practices and farm management objectives. Membership in these networks is diverse, segmented, frequently anonymous, and can span continents.

Second, this paper argues that actor-networks are not monolithic and unchanging; there is often competition among network segments which rationalize socio-material relationships in the agro-ecology of pest management practices. This analysis is organized to examine actor-network competition (Latour 2005; Law and Hassard 1999; Murdock 1998; and Sayer and Campbell 2004). Often, more than one knowledge network organizing and making sense of the same subject, object, or relational observation may exist. A single subject may at one moment see herself as a resource steward; in the next moment, a modern commercial farmer. In each moment she is applying different decision-making knowledge and supported in her understanding by a different configuration of actor-network members. These identity-forming configurations are referred to here as 'knowledge network segments.' The term, 'segments', is used when describing alternative role configurations within an actor-network where each segment has its own organizing knowledge system. Encounters between knowledge network segments involve negotiations and the leveraging of power relations from other networks. The use of the generic term, knowledge networks, refers to an undifferentiated actor-network knowledge system, invariably one which is perceived as dominant.

Third, using the insight afforded by knowledge network segments, this paper goes beyond the traditionally hypothesized dichotomy between scientific and local knowledge. Knowledge networks are framed locally, and many tend to remain so. These have often been described as indigenous knowledge systems reflecting shared understandings of customary practice. Other knowledge networks are

imperialistic and claim universality by standardizing knowledge across localities and incorporating subjects and objects from each of them. Two universalizing systems are discussed in this paper: the knowledge networks of science and of commerce. Both are invasive and tend to be destructive of existing local knowledge networks, standardizing actors and roles so that predictable relationships can be obtained across localities; however, these two are not synonymous. Indeed, as we will see, they are often in competition.

In pursuing this line of inquiry, this paper reconstructs the evolution of the theory and practice of fostering technological change in agriculture. It begins with an examination of the early success in technology transfer, the Green Revolution. The adoption-diffusion model in many ways still characterizes the standard approach taken by change agents (projects, extension services, NGOs, research institutes, donor agencies, etc.). Resistance to adoption of Green Revolution technologies led to the emergence of Farming Systems Research and Extension expanding the theoretical and practical recognition of other network actors and their roles, ultimately leading to Farmer Field Schools.

This retrospective is followed by three case studies to more closely scrutinize current practices promoting technological change in agriculture. The first two are selected because of my personal involvement in their implementation, the latter because of its central role in the debate over Farmer Field Schools. These re-studies of previously published work are analyzed through the lens of Callon's (1986) four moments of actor-network constitution.[1] The first case from Mali focuses on green bean production for export, highlighting how scientific knowledge was peripheral to a contractually established knowledge network. The second case demonstrates the power of extra-local commercial interests in the constitution of an entirely new actor-network in post-soviet Ukraine. Building on insights derived from the first two cases, the last case study reinterprets conflicting findings on

[1] There are four moments of translation in the constitution of subjects and objects as actors in a knowledge network (following Callon (1986) adapted from Clark and Murdock, 1997). The first moment is the invocation of actors around a certain definition of a problem, issue, constraint or need. The second moment involves a knowledge-promoting actor attempting to impose identities and roles on other actors that support interest in the defined problem, issue, constraint, need, etc. The third moment is when a solution to the defined problem is demonstrated or a critical new piece of information establishes an empirical relationship between components of the network. If this rationalization is successful, in the fourth moment the knowledge network consolidates a consensus concerning the 'facts,' and socio-material alliances are formed or reinforced across the network. Network knowledge reproduction is ensured through these alliances.

the success and functioning of Farmer Field Schools in Indonesia demonstrating that dominant knowledge network segments can be successfully challenged.

Fostering Technological Change in Agriculture

Diffusion of innovations represents the classic formulation of technology transfer and, consequently, of the transmission of knowledge. The goal of this model is to make productivity improvements in farmer practices at the local level through transfer of universally applicable technology developed on agricultural research stations. It is taken for granted that scientific knowledge, developed in the laboratory (or under controlled field conditions) and embodied in a form of technology (seed, implement, and/or technique), can produce an innovation sufficiently universal that it can be applied successfully in any farmer's field. Such technologies are specifically designed to overcome standardized constraints presumed to exist in farmers' fields.

The diffusion of innovations model is based on two broad assumptions (Rogers 1983): (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. Despite a more nuanced model in response to critics in subsequent editions, the *Diffusion of Innovations* retained the objective of persuading individual decision makers through an evaluative dialogue. In its most effective form, this approach promoted a short-term manipulative perspective appropriate for successful sales representatives. Consequently, efforts to change farming practices have focused on isolated choices made by individual farm operators. For agricultural scientists, this approach has proven most successful for the introduction of new varieties of crops already produced. Overall, the approach functions well in a network of trust and uncontested reciprocal identities (Busch 1978).

The Green Revolution transfer of improved rice, corn, and wheat varieties represents a successful example of this model. Let's examine the moments of translation constituting the subjects and objects in this knowledge network. The first moment of translation occurred with an agreement that production for sale should be increased. The second moment occurred when new inputs and information were introduced to farmer-adopters and additional network identities materialized to supply the need for external inputs. To the extent that the introduction of improved seed varieties did not require alterations in practices and farmers could afford the cost of additional inputs, the work of network

constitution progressed. In the third moment of knowledge network translation, increased productivity and incomes resulted, particularly for early adopters. Increased incomes allowed for the purchase of additional inputs (inorganic fertilizers and crop protection products), further standardizing the production environment and enhancing the performance of the new varieties. In the process, this growing standardization led to consolidation of the new network alliance and a coincidence of scientific and commercial interests (Hayami and Otsuka 1994). This application of scientific knowledge led to a wave of productivity increases, the hallmark of the Green Revolution.

