Stakeholder Learning and Innovation in Early Technology Adoption: An Evolutionary Model

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Abstract

The 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 6 postharvest 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 they play the evolutionary roles of *novelty generators* and *selectors*, and in their interactions with each other *promulgation* of selected novelties occurs. The participants' motivation is the source of *evolutionary drive*.

The model has implications for management of rural 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 able to provide a theoretical underpinning for participatory technology development (PTD).

Keywords: Participatory technology development, model of adoption process, postharvest technology, Philippines, Vietnam

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Introduction

Public sector agricultural research has been criticised for not doing enough to alleviate world poverty, which according to the Organisation for Economic Co-operation and Development (OECD) international development targets should be cut by half by 2015 (OECD, 1996). One commonly cited cause of the lack of impact in poor farmers' fields is the mental map that researchers have of the research, development and transfer process, and the approach to management that results from it (Biggs, 1989; Chambers and Jiggins, 1986). Conventional science is based on the paradigm that reality is objective, independent and based on natural laws that science can uncover (Röling, 1996). Scientific method can therefore be used to understand reality and design technologies. The corollary of this is the belief amongst agricultural scientists 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 the high yielding crop varieties that spawned the Green Revolution.

In 1995 IRRI began a study to examine what happens when relatively complex new technology is handed from research to extension, to examine the extent to which this picture fits reality. This helped us to discover that contrary to researchers' expectations new equipment technologies are by no means perfected when first released, as far as manufacturers and farmers are concerned. This paper presents an evolutionary model of the early stage of the adoption process which we found to fit much better than the conventional linear "hand-over" one. While developed from agricultural engineering data we suggest the model is also relevant to planning, implementing and evaluating participatory technology development in other disciplines.

Methodology

We chose to look at agricultural machinery because it has a physical manifestation that is relatively easy to modify (cut and weld) and then, in effect, leaves a "fossil" record because the changes are difficult to destroy.

We used case study methodology 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 we chose are all the rice harvesting and rice drying technologies introduced to the Philippines and Vietnam after 1975. Our definition of "introduced" was that we had to find at least a hundred cases of a technology being used in either country for it to qualify. Two types of harvester met this criterion. Both are relatively cheap and light as mechanical harvesters go, 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 means "very low cost" in Vietnamese—which can be bought for $100 and dries one tonne of rice in 2 to 4 days, to recirculating dryers imported from Taiwan which cost 150 times more but can dry 6 tonnes in 8 to 10 hours. The case study technologies are shown in Table 2 and Table 1.

Table 1: Description of case study technologies

Technology	Description	Adoption status	Lab. prod. hrt^{-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 l	1000 units sold in 17 years (Vietnam)	4.8	2000
Flash dryer	High temperature dryer	2000 units donated in 4 years (Philippines)	3*	3500
Recirculating dryer	Heated air dryer with mechanical mixing	1500 units sold in 6 years (Philippines)	1.5	15,000

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

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

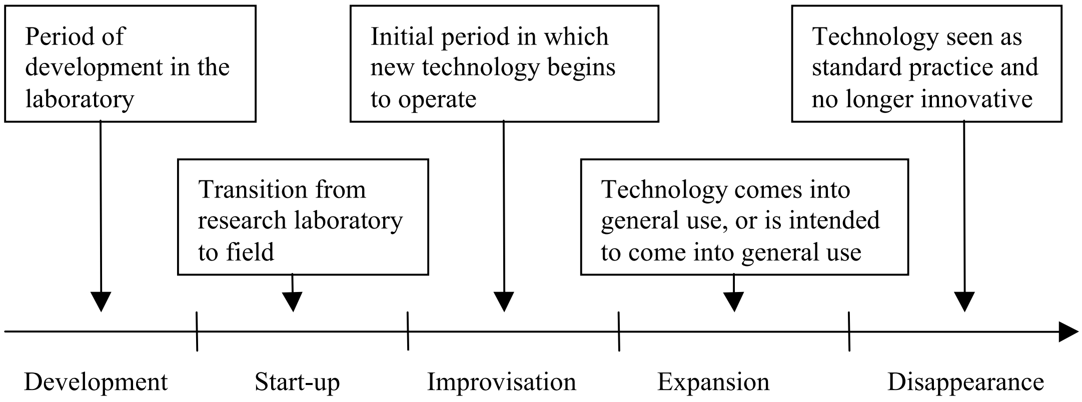
Technology	Source of innovation	Philippines	Vietnam
Harvesting			
SG	Public	□(x2)	□
Reaper	Public	□	□
	Private	□	
Drying			
SRR	Public		□
Flatbed	Public	□(x2)	□
Flash	Public	□(x2)	
Recirculating	Private	□	

