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Learning selection: an evolutionary model for understanding, implementing and evaluating participatory technology development

B. Douthwaite*, J.D.H. Keatinge[1], J.R. Park

Department of Agriculture, University of Reading, Earley Gate, PO Box 236, Reading RG6 6AT, UK

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Abstract

This paper develops a model of the early adoption process that takes into account modifications made by users. The model is based on data from 13 attempts to introduce six post-harvest technologies into the Philippines and Vietnam. It is built on an analogy between technology change and Darwinian evolution. At the core of the model is the interactive experiential learning process — *learning selection (LS)* — that is analogous to natural selection in the living world. In learning selection stakeholders engage with a new technology, individually playing the evolutionary roles of *novelty generation* and *selection,* and in their interactions creating *recombinations* of ideas and experiences and the *promulgation* of beneficial novelties. Peoples' motivations to engage in learning selection, and its outcomes, are influenced by the interaction between their *lifeworlds* and their environments. The model has implications for management of agricultural technology change. It suggests the need for a nurturing of new technology during its early adaptation and adoption, until the point where the beneficiary stakeholders (manufacturers and users) are sufficiently numerous and have adequate knowledge to play the evolutionary roles themselves. The LS model, while developed with data from agro-mechanical technologies, could provide a theoretical underpinning for participatory technology development. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Participatory technology development; Social construction of technology; Model of adoption process; Postharvest technology; Philippines; Vietnam

* Corresponding author. Present address: International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

E-mail address: b.douthwaite@cgiar.org (B. Douthwaite).

[1] Present address: International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria

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1. Introduction

The Food and Agriculture Organization estimates that international assistance to agricultural development fell from $16 billion in 1988 to $10 billion in 1994 (ODI, 1997). In 1996 the Organisation for Economic Co-operation and Development (OECD) agreed international development targets that included a halving of the proportion of people living in extreme poverty by 2015 (OECD, 1996). Poverty reduction has since been adopted as a goal by many donor organisations. The implication of these two developments is clear. If international agricultural research wants to increase its funding levels then it must demonstrate that it is having an impact in poor farmers' fields to a greater degree than it has done in the past.

Unfortunately though, Public-sector agricultural research is sometimes seen as having more impact in richer farmers' fields than in poorer ones. One commonly cited reason is that researchers implicitly assume a relatively simple mental map of the research, development and transfer process that better matches the relatively simple farming systems found in favourable production environments (where farmers tend to be richer) than those found in less favourable production environments. This simple mental map has been called the Transfer of Technology (TOT) model or Central Model (Chambers and Jiggins, 1986; Biggs, 1989). It is based on the positivist paradigm that underpins conventional science and considers that reality is objective, independent and based on natural laws that science can uncover (Röling, 1996). According to the TOT view, scientific method can be used to understand reality and design technologies. Hence agricultural scientists believe that they can and should be able to deliver technologies that work in farmers' fields. Local knowledge might be important for fine-tuning, but this can be captured during on-farm testing prior to release. The technology should not be released before it has been 'perfected' by which time the researchers have finished their job. It is then up to the extensionists to deliver the package to the farmers who either do or do not adopt, but are not expected to make innovative changes. This model has worked well in generating and delivering simple technologies — high yielding crop varieties — into relatively favourable production systems, and in the process spawned the Green Revolution.

In 1995 the International Rice Research Institute (IRRI) and the University of Reading began a study to examine the extent to which the TOT view fitted the innovation processes of relatively complex new agricultural technology. This paper presents an evolutionary model of the early stage of the adoption process which may fit reality much better than the TOT model. While developed from agricultural engineering data it is suggested here that the model is also relevant to planning, implementing and evaluating participatory technology development in other disciplines. Participatory approaches are increasingly being recognised as being more effective at achieving adoption and impact in poor farmers' fields than the technology generation and transfer approaches traditionally used by much agricultural research (World Bank, 1996).

2. Methodology

One of the challenges facing an ex-post study of innovation is that there is no evidence left of the critical steps in the innovation process, and that people have forgotten about them. This study considers agricultural machinery because it has a physical manifestation that is relatively easy to modify (cut and weld) and it then, in effect, leaves a 'fossil' record of adaptation because the changes are difficult to destroy.

A case study methodology is used because technology adoption is a complex process (Tidd et al., 1997) and case study methodology is, "a method for learning about a complex instance, based on a comprehensive understanding of that instance obtained by extensive description and analysis of that instance taken as a whole and in its context." GAO (1987, p. 9).

The case study technologies chosen are all the rice harvesting and rice drying technologies introduced to the Philippines and Vietnam after 1975. The definition of 'introduced' used in the paper was that at least 100 machines had been used in either country. Two types of harvester qualified. Both are relatively cheap and light mechanical harvesters, and achieve this by being controlled by an operator who walks behind the machine rather than riding on it. Four types of dryer were also eligible. They ranged in capacity and cost from the locally-made SRR dryer — SRR is an acronym for "very low cost" in Vietnamese — which can be bought for $100 and dries 1 t of rice in 2–4 days, to recirculating dryers imported from Taiwan which cost 150 times more but can dry 6 t in 8–10 h. The case study technologies are shown in Tables 1 and 2.

The Philippines and Vietnam were chosen to take advantage of a *natural experiment* (Freedman, 1991) created by the *Postharvest Technologies for Rice in the Humid Tropics project*.[2] This project gave National Agricultural Research and Extension Systems (NARES) in the Philippines and Vietnam similar resources to pilot test two technologies — the stripper gatherer (SG) harvester, and the low-temperature in-bin drying system (LT-IBDS), from which the SRR dryer was developed. The inputs into the pilot testing, modification and initial dissemination programs set up by the NARES in both countries were the same although the outcomes were quite different. This natural experiment allowed an analysis of the effect of people (their lifeworlds)[3] and the environment on the innovation process. Also, the GTZ Project generated a great deal of process documentation which is necessary for developing a detailed understanding of the adoption process. Furthermore the first author was a *complete participant* (project leader and chief designer) in the

[2] This project was co-ordinated by IRRI and funded by the German government, through GTZ. In the implementation phase of the project NARS chose postharvest technologies which they were then funded to evaluate and initiate commercialisation. The implementation phase ran from January 1993 to December 1997.