However, many times Green Revolution innovations were resisted (Griffin 1978). The Diffusion of Innovations approach simply failed to enroll and mobilize all the necessary social and ecological actants (Latour 2005). The universal application of scientific knowledge had its limits, although it was not recognized as such at the time. Two options to explain the situation were more readily available and consistent with the dominant scientific knowledge network segment. The first option was to blame someone: i.e., non-adopters were laggards or the extension service failed to properly communicate the new knowledge. Alternatively, one could follow the positivist method and identify the empirical constraints to adoption.

In response to the weaknesses of the Diffusion of Innovations Model, the latter option was followed leading to the development of the Farming Systems Research and Extension Model (Collinson 2000; Shaner, Philipp and Schmehl 1982). The goal of this model was to adapt scientific knowledge generated in the controlled laboratory/research station to local conditions through applied research in farmers' fields. This improved the capacity to translate knowledge and negotiate the incorporation of new subjects and objects into reconstituted actor-networks. Consequently, the Farming Systems Model developed technologies that were more relevant to, and within the capacity of, many farm households to successfully implement.

For many agricultural scientists trained within disciplinary knowledge network segments, this was the first time they had worked in multidisciplinary teams. For example, soil scientists found themselves talking to breeders about the limits of various soil types, and breeders found themselves telling soil scientists about their abilities to select for such traits. This knowledge network negotiation, involving the identification of new roles, specification of problems, and search for solutions built a new alliance between researchers, extension agents, and farmers integrating local and scientific knowledge into a more holistic understanding of farmers' production circumstances. For the first

time, scientific knowledge that had been 'locked up' behind disciplinary blinders began to cross-fertilize, increasing its scope, while at the same time recognizing its limits through confrontation with local diversity.

Not conversant in the language of science, the majority of farmers and less educated extension agents were often left out of meaningful participation in this dialogue. Scientists' participation with farmers was largely unidirectional; assuring that a multidisciplinary (i.e., scientific) definition of the research problem dominated (Biggs 1989; Long and Long 1992). The farmers' role was three-fold. It provided: (1) information about identified production constraints; (2) suitable fields for on-farm trials; and (3) feedback on the value of the tested technology. The role of extension in this partnership was two-fold: (1) to identify appropriate farmers to work with and interrogate concerning local conditions; and (2) to oversee the on-farm trials involving the adaptation of the new technology to local conditions. This initial identification and enrollment of network participants would prepare extension agents to assist in the later translation and diffusion of the applicable technologies to a broader clientele.

The most recent approach to fostering technological change in agriculture, Farmer Field Schools (FFS), was originally developed to promote integrated pest management in Indonesia and claims not to be a technology transfer approach. In this model, the focus of participatory activities shifts from research to facilitation of farmer learning (Kenmore 1991), bringing the dialogue closer to the farmer's domain. FFSs are a form of adult education based on experiential, or discovery-based, learning. In the first moment of translation in knowledge network formation, farmers are identified as equal learners with extension agent facilitators as they agree to work together growing a healthy crop. The second moment is obtained through weekly meetings over the course of a production season where farmers observe and experiment with the ecology of their crops, learning about population dynamics, distinguishing pests from beneficials, estimating crop damage-yield relationships, etc. Through this guided learning mode, the FFS model achieves the third moment as farmers solve their own pest management problems, build on local knowledge, and create a new knowledge network. In the fourth moment, formal village organizations are formed that strengthen farmer capacities to participate effectively in a knowledge-intensive IPM alliance of scientists and farmers.

While integrating farmer knowledge and capacities was an improvement over the Farming Systems Model, the FFS and other recent

participatory approaches have been limited by their failure to recognize and accommodate other knowledge network segments. The following sections examine three cases that introduce the full range of actors and roles involved in commercialized agricultural production and analyze the implications of these additional actors for the adoption of IPM practices.

Green Bean Producers in Mali

Fresh, ''extra thin'' green beans (*Phaseolus vulgaris*) are a delicacy in France, particularly during the holiday season when it is too cold for their production in Europe. At this time, high quality green beans earn a premium on the market. In order to serve this market, green bean production was introduced to farmers in Mali, West Africa, during the 1970s. Green bean production, like many horticultural crops for export, was not indigenous. This introduction was slow since farmers had never before grown or consumed green beans; consequently the first moment of translation stagnated. After two decades of difficulties establishing a viable production system, a currency devaluation in 1994 provided exporters a commercial opportunity for expanded production, and new methods of contract farming were instituted.[2]

In this instance, commercial interests defined relevant knowledge as well as the identities of the other actors in the network (growers, village groups, exporter field agents, exporters, importing brokers, inspection agents, wholesalers and retailers). Product quality and the generation of a constant supply for a two-month window were the keys to successful exportation. Product quality is defined by the French consumer. Standards of appearance and taste define the product itself, and these have been translated into regulations at the European Union level. The ''extra thin'' quality designation for fresh green beans requires that the beans be less than 9 mm in width (preferably less than 6 mm), tender, crisp, and without grains and defaults of form or color (Commission des Communautés Européennes 2001). Furthermore, successful importation requires that produce must not be the vector for exotic

[2] Initial enrollment of farmers by the commercial knowledge network segment was facilitated by farmers' own experience. Farmers in this region have worked with pesticides introduced by the state-run cotton board for decades and thus have substantial experience with another externally driven knowledge system. The similarity of identities, roles, and relationships generated in cotton production were easily adapted to the contract-legitimated green been production system leading to a nascent indigenous knowledge. One example of this evolving indigenous knowledge is a local technology demonstrated to me by an older farmer who used a perforated Nescafé can as a salt or pepper shaker to apply a locally available white powder (a crop protection chemical used in the production of cotton) in the protection of his crops.