Main case study technology

Although the technology generation and adoption process is unlikely to be linear there are discernible stages in the life of an innovation. One categorisation, after Yin (pers. comm. with S. Sechrest, 1996), is shown in Figure 1. Hand-over from research to extension happens at the end of the *start-up* phase so this and the *improvisation* phase that follows it are the two phase of interest in our study. We therefore selected the case studies to either be in the *improvisation* phase or to have recently moved to the *expansion* phase, so we could gain recent data on the two phases of interest.

The main analytical approach was to construct *life histories* from multiple data sources and then compare and contrast between them. *Life histories* describe the time-ordered sequence of events, the stakeholders who were responsible for or influenced the events, and other contextual influences (Sechrest *et al.,* 1996). For more details of the methodology see Douthwaite (1999).

Figure 1: Stages in the innovation process



Phases in the research, development, adoption and adaptation process

Pers. comm. with Prof. L. Sechrest, 1996, University of Arizona.

The choice of events that was described in the *life histories* was suggested by the *theory of the case* (Sechrest *et al.,* 1996) which is 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.*

The theory of the case is simply that there is an analogue, which we call *learning selection*, shown in Figure 2. Learning is central to innovation (Clark, 1995; Leonard, 1995; Mokyr, 1991; Nelson and Winter, 1983) which is why it is the basis of the model. Kolb's (1984) experiential learning model was chosen in particular because the two types of learning that characterise the innovation process—"learning by doing" and "learning by using" (Rosenberg, 1982)—are both types of experiential learning.

Figure 2 is a model of how *learning selection* works. It shows two of 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:

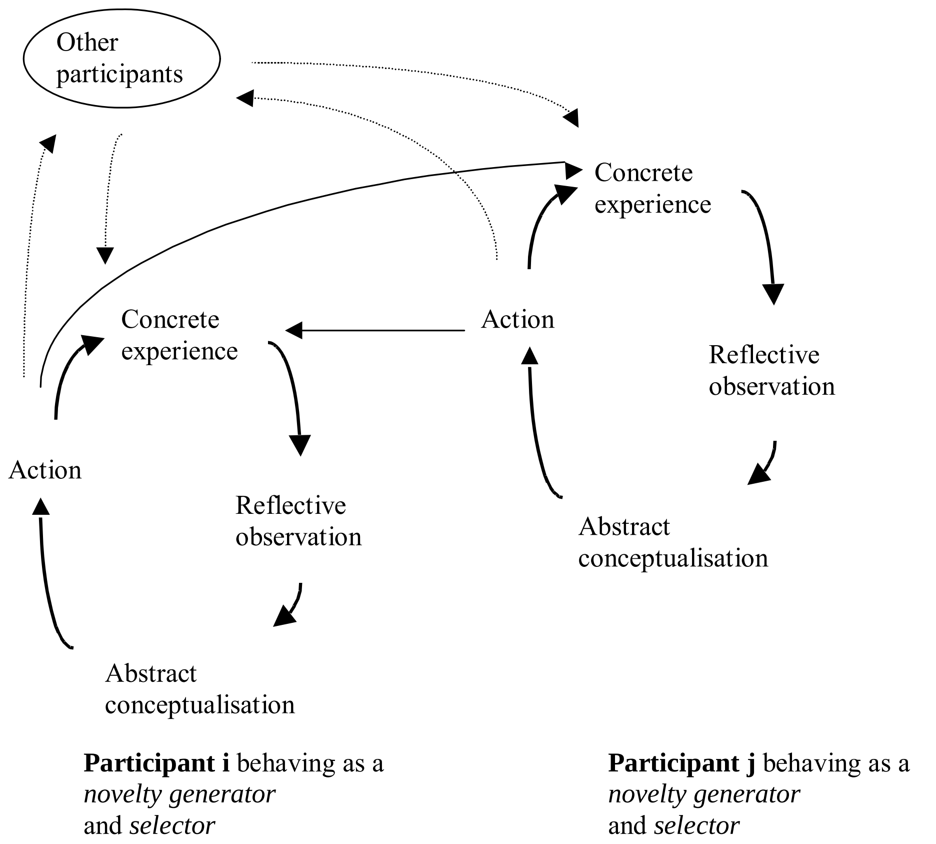
- *Novelty generation* that creates differences between individual members of the species (Nelson, 1987), e.g. individual differences between machines of the same type, or the way they are used.
- *Selection* of beneficial novelties (Nelson, 1987).