[3] Lifeworlds are the realities that people adaptively construct for themselves. They are the sum total of the mental maps and models that people have built to allow them to cope in their environments and as such are made up of past experience and personal and shared understanding (Long, 1992).

Table 1
Description of case study technologies

Technology	Description	Adoption status	Lab. prod[a].ha^{-1}	Cost $
Stripper Gatherer (SG) harvester	Walk-behind harvester	140 units sold in 5 years (Philippines)	7.5	2000
Mechanical reaper	Walk-behind harvester	1071 units sold in 8 years (Philippines)	15	3000
SRR dryer	Low temperature dryer	700 units sold in 3 years (Vietnam)	6.4	100
Flatbed dryer	Heated air dryer with manual mixing [a]	1000 units sold in 17 years (Vietnam)	4.8	2000
Flash dryer	High temperature dryer	2000 units *donated* in 4 years (Philippines)	3[b]	3500
Recirculating dryer	Heated air dryer with mechanical mixing	1500 units sold in 6 years (Philippines)	1.5	15,000

[a] Drying to 18% m.c. (wet base) not 14% m.c. as the other dryers.
[b] Lab. prod. = labour productivity measured in person hours per tonne of paddy rice (rough rice).

Table 2
Introduction of case study technologies in the Philippines and Vietnam

Technology	Source of innovation	Philippines	Vietnam
Harvesting			
SG	**Public**	**✓(×2)**	✓
Reaper	Public	✓	✓
	Private	✓	
Drying			
SRR	**Public**		✓
Flatbed	Public	✓(×2)	✓
Flash	Public	✓(×2)	
Recirculating	Private	✓	

Bold indicates main case study technology.

development of the SG harvester and a *participant observer*[4] (team member) in the development of the SRR dryer. Participant observation is a way of gathering data on the motives, meanings and experiences of stakeholders in a social process like innovation (Burgess, 1984). Hence the SG harvester and SRR dryer case studies were constructed with much more detail and data than the four others.

Although there is debate about whether the technology generation and adoption process is linear there are nevertheless discernible stages in the life of an innovation. One categorisation, after Yin (pers. comm. with S. Sechrest, 1996), is shown in Fig. 1. According to the TOT approach researchers should hand-over their technology to extension workers at the beginning of the *adaptation phase*, hence this phase and the *start-up* phase before it, are the two of interest in this study to test the validity of the TOT view of innovation.

Case studies may be criticised for lacking both internal and external validity (GAO, 1987; Yin, 1989; Sechrest et al., 1996). The main threat to external validity is that generalisation of the findings to other situations is not legitimate. The four ‘minor’ case studies provided a check to the relevance of the findings from the two ‘main’ ones. *Life histories* of all 13 innovation attempts were constructed describing the time-ordered sequence of events, the stakeholders who were responsible for or influenced the events, and other contextual influences (Sechrest et al., 1996). As well as analysing the individual life histories, cross case comparisons were also made.

Inaccuracy, bias and lack of objectivity are the main threats to internal validity (Yin, 1989). The use of life histories is an important guard against these. In addition, the large amount of process documentation for each of the main case studies, and the use of multiple data sources for all case studies, helped maintain internal validity.

[4] Complete participant and participant observer are two ideal field roles described by Gold (quoted by Burgess, 1984). For more details see Douthwaite (1999).

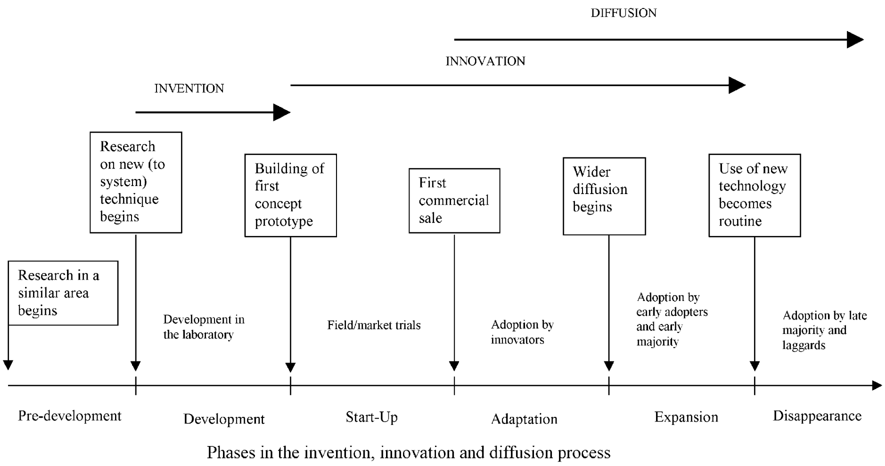

Fig. 1. Stages in the innovation process.

Multiple data sources included:

1. surveys of key stakeholders (manufacturers/suppliers and users);
2. participant observation (for the main case studies only);
3. process documentation and other secondary literature;
4. key informant interviews (often recorded and transcripts made); and
5. documentation of physical evidence by photograph and video.

The whole population of manufacturers was interviewed for the main case study technologies, and half the population of adopters, or 40, whichever was smaller. For the minor technologies an attempt was made to interview two manufacturers/suppliers and six adopters. Another methodological safeguard was that key people were asked to read the main case studies as a further guard against inaccuracy, and as a check against subjectivity and bias.[5]

One challenge to constructing effective and persuasive case studies is to avoid becoming swamped in data and detail. Sechrest et al. (1996) recommend construction of a *theory of the case* to act as a guide to data gathering and analysis. Our theory of the case was based on an analogy that has been made between technology change and Darwinian evolution (Nelson and Winter, 1982; Mokyr, 1990). If this analogy is valid then technology change must be driven by a process analogous to *natural selection*. Hence our theory of the case is simply that there is an analogue, which we call learning selection, shown in Fig. 2. Learning is central to innovation (Nelson and Winter, 1982; Mokyr, 1991; Clark, 1995; Leonard, 1995) which is why it is the basis of the learning selection model. Kolb's (1984) experiential learning

[5] Caesar J.M. Tado, Senior Research Specialist currently working on stripper harvesting at the Philippine Rice Research Institute commented on the SG harvester case studies, and Martin Gummert, former GTZ project manager and drying expert commented on the SRR dryer case study.