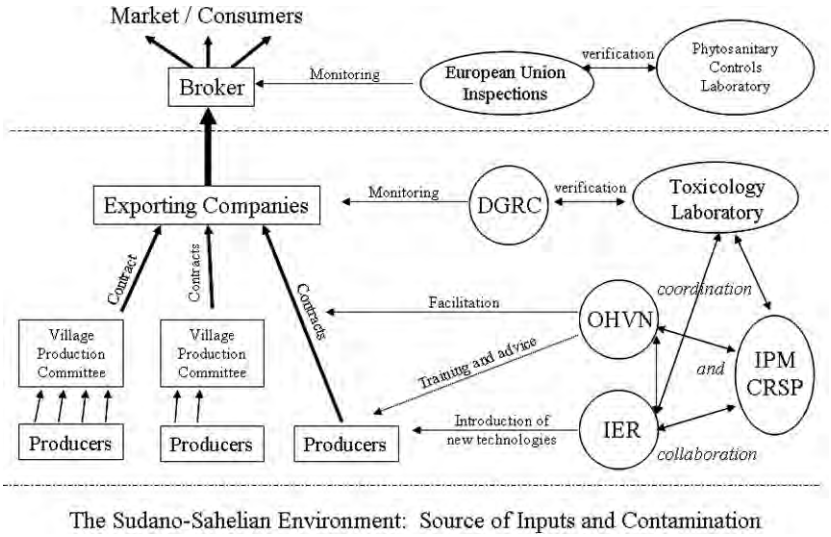

Figure 1. Green Bean Knowledge Network Segments

or invasive pests and that standards of food safety, primarily concerning pesticide residues, must also be met.

Exporters have dominated the negotiations of this knowledge network. They are responsible for the translation of appropriate knowledge at the farm level. Achieving these standards requires maintaining healthy plants and harvesting daily over the six-week productive period. In order to assure delivery of a sufficient volume of quality green beans, exporters contract with whole villages of producers, providing them with seed, fertilizer, and pesticides (or pesticide spraying services). Input expenses are deducted from the grower's payment after the end of the season. Exporters, in turn, contract with brokers at the International Market at Rungis, France, who make routine deliveries to wholesalers and retailers.

Contracts provide one mechanism for off-farm control over farm level practices and decision making. These contracts reflect conventional knowledge shared by network actors as suggested by Wolf, Hueth and Ligon (2001). Pest management practices are specified and exporters provide pesticides and spraying services for Malian green bean producers. Figure 1 presents the components of the network structure of the green bean production and marketing chain and its associated monitoring, research, and extension systems. While this schematic diagram does not necessarily include all possible network members (emphasizing human over non-human actors) it does

indicate distinguishable knowledge network segments. Each of these network segments has its own priorities, which need not necessarily be shared by other segments.

Production contracts do not identify all network actors. The production contract only applies to producers and exporters in the commodity chain (Moore et al. 2002). Another set of contracts are established between exporters and importing brokers. The regulatory network segment not only refers to sanitary and phytosanitary (SPS) inspectors in the importing country, but also the growing regulatory system in the exporting country that is attempting to assert its own identity in the network.

Contracts reflect regulatory, retailer, and consumer preferences, but they do not include scientific knowledge concerning the production system generated by research. As the responsible agency for economic development in the region, the *Office de la Haute Vallée du Niger* (OHVN) forms the core of an additional segment. OHVN extension agents were initially involved in identifying and linking producer villages with exporters. In order to improve the productivity of the new green bean sector, OHVN enrolled researchers at the Institut de l'Economie Rurale (IER) and their Integrated Pest Management Collaborative Research Support Program (IPM CRSP) partners. Experiments were designed and implemented according to the Farming Systems model to determine appropriate pest management strategies. Researchers and farmers found that pest pressure on green bean production was economically negligible. Indications of water quality reducing pesticide efficacy were found (Mullins et al. 2003), suggesting that green beans were often being grown with little or no effective chemical protection. Indeed, researchers found that farmers can produce high quality green beans with comparable yields without the use of chemical pesticides (Gamby et al. 2002).