They do this during the experiential learning process that Kolb (1984) described thus:

Concrete experience—The learner has a specific experience, for example from operating a harvest machine.
Reflective observation—She reflects on this experience from different points of view to give it meaning. For example, she observed that the grain loss was higher in one field than in another, and higher loss means lower profits.
Abstract conceptualisation—The learner develops personal explanations of what happened from her own or others previous experience or theories. For example, she might conclude that the grain loss is higher in the field that was riper because he knows from past experience that grain separates more easily from the panicle in over-ripe crop.

Active experimentation—He then decides to do something based on the conclusion, and this action leads to new concrete experiences, and so the cycle continues. For example, the farmer decides to change his harvest practice by harvesting earlier, and in so doing *generates a novelty*.

Figure 2: The *learning selection* algorithm, analogous to *natural selection*



Promulgation occurs as a result of participant interaction
Evolutionary drive = Motivation of stakeholders to participate

Adapted from Kolb (1984) and Hunt (1987)

Evaluating the novelty in a new learning cycle would lead to the farmer deciding to adopt, not adopt, or further modify the innovation. In making these decisions the farmer is carrying out the *selection* function.

In addition to the *novelty generators* and *selectors*, evolutionary systems also require:

- A *promulgation* mechanism by which beneficial differences are multiplied in future generations;
- *Evolutionary drive*—something that drives the process (Clark *et al.*, 1995), for example, profit motive.

Promulgation occurs when people interact and share experiences and innovations, as shown in Figure 2. This exchange of knowledge might also help learning processes. For example, a researcher witnessing a farmer harvesting over-ripe crop with high loss might be able to suggest the reason, if the farmer did not already know. The facilitator also learns in this process. In this example, the researcher might learn that a note is needed in the operator's manual. *Learning selection* is therefore a type of interactive learning.

Evolutionary drive in the *learning selection* process is provided by the motivation of the stakeholders to participate. Implicit in the use of an evolutionary model is that *learning selection* will lead to improvements in fitness, where fitness is taken in the biological sense to mean improvements in the likelihood that the technology will be adopted and promulgated.

Results

The objective of our study was to see whether the "hand-over" model actually described what happened at the research-extension interface. We were therefore interested in looking at how much *learning selection* took place after introduction of a new technology, and who was doing it, which is what this section examines. The data presented here is just a fraction of what was processed before drawing the inferences and conclusions discussed later. Interested readers are referred to Douthwaite (1999).

Researchers

The researchers' main role was to develop a promising prototype of a new technology that began the *learning selection* process. Researchers continued to modify their technology after, according to the hand-over model, they should have handed a "perfected" package to extension. Often their innovations benefited from knowledge gained by working with manufacturers and users. However, researchers' most important evolutionary roles were as *selectors* and *promulgators* of modifications made by manufacturers and users. For example, IRRI produced and distributed modified design drawings and training materials after the institute released the SG harvester. This material included innovations made by researchers, manufacturers and users. As part of the selector role researchers sometimes pointed out mistakes, detrimental changes and poor quality to manufacturers.

One of the main impediments to researcher *learning selection* after release were government programs that assumed the machinery was sufficiently perfected to promote it widely. Inclusion of a technology in such programs was an indicator of success for the R&D team but it also had the effect of making them defensive to subsequent criticism, hence taking away chances to further learn and improve the technology. Eight of the eleven 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.

Extension workers

The degree to which extension workers became involved in *learning selection* depended on how the extension program was organised. If it assumed the "hand-over" model, as was the case with the program that promoted the SG harvester and flash dryer, then they were not expected to make modifications and were not given the resources or responsibilities. 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.