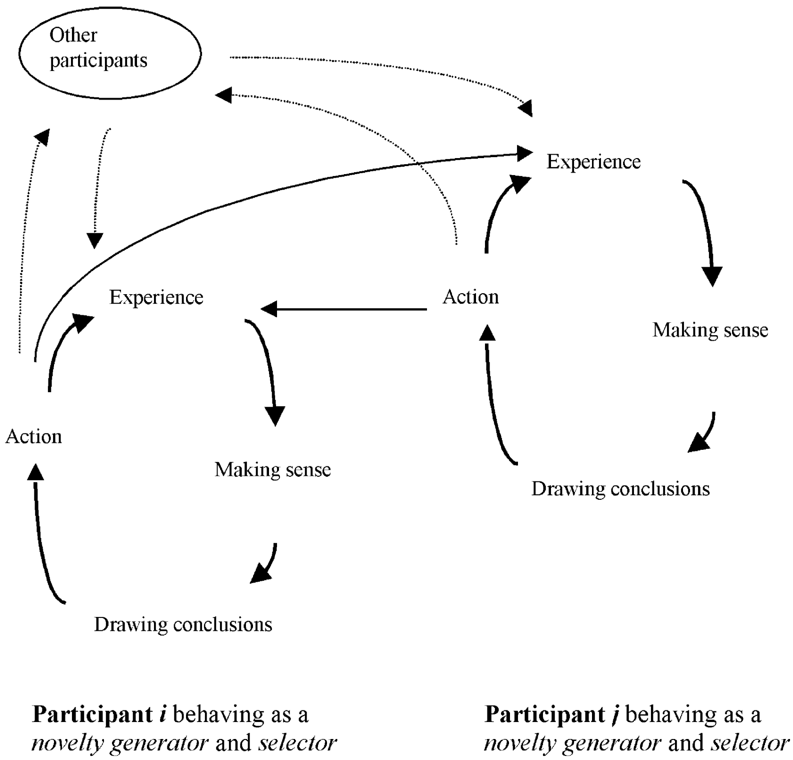

Fig. 2. The *learning selection* algorithm, analogous to *natural selection*.

model was chosen in particular because the two types of learning that characterise the innovation process — 'learning by using' and 'learning by doing' (Rosenberg, 1982) — are both types of experiential learning. Rosenberg defines 'learning by using' as learning during manufacturing that leads to improvements in the manufacturing process while 'learning by doing' is learning during the use of the technology that make it work better.

The analogy suggested here between natural selection and learning selection is not perfect. Rather, it is an 'analogy as a heuristic'; an analogy that suggests ways of thinking about innovation processes from the much better understood evolutionary process (Ruse, 1984). One obvious difference between natural and learning selection is that natural selection is 'mindless' while learning selection is not — genetic mutations occur at random but farmers make changes to their machines for a reason. This difference means that to make learning selection into a useful tool for understanding and predicting the outcomes of the early stages of innovation processes, an understanding of the motivations of people involved in learning processes is required. For instance, what motivates people to want to interact with new technology in the first place? … what is likely to influence the outcomes of the learning selection iterations they go through? Some factors will help the technology evolve.

Long's (1992) actor-oriented approach is designed to understand the ways in which groups interact with an intervention such as a new technology, and how these interactions are affected by cultural, social, political and power dynamics. Douthwaite et al. (2000) examine how the actor-oriented approach and the learning selection approach can be integrated.

Fig. 2 is a model of how learning selection works. It illustrates two of the potentially many participants involved in their own learning cycles while at the same time interacting with others. Individually participant *i* and *j* are carrying out two of the three roles necessary within an evolutionary system:

1. *Novelty generation* that creates differences between individual members of the species (Nelson, 1987), e.g. individual differences between machines of the same type, or the way they are used.
2. *Selection* of beneficial novelties (Nelson, 1987).

They do this during an experiential learning process based on work by Kolb (1984) and Hunt (1987) and consisting of four stages shown in Fig. 2.

Experience — suppose a farmer finds that the rice miller pays her a low price for the grain dried in her dryer because some of it is not properly dried.
Making Sense — she reflects on this experience from different points of view to give it meaning. For example, she realises that uneven drying is losing her money and that it might be sensible to try and improve the dryer's performance.
Drawing conclusions — she then develops personal explanations of what happened from her own or others previous experience or theories. For example, she hypotheses that if she reduces the amount of paddy she loads into the dryer then drying will be more uniform.
Action — she then decides to test her hypothesis, and in so doing *generates a novelty*.

Testing the novelty begins another learning cycle. Her *selection* decision to adopt or reject the novelty will depend on whether the rice miller pays her more for her product. The miller will make this price decision after going through his own learning cycle when he tests a sample of her rice for milling quality. If the farmer is participant *i* in Fig. 2 then the miller represents participant *j*.

The third component required of an evolutionary system is a *promulgation and diffusion* mechanism. In our example promulgation of the novelty occurs when the farmer tells people in her social network, represented in Fig. 2 by the 'other participants' box, about the benefits of her novelty and they select to adopt it. Moreover, many of these people may be going through their own learning cycles creating the conditions for the *recombination* of differing observations and experiences that can lead to the generation of novelties that have 'hybrid vigour'. In the process the technology evolves and with it the participants' opinions and knowledge of it and the way they organize themselves to use and promote the technology. These processes are all involved in learning selection, and the implicit assumption is that they will lead to improvements in fitness of the technology, where fitness is taken in the biological sense to mean improvements in the likelihood that the technology will be adopted and promulgated. This concept of fitness, or adoptability, is similar to

Lyotard's (1996) concept of performativity, which he defines as the best possible input/output ratio. Lyotard argues that performativity itself is the main form of legitmisation of knowledge.

Part of the purpose of developing the learning selection model is to guide case study data collection, as already discussed. The model does this by suggesting that life histories describe the degree to which learning selection took place. Modifications made to a technology are evidence of learning selection having been carried out. The life histories should therefore identify modifications and evaluate their effect on the performance of the technology. This is an investigation of the *novelty generation* function. Data should also be collected on the *selection* and *promulgation* functions, namely, which modifications were selected and who promoted the modifications and the technology itself, and how. Contextual data should be gathered on participant characteristics and their environment to explain the outcomes of the learning selection iterations. This data will also help identify factors that affected peoples' motivation to participate.