Farmer Field Schools (FFS) were set up to help farmers learn how to identify pests, determine threat levels, and adapt a menu of pesticide-free technologies. In the first moment of translation, farmers in selected villages in the Commune of Dialakoroba were brought together by OHVN agents and IER researchers around their interest in learning more about producing green beans for export. Village producers provided a protected garden and agreed to participate in a 15-week FFS over the course of a growing season. In the second moment of translation, farmer and researcher green bean plots were established side-by-side, and alternative practices were introduced on the researcher plots while farmers maintained their conventional practices on their own plots. The farmers, extension agents, and

Table 1. Decision-making Role of Green Bean Exporter in Production Activities According to Farmer Perceptions (N = 106)

	Role of Exporter in Production Activity (in percent of respondents)			
Production Activity	No role	Advice	Influence	Decide
Fencing Garden	99.0	1.0		
Tilling	99.0	1.0		
Seedbed Preparation	98.1	1.9		
Seeding	36.2	55.2	1.9	6.7
Fertilizing	45.7	44.8	9.5	
Weeding	95.2	4.8		
Watering	89.5	10.5		
Pesticide application	9.5	31.4	50.5	8.6
Harvesting	34.3	43.8	2.9	19.0
Sorting	3.8	6.7	31.4	58.1
Packing	.9	7.5	25.5	66.0
Stocking	1.9	3.8	11.3	83.0
Transporting	4.7	1.9	8.5	84.9
Sales and weighing	0.0	1.9	7.5	90.6

Source: Sissoko et al. 2001. *IPM CRSP Eighth Annual Report.* Virginia Tech. Blacksburg, Virginia.

researchers met for one morning each week to monitor pest infestations and plant health. They learned about alternative practices and made observations on each plot. Farmers, extension agents, and researchers all saw that pesticide free production was effective and productive. This led to the third moment of translation as this new knowledge network consolidated around a shared experience of combining local and scientific knowledge about green bean production. Unfortunately, exporters were not incorporated into this new knowledge network and the fourth moment was never achieved.

As part of this research program, an evaluation survey of 106 male and female green bean producers in the targeted villages was conducted to identify information sources, decision making, and adoption of IPM practices (Sissoko et al. 2001). Among other questions, respondents were asked about the extent of exporter influence over production practices. Table 1 demonstrates the impact of this commercially driven knowledge network on green bean production practices. The table arranges production tasks in chronological order by the degree of field agent influence over each task (no role; advise only; shares in task decision making; or specifies how the task will be conducted). Exporters have almost no role in early season tasks of fencing the garden, tillage, and seedbed preparation; however, farmers perceive a growing exporter influence in their field management practices from the point of seed selection and seeding date on through

pesticide application and seed treatment. The later stages of production are perceived as even more heavily influenced by the exporter.

This dominance of on-farm decision-making by off-farm actors has been maintained despite training in FFS.[3] Further follow-up research involved informal interviews with all participants in the marketing chain and associated knowledge networks from village producer committees and IPM researchers to exporting companies, SPS agents, and brokers in the distribution center at Rungis, France (Moore et al. 2002; Moore et al. 2003b). Growing green beans for export with little or no pesticides was perceived as risky by all network participants with the exception of the marginalized researchers. Despite researcher efforts to introduce new findings into the knowledge network through the FFS, discourse concerning green bean production continues to be dominated by the commercially oriented (and pesticide applying) knowledge network segment. For example, brokers in Rungis reported having no market outlets for pesticide-free green beans. The research and extension network segment appears to overflow the network frame (Callon 1999) and, consequently, is excluded from a meaningful role.

Once established, the presence of contracts reduces the potential for introducing new knowledge and negotiating new identities. Contracts continue to reflect two knowledge network segments: commercial interests and regulatory interests. Other knowledge network segments, such as research and extension (knowledgeable in locally adapted science-based production technologies and techniques) and indigenous village networks (knowledgeable in local know-how for managing the production process) are rarely involved in contract formulation and the negotiation of the knowledge network consensus that legitimates them. Not all networks, however, involve formal contracts. Let's consider another knowledge network context.

Factors Shaping Ukrainian Farmer Pest Management Decisions

During the 1990s, Ukrainian farm workers gained the right to farm their own plots of land after over forty years of collectivized agriculture.

[3] This knowledge network has been recently reinforced by the European industry-driven Liaison Committee for Europe, Africa, Caribbean and the Pacific (COLEACP) whose mandate is to develop and promote standardized Best Management Practices (BMPs) for those exporting to the European Union. These BMPs embody European based science validated by Malian scientists. The actor-network alliance thus framed includes the entire commodity chain from producer to consumer, including pesticides successfully enrolling not only Malian farmers and exporters, but also brokers, inspectors, and retail outlets in Europe.

Unfortunately, they were ill-prepared to do so. The intervening years of centralized production and the isolation of agricultural producers had provided them with little experience or knowledge about how to farm independently. Under collectivization, farm workers were cast in the role of mindless workers executing the tasks specified in the instructions accompanying the production orders. Even farm managers made few technical decisions as planting and harvesting dates were set centrally (Ash 1998).

The transition from a command to a market economy entailed the development of a new actor-network. New public and private sector roles and accompanying decision making knowledge for the operation of market-based entities was required. Knowledge of market economies and how they function was limited and experience non-existent. In addition to the technical scientific knowledge for enterprise decision making, market actors needed to learn new institutional roles, norms, and behaviors for the application of technical information. Into this void stepped the Western donor community and a group of international agricultural chemical producers and distributors. Business management services-based development projects provided the foundation for a new commercial knowledge network segment to emerge. Relying in part on donor subsidies, international pesticide producers financed marketing-intensive information campaigns to negotiate themselves a position in this potentially lucrative market (Beeler 1999).

In order to avoid any unintended environmental or health consequences due to supplying pesticides in the context of U.S. technical assistance projects, the U.S. Congress mandates that U.S. Agency for International Development (AID) provide mitigation services (pesticide safety training and improved pest management practices for food safety and environmental health). In the Ukraine, these services were provided by the USAID-funded Pest and Pesticide Management Project (PPMP). In 1996–7, teams of Ukrainian and U.S. scientists, in collaboration with the local Plant Protection Stations (PPS), conducted a series of week-long pesticide safety and pest management workshops (Moore, Vaughan and Biyashem 1997).