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:

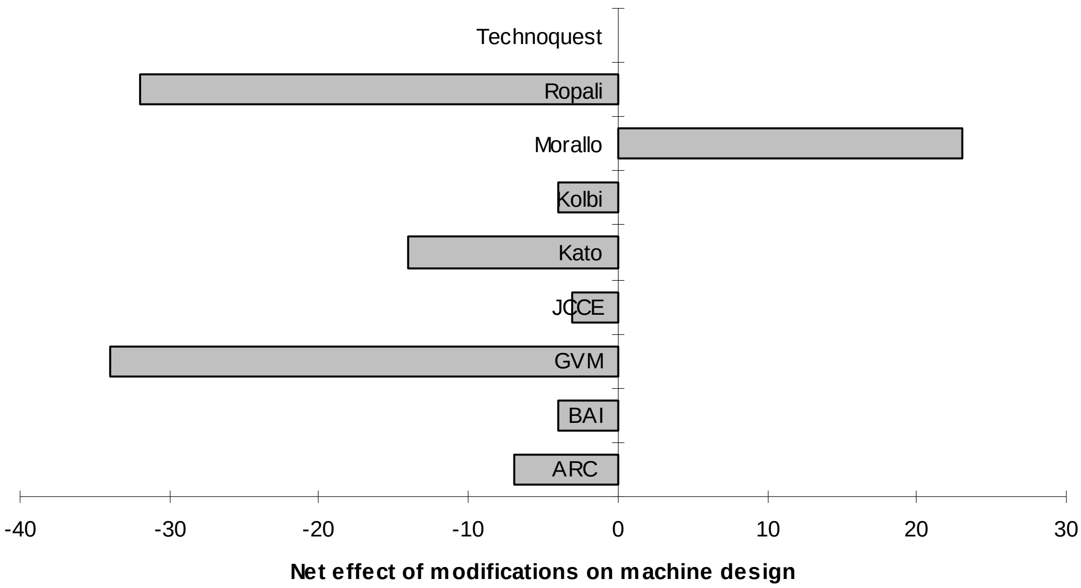
1. Changes to the design to make it cheaper or easier to build;
2. Changes to the design to improve the performance of the machine;

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;
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 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, one 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. Figure 3, which shows the net effect of the modifications made by nine SG harvester manufactures, makes this point[1]. It shows that only one manufacturer would have had a net positive effect on the design without some "industrial extension" by the research team. One disastrous modification 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.

Figure 3: Net effect of manufacturers on the design of the Mark II SG harvester



Manufacturers also made some important innovations to the software knowledge. Software knowledge is the knowledge necessary to build the machine cheaply and well, or to use it properly, that is not embedded in the machine itself. For example, some manufacturers developed jigs and fixtures to make fabrication quicker and easier.

[1] See Douthwaite (1999) for methodological details.

Government programs motivated manufacturers to start building new technologies in the hope of winning orders. As such, it encouraged participation and learning. However, in the Philippines the tendering process restricted *learning selection* because it compelled manufacturers to follow the standard design. Furthermore by selling to the government the programs further restricted *learning selection* by restricting user-manufacturer interaction.

The type of innovation that the local manufacturers were making can all be classed as micro-inventions (Mokyr, 1990), that is, modifications to an existing design. We found that nearly all lacked the resources and access to information to develop a macro-invention, that is, a new technology without precedent in the country. Even if they did have the resources, lack of workable patent protection deterred them from making the necessary investment for fear of early copying by competitors. The multinational companies included in the survey protected their macro-inventions (the Kubota mechanical reaper and Suncue recirculating dryer) by a natural patent—complexity of the machine that made local copying very difficult.

Users

Owners, in contrast to manufacturers, made most modifications to the technology software. For example some SG harvester owners came up with the innovation of paying 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).

Table 3: Level of harvester usage by incentive for SG operators

	Incentive for SG operators			
Harvester usage rate, ha per season	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))

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, although not necessarily as a result of the farmer suggestion.

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 installed dryer 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. Word of mouth and the adoption of neighbours and associates were important factors in the adoption of the recirculating dryer. 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 generally gave equipment to users at a highly subsidised rate which we found reduced *learning selection* by reducing 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).