3. Case study findings

The six technologies shown in Table 1 were major inventions when they were first introduced into Vietnam and the Philippines. The 13 subsequent innovation attempts provide data to support Mokyr's (1990) conclusion that major inventions are nearly always followed by a learning process which improved the 'fitness' of the technology. The case studies of the technologies with a public source of innovation (*public* technologies) clearly show that manufacturers, users and sometimes researchers made many modifications and selection decisions after commercialisation. While the overall effect of these changes was to generally reduce production and operation costs (improve input/output ratio), some changes, particularly in the early adoption stages, proved detrimental to the technology's fitness and its evolutionary prospects. Examples of equipment evolution after commercialisation are given for four technologies, followed by an examination of the degree to which learning selection occurred. The full details of the case studies are presented in Douthwaite (1999).

3.1. Examples of equipment evolution

3.1.1. The flatbed dryer in Vietnam

A university lecturer installed the first flatbed dryer in 1983 in Soc Trang Province in the Mekong Delta. The dryer was introduced into an area where the move from single rice cropping to double rice cropping, made possible by the development by IRRI of shorter growth duration rice varieties, was being seriously constrained by problems drying the first crop in the middle of the wet season. By 1985 local entrepreneurs began copying the design but made mistakes in replicating the blowers due to a lack of technical knowledge. As a result rice traders paid 5% less for flat-bed-dried rice compared with sun-dried rice. Nevertheless farmers used the dryers because they were often the only way of drying their produce. Over a 10-year period a whole set of improvements to the dryer and the way it was used meant that the price paid for mechanically dried paddy was by 1994 5% higher than the price paid for sun-dried paddy. These improvements were made by manufacturers and users as part of 'learning by doing' and 'learning by using', respectively. In this period the cost to farmers of using flatbed dryers fell from as much as 12% of the value of the yield to 5%. A reduction in fuel costs was largely responsible for this fall, brought about by village craftspeople realising that their indigenous rice hull cook-stove could be used as the basis of a furnace design that would burn rice hull instead of more expensive wood. As the flatbed dryer became cheaper to use, it spread without public sector intervention, beyond its cradle in Soc Trang Province to other areas of the Mekong Delta. There are now an estimated 1000 dryers in the Mekong Delta drying about half a million tonnes of paddy per year, and in so doing saving Vietnam millions of dollars.

3.1.2. The SG harvester in the Philippines

The SG harvester was first commercialised in 1993. The first farmers to adopt in the Philippines, and the first larger-scale manufacturer to start building, did so after hearing about the technology in newspaper and other media stories that resulted from an IRRI press-release. The initial units sold had problems with the reliability of the ground-drive transmission, due in part to the substitution by manufacturers of cheaper and lower quality components. In 1995 IRRI released the Mark II SG harvester design which had a heavier duty transmission, as well as other strengthened components. This reduced the reliability problem, but increased the weight by 31%, making the machine harder to manoeuvre and more liable to bog down in soft field conditions. In 1996 a manufacturer — Morallo Metal Industries — developed its own version of the Mark II design that was almost as light as the first version but far more reliable. Another manufacturer developed an idea for an improved wheel design that was further developed by IRRI and proved to give much better mobility in muddy field conditions. In 1997 IRRI released drawings of the Mark III SG harvester based on the Morallo SG harvester and incorporating the novel wheel.

3.1.3. The SRR ("very low cost") dryer in Vietnam

The first SRR dryer was sold to a farmer in October 1995, built by an R&D team at the University of Agriculture and Forestry (UAF). The first units sold were fitted with a 1 kW electric cooker element to heat the air blown into the paddy being dried. Again, the first farmers to buy heard about the dryer from the media and came to UAF to find out more about the technology. Initially sales were limited to areas near Ho Chi Minh City where farmers had a good electricity supply. In 1996 the R&D team added a coal stove as an optional replacement for the electric cooker element. This meant that the SRR dryer could be used in areas with a poor electricity supply (low voltage). Another manufacturer started copying the SRR dryer in 1995 and began supplying dryers with a 110 V motor rather than 220 V one to operate in areas with poor electricity supply. He also reduced the power demand and capacity of the blower. These modifications increased the potential market for the SRR dryer still further but the 110 V motors proved more liable to damage from voltage fluctuations and the reduced blower capacity reduced drying efficiency. The net effect of these manufacturers' modifications on the fitness of the technology was negative.

Owners of the SRR dryer made important modifications to the operation instructions provided by UAF with the machine. UAF's instructions to turn the heater off during the day were to minimise fuel costs, but led to long drying times. Most farmers, however, had more than one batch (1 t) to dry at a time and so reducing drying time was their main priority. Hence most ignored the UAF recommendation and kept the heater on all, or nearly all, of the time. Even if they did turn the heater off, hardly any used the UAF-recommended drying strategy, choosing instead to devise versions of their own, matched to their electrical supply, the initial moisture content of paddy to be dried, and personal preference. By adopting such strategies owners were able to reduce the drying time by 39%, or by 42 h for a 22% increase in energy costs if coal was used, or 37% increase if an electric heater was used.

3.1.4. The mechanical reaper in the Philippines

The Kubota mechanical reaper sold in the Philippines is one of the two technologies that had a private sector source of innovation (*private* technology). The same machine is still being sold and has not been modified at all. This is in contrast to the *public* technologies which were all modified, some a great deal, after first commercialisation. Very limited numbers of changes have been made to the other *private* technology in the survey, the recirculating dryer. The *private* technology hardware evolved less than the *public* technologies because both had been developed, commercialised and 'perfected' in other countries before introduction into the Philippines, and because the designs were being built by only one manufacturer. *Public* technologies were often built by many manufacturers and so had multiple sources of *novelty generation* and *selection*. For example 12 manufacturers have built the SG harvester. The advantage, therefore, of *private* technology is that it can be expected to work better when first released onto the market. The disadvantage is that there is just one source of hardware novelty generation that is often geographically distant from the market. As a result *private* technology can be expected to be less responsive than *public* technology to changing local needs.