Under the Soviet administration, the PPS had been the source of pest management knowledge and information. With the transition to a market economy, the PPS sought to retain this knowledge-providing role by renewing itself as the principal source for farmer decision making information with respect to pest management. In collaboration with local and expatriate researchers, it conducted PPMP training programs and later led a participatory workshop to better understand

farmer priorities and further promote their science-based IPM training program (L'viv Plant Protection Station 1998). At the outset of the pesticide safety and pest management training workshops, local pesticide company representatives had been invited to make technical presentations. Their contributions, however, were perceived by project administrators as purely commercial, lacking technical content. This led to their exclusion from subsequent training sessions (Moore et al. 1997).

In order to understand pest management information needs, information seeking practices and sources, and current practices, a 1997 survey of 70 private farmers and 70 collective farm operators (representing 20 and 43 percent of each population) in five *raions*[4] northeast of the city of L'viv was conducted (Moore et al. 2003a). The survey addressed pest management information needs, information seeking practices and sources, and current practices. University students were recruited and trained in applying the close-ended questionnaire and were involved in the pre-test and item refinement. Survey findings demonstrated that the PPS was indeed a respected institution. Despite differences in the frequency of information-seeking by different stakeholder groups, small and large enterprise managers shared many information sources. When asked about their methods of gaining information, farmers responded that they primarily visited the Plant Protection Service and read newspapers and magazines. The PPS, the traditionally legitimate source of pest management 'instructions,' was the most frequently sought out information resource in this new market economy.

When asked about pest management decision making, however, another picture emerged. Table 2 presents an OLS regression analysis of decision making influences for two strategic pest management practices relating to the use of pesticides. The first indicates the practice of spraying pesticides according to a fixed schedule. The second indicates pesticide application predicated on up-to-date, site-specific knowledge of pest populations and crop conditions.[5] What

[4] *Raions:* a unit of local government administration approximating the size and character of a U.S. county.

[5] Both dependent variables were measured on a 3-point scale indicating the frequency with which the practice was used (regularly; sometimes; and never). The independent variables of 'Pesticide Dealer's Advice' and 'Agricultural Agent's Advice' were measured on the same scale. 'Age of Farm Decision Maker' and 'Education of Farm Decision Maker' were also measured ranked categories (18 to 25, 26 to 35, 36 to 45, 45 to 55, and 55 and over; and less than high school, high school, some college, university degree holder; respectively). 'Type of Farm' was coded '1' for small private farm and '2' for collective farm. 'Amount of Time Seeking Information' was measured on a rank-order scale (none; rarely; a few hours a month; several hours a week; and more than an hour a day). 'Diversity of Information Sources' was a summation of use of 12 different sources including the PPS, mass media, other farmers, sales representatives, university researchers, farm agronomists, etc.

Table 2. Determinants of Pesticide Spraying Practices, Two Regression Models

	Dependent			
	Spraying on a Fixed Schedule		Spraying for an Economically Significant Pest Problem	
Independent	Full Model	Reduced Model	Full Model	Reduced Model
Age of Farm Decision Maker	.071		−.092	
Education of Farm Decision Maker	−.031		.141	.177*
Type of Farm	.221**	.255**	−.121	
Pesticide Dealer's Advice	.380**	.368**	−.251**	−.226**
Agricultural Agent's Advice	−.064		.086	
Amount of Time Seeking Information	−.108		−.095	
Diversity of Information Sources	−.087		−.184*	−.171*
Adjusted R^2	.235	.233	.091	.086
Model Significance	.000	.000	.006	.002

* Beta coefficient significant at the .05 level (two-tailed test).

** Beta coefficient significant at the .01 level (two-tailed test).

From: Moore et al. 2003a. Extension Services in the Transition from Post-Communist Agrarian Systems: the Case of Plant Protection Stations in Ukraine. *Southern Rural Sociology* 19:138–65.

stands out in this analysis is the pivotal role of pesticide dealers' advice, positively encouraging the use of a fixed schedule for pesticide application (particularly for individual private farmers) and discouraging spraying for only economically significant pest problems. The predominance of scheduled pesticide applications indicates a decision to use pesticides intensively in the absence of field-level observations. Pest management decision making among the studied farmers does not appear to be influenced by farm profit margins or the current scientifically based best practices of integrated pest management transmitted during the pesticide safety and pest management workshops.

Consequently, it appears that the knowledge network for pest management in Ukraine is dominated by pesticide distributors. The dynamism of this commercially driven knowledge network segment comes from the rapacious nature of the pesticide sales personnel marginalizing the role of scientific knowledge as mobilized by the public sector PPS. The implication of this is that it is not enough for the PPS to communicate good science to farmers to ensure behavioral change with respect to IPM practices. Indeed, the pesticide industry has framed an alternative identity for the well-respected, but under-funded PPS—that of arbiter of pesticide efficacy, rather than arbiter of pest management alternatives.

Entry into the global market economy has not led to a scientifically based transformation in the Ukrainian agricultural knowledge network. Under the command economy, the state structured market relations and supplied agricultural knowledge in the form of production instructions. There was little room for resistance and no local capacity to negotiate new actor-network alliances under these circumstances. Under conditions of a market economy, economic actors are required to make choices. The resulting interplay of state and market actors has framed a consensus concerning certain forms of technical and commercial knowledge, bequeathing legitimacy on them. However, as noted in the Table, the commercial knowledge system does not necessarily lead to the most profitable individual choices. This institutional culture has been modified by a re-interpretation of actor interests and enrollment of western chemical company partners in the renegotiated knowledge network.