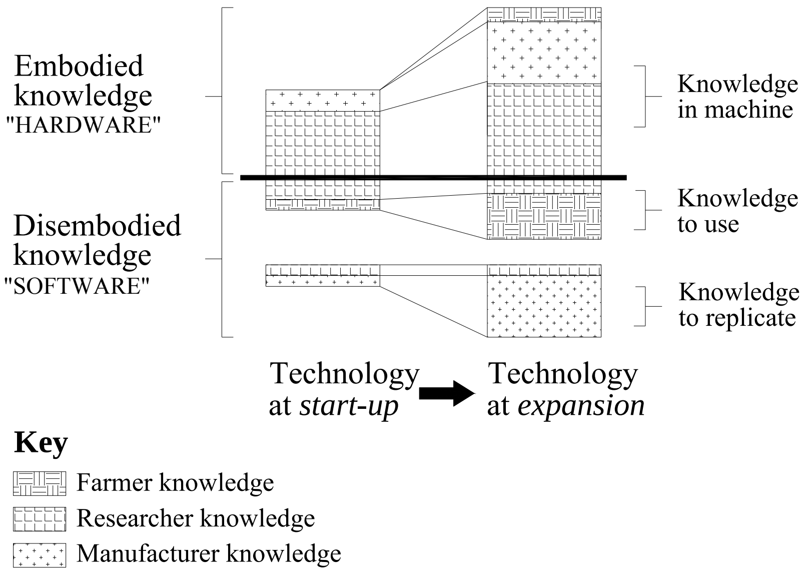
Discussion

Developing an evolutionary model for early adoption based on learning selection

The case studies we looked showed that a very large amount of innovation took place after release of the technology. The "hand-over" model did not fit reality—scientists and engineers were not able to produce useful technologies, only prototypes that promised to be useful. However, this role should not be underestimated. Market failures (e.g., lack of adequate protection for intellectual property rights, lack of access to information) meant that local manufacturers did not have either the resources or the incentive to develop new technologies. Multi-national companies were interested in providing new technologies to rich rice millers and farmers and not in providing simple, low cost machines that could be easily copied. The one-hundred-dollar SRR dryer, for example, had a clear public good through saving family labour. The survey found men and women could do more profitable things than manually dry rice in the wet season, and children spent more time studying.

The "promise" created by the public sector researchers motivated the beneficiary stakeholders—those with most to gain—to carry out *learning selection* that over time improved the technology so that in some cases the promise was realised. An evolutionary model based on *learning selection* should therefore be able to produce a better approximation of reality than the hand-over model, and in this section we describe the model we have developed, based on the case study data.

Figure 4: Knowledge change of an equipment technology during the *improvisation* phase



A model is a simplification that helps understanding, prediction and hence management. The simplification that we begin with is to depict technology as knowledge contributed from different sources, and the innovation that takes place in the *improvisation* phase as a change in that knowledge. This is shown in Figure 4 where the area of the bar chart is a representation of the new knowledge, or existing knowledge used in a novel way, associated with a piece of equipment technology.

Figure 4 shows that at the beginning of the *improvisation* phase most of the knowledge comes from researchers. The amount of beneficiary stakeholder (farmers and manufacturers) knowledge incorporated reflects their level of participation in the *development* and *start-up* phases. Their knowledge contribution increases sharply during the *improvisation* phase because once they begin to build and use the technology their participation and *learning selection* greatly increases. Figure 5 shows that it is many iterations of the *learning selection* algorithm that builds new knowledge. Manufacturers contribute most to hardware knowledge by "learning by doing" while farmers contribute most to software knowledge by "learning by using".

Figure 5: How a new technology evolves during the *improvisation* phase through *learning selection*