While the *private* technology hardware changed little, owners and operators made important changes to the way they used the technologies, as they did with the *public* technologies. For example, teams of harvest labourers now hire Kubota mechanical reapers when prior to 1983 all harvesting was done by hand. When the Kubota reaper was first introduced owners competed directly with manual harvest teams for work. Manual harvesters responded in some cases by sabotaging the machines by placing iron rods in unharvested crops to destroy the reaper cutterbar.[6] Another strategy for discouraging the use of the machine was for labourers to refuse to hand harvest crops for reaper owners when the reaper did not work, for example in badly lodged crops and deep mud. The organisational innovation that helped solve this

[6] The sabotage technique was also used when mechanical harvesting was first introduced into the UK (Farming Today on BBC Radio 4, 7 November, 1998).

problem is one that allows the labourers to decide if and when to use the reaper, so they no longer see it as competition. Rather they see it as a useful tool that allows them to harvest a greater area and earn more. Increasing labour shortage due to alternative off-farm employment has meant that harvesting teams have not come into conflict with each other. Harvest teams now use the machine in good crop conditions, while in poor crop and field conditions they hand harvest but charge farmers more. This willingness to compensate for the technical shortcomings of the machine has made them less of a constraint to usage and adoption. The SG harvester case study showed that similar technical limitations have reduced the utilisation rate of the technology.

3.2. Learning selection carried out by stakeholders

3.2.1. Researchers

The researchers' main role was to develop a promising prototype of a new technology. This 'plausible promise' began the learning selection process by convincing at least some manufacturers and farmers that it could be of benefit to them, and hence to adopt. However, rather than handing the technology over to an extension organisation at this point, as the TOT model dictates, in many cases the R&D team continued to stay involved. In eight out of the 13 case studies the R&D team played a clear 'product champion' role in working after initial adoption "to push the new technology through the innovation process and overcome obstacles" (Peters and Waterman, 1982, p. 64). In terms of the learning selection model the researchers championed their technologies by *selecting* beneficial modifications made by manufacturers and users, and then *promulgating* them. Researchers often facilitated learning selection by identifying 'knowledge gaps' that were causing the key stakeholders problems, and then working to fill them, while at the same time recognising and filling the gaps in their own learning. The net effect of the R&D teams efforts was often to build a 'common property regime' in which manufacturers, who would otherwise be competing with each other, contributed their ideas towards the common goal of developing a better technology. Engineer Lawrence Morallo of Morallo Metal Industries explained why he let IRRI take his improved design (see Fig. 3) and then give the drawings out for free. "Further improvements can still be made on the design that we gave to IRRI. Improvements can always be made to the stripper. Even other manufacturers can still make changes. At least we can also get ideas from them. We can adapt their ideas."

One of the main impediments to researcher learning selection were government programs that began widespread diffusion of technologies too early because they assumed the machinery was sufficiently perfected. Eight of the 11 public sector innovations were promoted in nation-wide programs which began very early — on average just 2.3 years after research started. According to Collinson and Tollens (1994) it can take 10 years to produce a useful technology if beginning with basic research. Nevertheless R&D teams and their donors agreed to the inclusion of their technologies in these programs because they saw this as an indicator of success because it meant large numbers were built and sent to the field. However, this effectively set the design in stone (it is hard to tell a manufacturer you made a

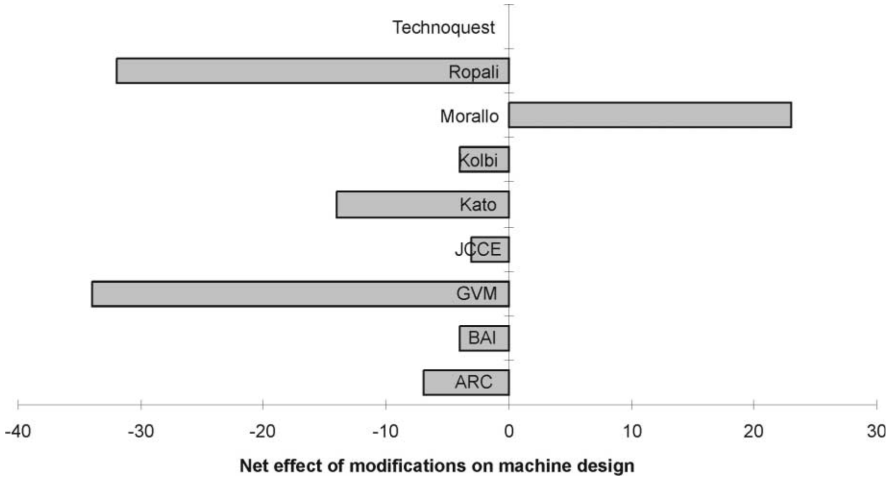

Fig. 3. Net effect of manufacturers on the design of the Mark II SG harvester.

mistake and to recall hundreds of machines) and made the R&D team defensive to subsequent criticism. Furthermore, even if the R&D team remained receptive to suggestions for improvement the SG harvester case study showed that once the government promotion program began most of the R&D team's time was taken up with training regional technicians.

3.2.2. Extension workers

The degree to which extension workers became involved in learning selection depended on how the extension program was organised. If the program assumed the TOT model, as was the case with the promotion of the SG harvester and flash dryer, then they were not expected to make modifications and were not given the resources or responsibility to do so. Worse still, they felt that their recommendations and suggestions were ignored. They had very little incentive to be pro-active in solving or reporting problems. In contrast, when extension workers were able to modify and promote the SRR dryer on their own initiative, they became a large driving force behind the dryer's refinement and rapid adoption.

3.2.3. Manufacturers

Manufacturers modified the technology hardware a great deal, making, for example, an average of 23 changes to the basic design of the SG harvester they were copying. These changes came in four categories:

1. changes to the design to make it cheaper or easier to build;
2. changes to the design to improve the performance of the machine;
3. continuing to use a feature of an older design that they had been building prior to adopting the new design, and which they did not think was worth changing; and
4. mistakes or oversights.

Manufacturers were behaving as *novelty generators* when making the first two types of change. In the third category they were behaving as *selectors* in deciding not to adopt certain aspects of the design. The fourth category of modification did not immediately involve learning because it was a mistake or oversight. Once the mistake was made, however, feedback sometimes led to a changed perception, learning and modification. *Promulgation* occurred when manufacturers copied changes made by other manufacturers, or detailed in the periodically updated drawings circulated by the R&D group.