Farmer Field Schools in Indonesia

Irrigated rice production was a Green Revolution success story. Where the environment could be transformed by these universal standards, the knowledge network of the Green Revolution was triumphant. Irrigated rice paddies provided the homogenizing environmental condition that allowed for adoption of improved technologies by both large and smallholders. The classical model of technology transfer was used to disseminate the capacity to make historical advances in productivity at the farm level; however, it subsequently led to substantial and indiscriminant use of pesticides that upset the ecological balance and generated pest resistance, resurgence, and massive pest outbreaks (Settle et al. 1996). Ultimately, environmental factors betrayed the Green Revolution network alliance of science and commercial knowledge network segments. By the mid-1980s, productivity achievements were being reversed, and famine threatened.

It was in this context that the Farmer Field School (FFS) approach was developed in Indonesia to educate farmers about how to make sound pest management decisions to restore ecological balance and improve pest management (Röling and van de Fliert 1994). During the 1990s, tens of thousands of Indonesian farmers were exposed to this large-scale, vigorous Indonesian national program that has served as a model for national programs worldwide. Although some decline in pesticide use can be attributed to policy changes, subsequent studies stressed substantial impacts of the FFS approach (Thiers 1997). Analyzing 25 impact studies, van den Berg (2004) reported immediate

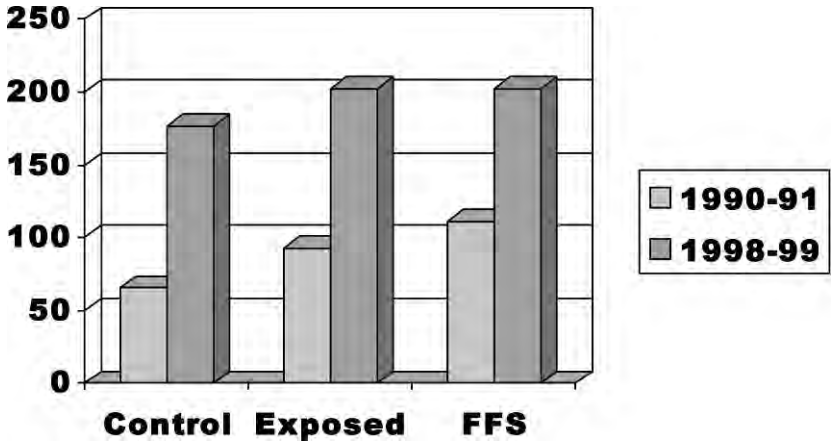

Figure 2. Pesticide Expenditures in Indonesia: 1990–91 to 1998–99 (in 1000s rupees inflation adjusted)

impacts with respect to pesticide use reductions and even increases in yields. He also noted that a number of studies highlighted developmental impacts of the training. These included the stimulation of continued learning and strengthened social and political skills that improved agro-ecosystem management.

Feder et al. (2004) also reviewed this work from a cost-benefit perspective and were unsatisfied with the methodological rigor of FFS impact studies. They argued that earlier studies had been partial and suffered from serious sampling errors that reduced the potential to accurately estimate program impacts. Their re-examination of FFS impacts used a double difference methodology to analyze a panel data set of both FFS graduates and other farmers from 1990 to 1991 and 1998 to 1999. This methodology allowed for separate identification of the direct impact on FFS participants from the secondary impact on other community members while controlling for concurrent exogenous events and interventions. Selection biases in the non-random placement of programs in communities were also taken into account. Their findings demonstrate that over the decade since the introduction of FFS, pesticide expenditures have increased (see Figure 2), pesticide use has not changed, and economic performance has not significantly improved.

The failure of IPM knowledge to inform decision-making as expected when transferred through a FFS methodology designed for a more sustainable agriculture draws into question the validity of the overall approach. Feder et al. (2004) list a set of reasons detailing why FFS did

not influence farmer performance, including: environmental factors overwhelming gains; re-infestation from imperfect transmission of lessons to non-FFS participating neighbors; logistical and trainer recruitment problems of scaling up diluted program effectiveness; biased sampling by the initial evaluation of promoters; and the realization that the costs of pest management are only a minor component of the costs of production that do not require farmer attention. This analysis stirred up a heated debate over the adequacy of the FFS approach.

What, if anything, went wrong? From the knowledge network perspective, the enrollment and persuasiveness of the FFS methodology were highly successful. It is clear that farmers found the IPM knowledge system introduced through the FFS adaptable to their circumstances and achieved initial gains in productivity and reduced pesticide use. Knowledge developed for implementation of the FFS program in rice production was scientifically based, incorporating IPM research on insect pest problems that had been conducted over the course of the 1970s and 1980s (Norton et al. 2005; Settle et al. 1996). The learning exercises designed by scientists for farmer participants to discover outcomes for themselves built on this work (Röling and Jiggins 2004). The first moment of translation involved defining the problem together. The second moment was characterized by the enrollment of farmers in the discovery-based learning process, leading to the third moment when all participants realized that successful production could be obtained with reduced pesticide applications. This new knowledge network consolidated with the extension of the FFS to other farmers and villages throughout Indonesia, and later to other parts of Southeast Asia.