Manufacturers made some very important improvements to the technology. For example, Morallo Metal Industries reduced the weight of the SG harvester by 25% making it cheaper and easier to use. In the medium-term manufacturers improved the fitness of the technology, but when they first started building machines there was a tendency for them to make more detrimental changes than improvements. Fig. 3, which shows the net effect of the modifications made by nine SG harvester manufactures, indicates that only Morallo Metal Industries would have had a net positive effect on the design without some 'industrial extension' by the research team.[7] An example of one manufacturer modification that was particularly disastrous was the reduction of the rotor and forward speed on the 14 units supplied to regional demonstration centres in the Philippines. The change meant the machines harvested with high loss and as a result much damage was done to the reputation of the technology amongst extensionists and co-operative members who attended the demonstrations. The manufacturer did change back to the original speeds a few months later but did not recall the demonstration units or even mention the problem. The R&D team who perhaps should have noticed the problem were too busy training regional technicians to thoroughly test the units before they went out to the regional demonstration sites.

Most of the modifications made by manufacturers were to the machine hardware, i.e. the embodied knowledge. Nevertheless they also made some important innovations to the software knowledge, that is the knowledge not embodied in the machine itself, but necessary to build the machine cheaply and well, or to use it properly. For example, some manufacturers developed jigs and fixtures to make fabrication quicker and easier. An example of an innovation made in the way labour was organised in building the machine is the adoption of the *pakyaw* system of hiring contract labour to avoid employer obligations under Philippine labour laws. The workers were paid a piece rate according to their output but as a result tended to rush the work. Without strict quality control the *pakyaw* system had a large detrimental effect on quality. Even though some manufacturers and customers knew this, adequate quality control was rarely in place.

Government machinery programs were found to be a disincentive to learning selection, partly because of the tendering process. Manufacturers wishing to build machines for a government program had to copy a standard design and then submit a prototype to be checked for compliance with the standard. This accreditation

[7] Each modification made by a manufacturer and identified during the survey was rated on a +5 to –5 scale. The sum of these valuations is shown in Fig. 3. See Douthwaite (1999) for methodological details.

process, plus the fact that manufacturers were not selling directly to the intended users, hampered learning selection by reducing the manufacturers' scope to make changes and by reducing feedback about potential shortcomings, respectively.

3.2.4. Users

In contrast to the manufacturers, users made most of their changes to the technology software. The organisational innovation already discussed above surrounding the use of the reaper is one example. Another was that some SG harvester owners paid their operators according to area harvested, rather than a daily wage, and enjoyed a significantly higher seasonal usage rate as a result (see Table 3).

Although owners were making less than one tenth of the number of modifications made by manufacturers they nevertheless represented an important source of design improvement through their recommendations for modifications. Over half of the 24 non-trivial recommendations recorded by owners in the survey were incorporated in later designs by manufacturers, or in the drawings produced by IRRI.

Users also played an important *promulgation* role. This was particularly clear in the case of the SRR dryer where on average 68 people visited each unit in the survey sample. UAF built their extension strategy for the SRR dryer around users in key villages who would teach and promote the technology to others. In the case of the recirculating dryer, adopters said that recommendations made by neighbours and associates were important in persuading them to buy the machine. The SG harvester and flash dryer case studies showed how adopters who have a negative experience with a technology could dissuade others from buying or using the machine.

Government programs also tended to limit user learning selection because by giving equipment to users at a highly subsidised rate they reduced the incentive to sort problems out when they occurred. As one manufacturer said, "farmers don't appreciate the machine if it is a dole-out (given for free)." (pers. comm. with A. Atienza, 1997). Co-operatives who acquired the SG harvester virtually free under a government program used the machine less than private individuals who had paid the full price for the machine.

Table 3
Level of harvester usage by incentive for SG operators

Harvester usage rate (ha per season)	Incentive for SG operators			
	Piece rate	Daily wage	None	Totals
>3	5	1	0	6
1–3	1	4	3	8
<1	1	0	4	5
Totals	7	5	7	19

$P=0.011$ [significant at the 5% confidence limit level according to the Fisher exact test (Everitt, 1992)].

4. Discussion

4.1. Developing a conceptual model of the innovation process

The case studies show that a very large amount of innovation took place after release of the technology. The conventional TOT model did not fit reality — scientists and engineers were not able to produce useful technologies, only prototypes that promised to be useful.

Fig. 4 shows a schematic representation of what really happened, and as such is a component of a new conceptual model of the innovation process. It shows a successful case-study technology beginning its life history as a bright idea that is then developed during the development phase. At this stage the R&D team are driving the process and the farmers and manufacturers — the key stakeholders — participate, if at all, as consultants. This laboratory phase ends when the researchers develop their 'best bet' — a prototype embodiment of what they believe will benefit the key stakeholders — and take it to the field. During the start-up phase the R&D team demonstrates the machine or loans it, and then seeks feedback from potential customers and manufacturers. On the basis of this feedback the R&D team modify their 'best bet'. Key stakeholders become increasingly interested in the technology to the point where one or two manufacturers and a few farmers believe that the machine makes a 'plausible promise' of being of benefit to them. The essential difference between a 'best bet' and a 'plausible promise' is, therefore, that the former is

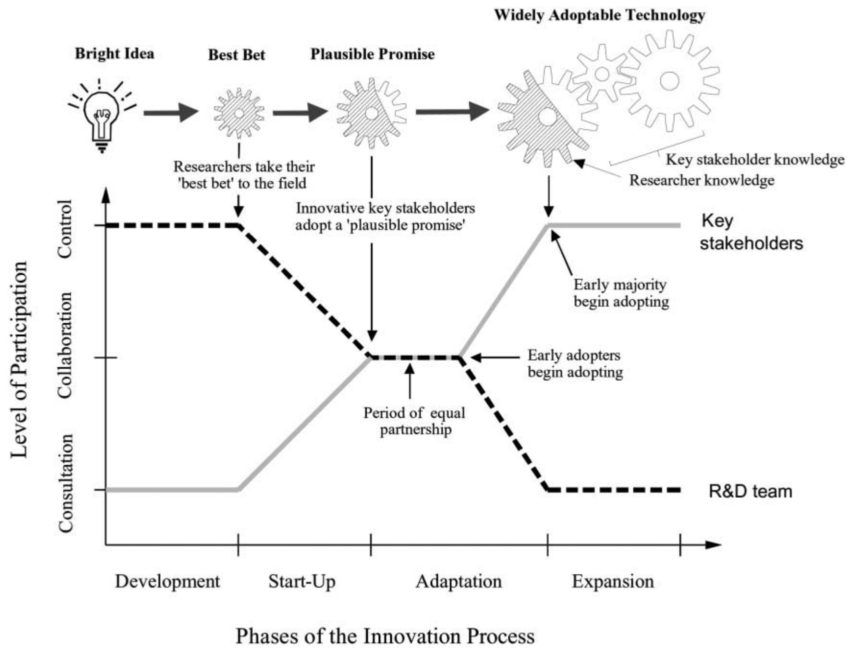

Fig. 4. Evolution of knowledge during the innovation process and how stakeholder participation changed.

defined by the R&D team and the latter is decided by the key stakeholders. Another difference is that the ‘plausible promise’ embodies more knowledge, some of which comes from the key stakeholders. This is shown in Fig. 4 as an increase in the area of the gear-wheel depiction of the technology, and a change in its shading.

The adaptation phase begins when the key stakeholders show they believe in the ‘plausible promise’ by adopting, and in so doing invest materially in the technology. This research found that the first farmers to adopt closely resembled Rogers (1995) definition of an innovator, the first in five categories of adopter types he identified. The others are early adopters, early majority, late majority and laggards. Rogers described innovators as venturesome, enjoying the technical challenges posed by new technologies and actively seeking them out.

It has been suggested that the R&D team needs to remain involved during the adaptation phase to nurture learning selection by filling knowledge gaps amongst the key stakeholders, selecting beneficial modifications and promulgating them, and in carrying out their own learning selection iterations. It is exactly this phase, though, that the conventional mental maps of the innovation process ignore, or regard as a black box — somewhere inside which one cannot look and therefore understand or use as the basis for predictions.

Fig. 5 shows how the learning selection model can explain the workings of the black box. It shows that the ‘plausible promise’, which embodies some key stakeholder knowledge but is largely a creation of the R&D team, gains knowledge and evolves into a fitter ‘widely adoptable technology’ through many learning selection iterations. The widely adopable technology is depicted as a set of interlocking gear-wheels to represent the ‘meshing in’ that takes place during the adaptation phase.

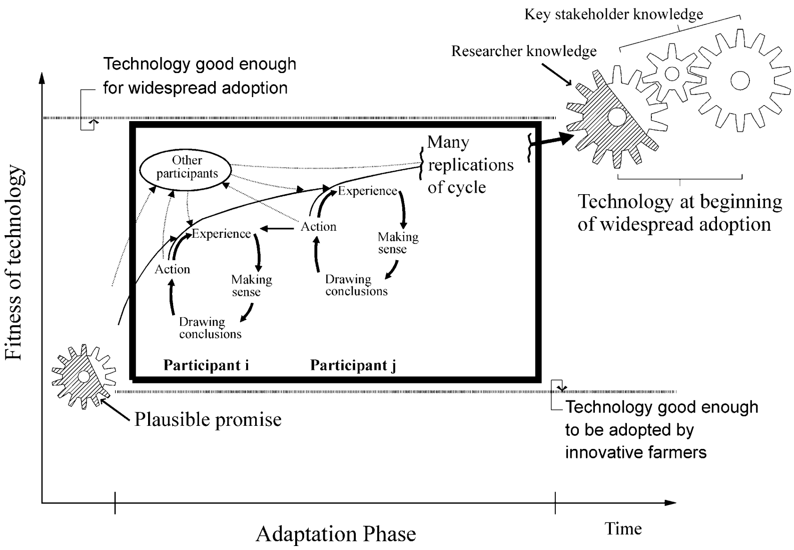

Fig. 5. The learning selection model of how a ‘plausible promise’ evolves into a ‘widely adoptable technology’ during the adaptation phase.

This 'meshing in' process, in which a new technology is shaped by the community in which it is adopted, and that community is in turn shaped by the technology has been called 'the social construction of the technology' by Bijker (1994). The labour arrangement innovation negotiated between the owners of the mechanical reaper and the manual rice labourers is a good example of part of the social construction of a new technology. As already discussed Long's (1992) actor-oriented approach can help understand how learning selection and the social construction process is affected by cultural, social, political and power dynamics between groups in a community.

5. Implications of the learning selection (LS) model to managing R&D — the LS approach

The conceptual model of the innovation process based on learning selection (i.e. the LS model) is a better match to reality than the TOT conceptual model for the case study innovations presented here because it explicitly recognises key stakeholder innovation during the early adoption phase, something that the TOT model does not. The LS model, together with the experience derived from the case studies, has some clear implications for the design and management of public sector agricultural engineering projects, which is referred to as the Learning Selection approach. Below are seven principles for setting up and managing a successful co-development effort.

5.1. Start with a 'plausible promise'

The key to developing a successful innovation is a successful partnership between the stakeholder, who holds the technical knowledge about the new technology, and the key stakeholders, the people who are going to build and use it. This partnership needs to be motivated by the belief amongst at least some of the key stakeholders that the prototype technology makes a plausible promise to benefit them. A measure of whether the R&D team's 'best bet' makes a 'plausible promise' is whether some key stakeholders adopt it and hence invest time, money and effort.

5.2. Keep the 'plausible promise' simple

A plausible promise should be simple, flexible enough to allow revision by the key stakeholders, and robust enough to work well even when not perfectly optimised. It should match the key stakeholders' needs and knowledge levels rather than the R&D team's inclination to technical sophistication and elegance.

5.3. Find a product champion

During the early adoption of a new technology many things can go wrong, any one of which could potentially kill off the technology. It is, therefore, important to identify an individual or a small group who have sufficient interest and knowledge to nurture the innovation. Nurturing means building a common property regime and promoting learning selection — working with the key stakeholders to identify and promulgate beneficial modifications, weeding out detrimental ones, plugging knowledge gaps while at the same time engaging in experiential learning oneself. Nurturing also means being a good facilitator of adult learning, for which the literature on people-centred learning can provide a guide (e.g. MacKeracher, 1994). In practice the product champion is likely to come from the R&D team who developed the 'plausible promise' because they have both the technical expertise and the motivation to do the job.

5.4. *Work in a pilot site or sites where the need for the innovation is great*

The key stakeholders will be influenced by their environment. Their motivation levels will be sustained for longer if they live or operate in an environment where the new technology promises to provide great benefits. In addition, they are more likely to receive encouraging feedback from members of their community.