During the years between introduction of the IPM approach and the later resurgence in levels of pesticide use, the pest ecology adapted and threatened productivity (Hasanuddin, Widiarta, and Yulianto 1998). The FFS-IPM knowledge network was betrayed by an evolving pest complex. Both trust and saliency of the knowledge network were put in question. The new learning that was needed was not yet supported by the research/extension network segment (van de Fliert and Winarto 1993). Without outside assistance, evolution of the knowledge network was impeded because the primary disciplinary insights relevant to the new problems required a change from entomology (with easily observable pests) to plant pathology (with largely invisible pests). The FFS/IPM knowledge network segment no longer mobilized the relevant actors and was replaced. The pesticide industry's commercial knowledge network was ready to step in with new and improved chemical

management practices (Röling and Jiggins 2004). Pesticide sales programs defined the pest problem; re-identified farmers as users of chemical pest control products and linked them with sales representatives; enrolled all of these actors in the chemically based resolution of the pest problem; and demonstrated effective control by saving the farmers crops–albeit at a profit for the pesticide producers and distributors.

While FFS-IPM programs were effective in the short-term in reducing pesticide applications and negotiating an alternative network of knowledge and practice (van den Berg 2004), in the medium term (a decade) key changes in the subjects and objects of the knowledge network occurred. The proactive scientific actor with the proper expertise providing new information had become virtually invisible and no longer actively participated in negotiating the evolving actor-networks at the local level. Another network actor (pesticide sales representatives) mediated the translation of how to manage these new pests.

Secondly, institutional network building had been short-circuited when the initial program implementers circumvented the established knowledge networks for agricultural development. Rather than mobilizing actors within the Ministry of Agriculture, the pilot phase of the National IPM Programme was run by expatriate and local experts based in BAPPENAS, the planning agency (Röling and van de Fliert 1998). This provided greater initial flexibility for implementation of a new program, but left it without the necessary understanding and support in the key government Ministry of Agriculture.

Thirdly, pesticide producers and their associations over the course of the 1990s have struggled back with stronger training and advising of their own, including pesticide safety programs (CropLife International 2005). For the most part, the pesticide industry transfers simpler messages and much of the message passed through the product itself (i.e., the chemical). The efficacy of this material actor in responding to the changed circumstances re-framed the problem and supported a renegotiation of the knowledge network. The new consensus, thus achieved, returned the commercial knowledge network segment to dominance, and consequently, increased enrollment of farmers in pesticide application.

Summary

In all three cases we find that pest management is not a matter of individual decision making, but that external forces are shaping the

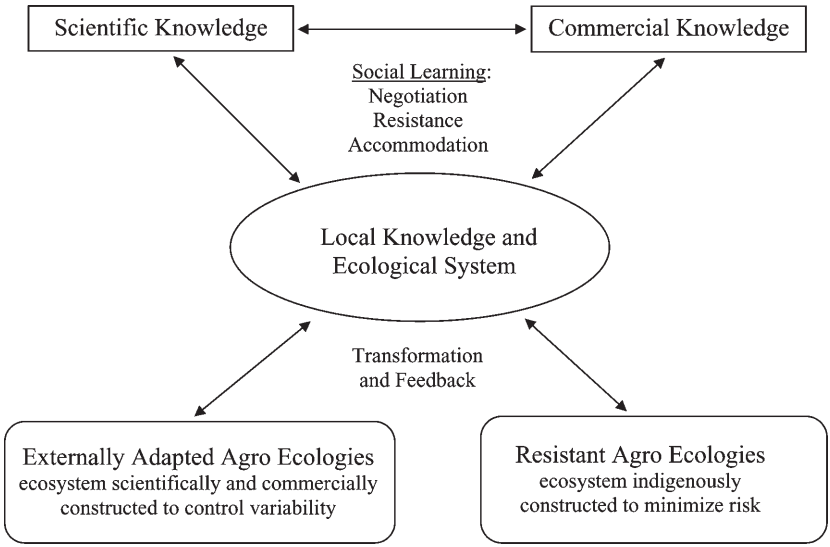

Figure 3. Actor-network Knowledge Segments Negotiating Agro-ecologies

parameters of on-farm knowledge and technological change. Although local and scientific knowledge network segments are contributing to on-farm decision making, the commercial knowledge network segment often plays the dominant role in pest management. Figure 3 presents a schematic representation of the three-way interaction of scientific, commercial, and local actor-network knowledge segments with the local environment that creates conventional and resistant agro-ecologies.

Schematically, local indigenous knowledge networks were, within their local domains, historically dominant and often capable of resisting the cultural and technological incursions of the Green Revolution. The successes of the Green Revolution can be attributed to an alliance of commercial and scientific knowledge network segments overpowering local resistance where it could promote improved local living standards. Where failures occurred, scientists began asking why in the form of Farming Systems Research and Extension. Led by social scientists with the skills to better understand and mediate relationships with local agricultural knowledge systems, a new alliance of scientific and local actor-networks was negotiated. Combined with emerging ecological concerns of biophysical scientists, this alliance began to materialize a method, Farmer Field Schools, to negotiate new knowledge networks locally. As presented here, this alliance has had marginal success in resisting the domination of the commercial knowledge networks.