5.5. *Work with innovative and motivated partners*

The outcome of learning is a function of the interaction between the learner and his or her environment (Lewin, 1951; MacKeracher, 1994). Having chosen the right environment the next step is to choose innovative-adopters who possess the ability to make improvements and are drawn to the challenge of doing this. The SG harvester and SRR dryer case studies showed that media coverage was very effective at prompting innovative-adopters to seek out the technology and then buy it, hence effectively selecting themselves. Enquirers should be charged the market value for the machine to ensure they are adopting because they believe in the 'plausible promise' and not to get something cheap or for free. Also, people generally value something more highly if they have paid for it and they will be more committed to sort out the problems when they emerge. On the other hand the first adopters will need to know that they are working with the product champion as co-developers, and as such will not be left taking all the risk.

5.6. *Don't release the innovation too widely too soon*

For the innovation to evolve satisfactorily, the changes the stakeholders make to it need to be beneficial. As those generating the novelties will have gaps in their knowledge, product champions should restrict the number of co-developers so that they can work with them effectively. When people show enthusiasm for a prototype it is very tempting to release it as widely as possible but this entails jumping from the start-up to the expansion phase and missing out the adaptation one. This should be resisted. However promising the technology might appear, there are many things that can and will go wrong. First adopters need to be aware of this and have ready access to the product champion. Otherwise, their enthusiasm will quickly turn to frustration and the product champion will end up defending the technology against their criticisms when the problems appear. Once the product champion becomes defensive, he or she will be far less useful at sorting out problems.

5.7. *Know when to let go*

Product champions need to become personally involved and emotionally attached to their projects to do their jobs properly. This makes it easy for them to continue championing a technology when it has become clear to everyone else that the technology is not going to succeed. Equally, project champions can continue trying to nurture their innovations long after they entered the expansion phase and proper market selection has begun. Market selection begins when enough of the key stakeholders know enough, and are sufficiently motivated, to ensure the technology continues to evolve and diffuse through their own novelty generation, selection and promulgation efforts alone.

6. Application of the LS model beyond agricultural engineering

The LS model describes a process by which key stakeholders, helped by researchers, experiment with technology and make it their own through adaptation. The researchers are learning in the process and making their own innovations. This is the essence of participating technology development (PTD) which van Veldhuizen et al. (1997) describe as a process by which outside facilitators and rural people interact so that the target groups have a greater capacity to adapt new technology to their conditions and the facilitators have a better understanding of traits and characteristics of local farming systems. Therefore, the LS model may help understand PTD by focusing attention on the fundamental process by which rural technology change occurs: interactive experiential learning, or learning selection as it is referred to here. Loevinsohn (1998) has gone further than this in saying that evolutionary theory could provide the needed theoretical underpinning to assist understanding and design of participatory research in general.

As well as helping to provide a fundamental understanding of PTD, learning selection should also be able to provide a guide to planning and managing a PTD approach through implementing the seven steps of the LS approach. Furthermore, learning selection may be able to help in the monitoring and evaluation of PTD projects by measuring increases in the capacity of the target groups to interact with technology through identifying and explaining the novelties generated, selection decisions made and promulgation mechanisms. Combining the LS approach with Long's actor-oriented approach can give a full picture of how cultural, social, political and power dynamics affected the process.

The LS approach may be relevant beyond agriculture. Von Hippel (1988) in his influential book the *Sources of Innovation* found that people working in the USA industry employed a mental map of the innovation process that is similar to the TOT model. He writes: "It has long been assumed that product innovations are typically developed by product manufacturers. Because this assumption deals with the basic matter of who the innovator is, it has inevitably had a major impact on innovation-related research, on firms' management of research and development, and on government innovation policy. However, it now appears that this basic assumption is often wrong.'' (von Hippel, 1988, p. 3). Douthwaite (2001) finds evidence of LS-type innovation processes in areas as far apart as the development of the Linux computer operating system and the Danish wind turbine industry. He concludes that the LS approach is relevant beyond agriculture.

Further evidence that the LS model and approach may be valid beyond agricultural engineering is that others, from different backgrounds and disciplines, have developed similar models. Eric Raymonds (1997) in his paper *The Cathedral and the Bazaar* describes what he calls a bazaar innovation model to develop software. In the bazaar approach a product champion uses a plausible promise to build a co-developer community to write code, fix 'bugs' and build the program into something better. Raymond grounded his bazaar model on the innovation history of the very successful Linux operating system (Douthwaite, 2001). The LS approach is also similar to the Center for International Forestry Research's (CIFOR) *adaptive co-management* (pers. comm. with C. Colfer, 2000; Belcher et al., 2000) developed for forestry.

7. Conclusions

In agricultural research it has often been assumed that researchers develop new technology and farmers either adopt it or not, without significantly adapting it themselves. A similar assumption in industry, that manufacturers are the sole source of innovation for new products, has been shown to be incorrect with some types of technology. This paper has shown that at least with agricultural equipment, user, manufacturer and researcher innovations are present and essential in machinery that is widely adopted. Failure by public sector researchers to realise farmers and manufacturers must first adapt new technology to local conditions before widespread adoption will occur has led to the too-early promotion of some equipment and wastage of public money. The *learning selection* (LS) cognitive model of the early adoption process can help research planners and managers see innovation as an evolutionary process, and manage it as such.

The LS model sees technology evolving during adoption as a result of stakeholders making modifications (novelty generation), and then selecting and promulgating some of these. The model explicitly recognises that during the initial adoption of a publicly-developed technology, the key stakeholders (those with most to gain) may not know enough about the new technology for this *learning selection* to improve the fitness of the new technology. Also, the technology may not work well enough for them to be motivated to persevere when unforeseen problems arise. Researchers need to be active participants in the early adoption process to nurture new technology until market selection begins to work. In this way early release of new machinery can provide a mechanism to create a valuable synthesis between local and research knowledge that should lead to more appropriate technology, and increase key stakeholder capacity to interact with new technology.

The LS model is based on the view that new technology can be seen as an increment in the knowledge of the system into which it is introduced. Although developed based on data from equipment technology this generic basis makes the LS model applicable to any technology where 'learning by using' and 'learning by doing' are likely to significantly improve its fitness and adoption prospects.

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