In Mali, the commercial sector introduced green bean production for export and expanded it when the commercial moment was right. Contracts were developed to mobilize a standardized supply of quality controlled green beans, providing identities for growers, beans, pests, extension agents, and exporters. The mobilization of contracts and SPS regulations assured that green beans would be healthy and of a size and shape to be qualified as 'very thin.' Farmers and exporters understood their roles and, except for occasional commercial failures (non-payment due to lapses in the cold chain), there were no technical issues. Researchers, on the other hand, found that farmers had little knowledge of standard agronomic practices and that there were alternative, lower cost and locally available non-chemical means for pest management. This knowledge had little impact on practices, since it was not meaningful in the context of the contractual relationships between producers and exporters.

In the Ukrainian case, both commercial and scientific knowledge network segments were weak at the outset of the transition from command to market economy. Nevertheless, commercial actors quickly gained dominance in production decision making. This outcome was assured by donor program emphasis on the development of commercial rather than scientific knowledge network segments. The Plant Protection Station, while well-respected, came to be considered irrelevant to production decision making despite its promotion of cost-effective pest management practices. Indeed, reasoned and locally adapted IPM had little opportunity to frame problems in a network dominated by a history of top-down flow of decision making information. Resistance had no repertoire or alternative network to build on. While knowledge for more economical/profitable decisions was available, farmers had yet to recognize themselves as capable of making independent choices.

In the case of the FFS evaluations in Indonesia, competition for dominance between scientific and commercial knowledge network segments was more active, yet unrecognized in the evaluation of FFS impacts. The FAO-supported FFS knowledge network segment mounted strong resistance to the commercial network segment, to the point of becoming dominant; however, it was not sustained. Sales of pesticides surged back as the pest complex betrayed the FFS-IPM training program-created knowledge network. As Röling and Jiggins (2004) note, FFS requires more than a curriculum and trainers; it requires the support of complete institutional and policy frameworks. Teaching farmers to do science did empower them in the short term; however, it did not transform them into scientists capable of re-framing

problems to derive new knowledge as problems evolved. They were still farmers and vulnerable to being re-identified by the imperialistic commercial knowledge network segment.

Discussion

ANT analyses have focused on the distinction between universally applicable ''scientific'' knowledge and ''local'' knowledge. This opposition has mobilized considerable research advancing our understanding of what happens when science leaves the laboratory and enters the world of application in other 'localities' (Latour 1987; Law and Hassard 1999; Murdoch 1998). The analysis presented here has demonstrated that the reality of knowledge networks is more than simply a dichotomy between science and local knowledge as the indigenous knowledge advocates would have it.

Commerce constitutes another powerful knowledge network (Sayer and Campbell 2004). The success of the market/cash economy is that it, too, reduces socio-material subjects and objects to a standardized, easily translated medium: money. Commercial knowledge is based on this fundamental principle, as demonstrated by Callon (1999) in his analysis of the market as a frame for actor-networks. Commercial knowledge systems have the same mobile and imperialistic tendencies as scientific ones. Scientific and commercial knowledge network segments may enroll one another, but they stem from different universalizing principles.[6]

The analytical framework of actor-networks can and should be adapted to the analysis of competing, imperialistic knowledge systems. By extending its application to knowledge network segments, we can explain otherwise inexplicable findings of resistance and accommodation. We have seen the importance of focusing on knowledge network segments when trying to understand the dynamics of how innovations are introduced and practices change. Successful extension of a knowledge network depends on its ability to negotiate consensus among relevant actors–subjects and objects (Leeuwis 2004) or to establish advocacy coalitions (Flora and Flora 2008). Consensus does not imply the non-existence of alternative knowledge, but that resistance based on it is effectively negated by the functioning of the actor-network in that moment.

This means that some network actors can betray, or beyond that, reframe and/or renegotiate network identities. Capacity to dominate

[6] One might go on to note that the success of economics as a discipline has been its ability to translate between the knowledge networks of science and commerce.

knowledge network framing for the negotiation of roles and behaviors is not limited to political or economic powers. The early successes of the FFS indicate that scientific knowledge network segments can successfully negotiate new actor-network identities. However, we have seen that both human and non-human actors influence the success and durability of a knowledge system. This research demonstrates that resistance requires more than scientific knowledge, it also requires the enrollment of additional actors and the incentives and powers they bring to the table.

The Participatory IPM approach of the IPM Collaborative Research Support Program (Norton et al. 2005) adopted the practice of incorporating additional stakeholders in participatory appraisals to help define the problem(s) and coalesce a problem-solving partnership. Jordan et al. (2003) are also explicit about the need to facilitate the creation and development of ecological knowledge networks for social learning. However, these proactive approaches do not explicitly recognize the challenge to science from other imperialistic knowledge network segments. In his work on ''environmentality,'' Agrawal (2005) stresses the central role of power in the negotiation of knowledge networks and subject formation. To be effective, scientists must negotiate knowledge with the often powerful subjects and objects of other network segments. By consciously enrolling all the relevant actors, science-based knowledge segment actors can negotiate improved management by arbitrating between local and commercial knowledge network segments. In this way, promoters of scientifically based IPM can successfully achieve safer and more effective pest management.

Making choices among pest management practices by locally based producers is an ongoing process dependent on negotiated identities within dominant knowledge systems. Actor-networks are not static structures where one can make sense of a locality once and then know it for all time. Both subjects and objects are co-evolving in a recursive process. This leads to shifts in power relations and the opportunity to dominate knowledge production and legitimation networks. Knowledge systems and their supporting actor-networks are continually reconstituting themselves. In proactive fashion, agricultural scientists need to be conscious of the negotiations framing legitimate knowledge about the environments in which producers are embedded and the practices that yield their livelihoods.

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