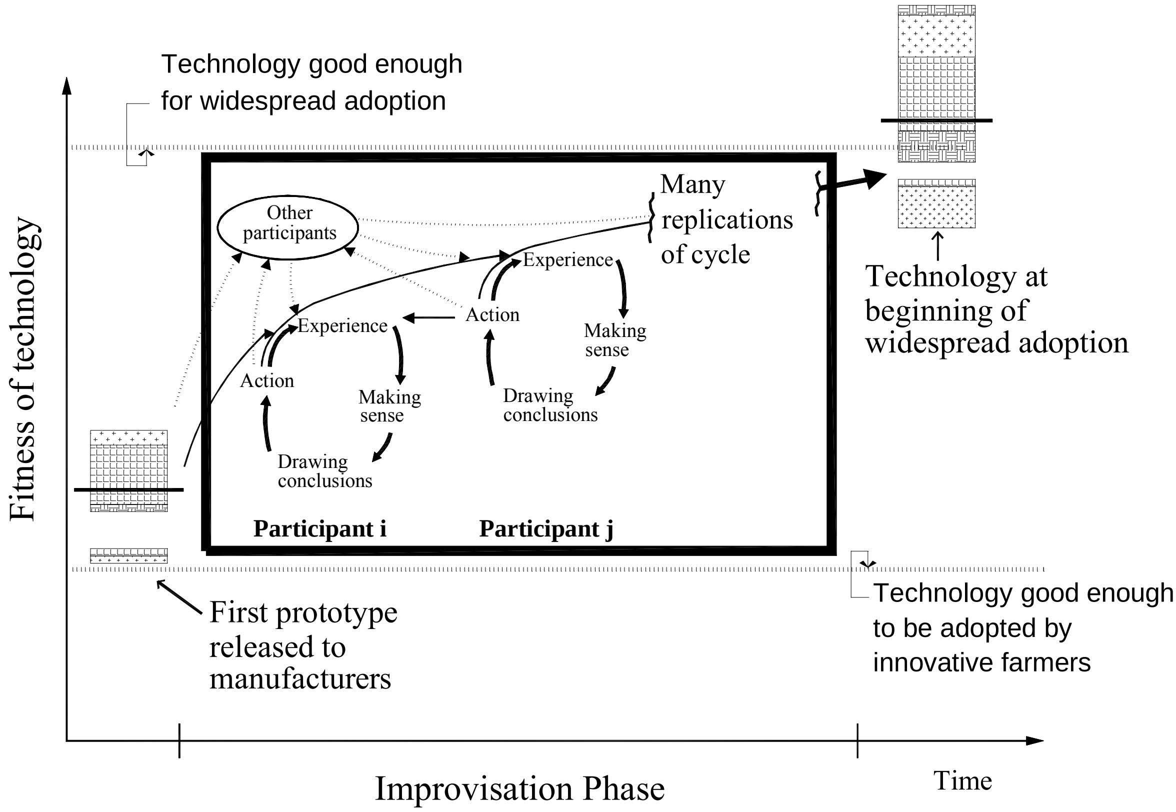


Figure 5 also shows that effect of *learning selection* is to increase fitness from a point where it shows sufficient "promise" to interest innovative-adopters to buy it, to a point where it works well enough to appeal to a wider group.

Figure 5 shows a technology that passes through the *improvisation* phase successfully, which relies on at least two things. Firstly there must be sufficient *evolutionary drive* to push the process. In other words the technology should promise to solve an important problem. Secondly, the technology should survive the first round of beneficiary stakeholder *learning selection* that can reduce the fitness of the technology, highlighted in Figure 3.

Implications of the LS model to managing R&D—the LS approach

The LS model has some clear implications for the design and management of public sector agricultural engineering projects. Firstly, it makes the R&D team aware that they should not be trying to develop a "perfected" technology but rather should be trying to make a credible and needed promise. Secondly, there is a clear need for someone to nurture the technology during the *improvisation* phase. Nurturing involves working with the beneficiary stakeholders to identify and promulgate beneficial modifications, weed out detrimental ones and plug knowledge gaps. The R&D team has the requisite knowledge to do this, will be motivated to see their "baby" succeed and are in a good position to make useful improvements themselves from the experience gained in working with manufacturers and farmers. Therefore, in most cases the R&D team will be better placed than extension workers to play the nurturing role in the *improvisation* phase.

Whoever plays this nurturing role, the LS model suggests the following:

- The team should promote *learning selection* by acting as facilitators of adult education. Literature on people-centred education can provide a guide to this behaviour (e.g., MacKeracher, 1994).
- They should also carry out *learning selection* themselves.
- To maximise evolutionary drive (motivation to participate) the team should concentrate on areas where there is a real need for the technology and where use is likely to be profitable.
- The outcome of learning is a function of the interaction between the learner and his or her environment (MacKeracher, 1996; Lewin, 1951). Having chosen the right environment in terms of need the R&D team should choose to work with innovative-adopters who possess the ability to make improvements and are drawn to the challenge of doing this (Rogers, 1995). 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.
- The team should encourage *evolutionary drive* by being pro-active in encouraging and sustaining stakeholder participation, and in removing obstacles to it. This type of behaviour is described in the innovation literature describing product champions (e.g. Peters and Waterman, 1982).

Obviously nurturing should not last forever. One definition of the end of the *improvisation* phase could be the point where the beneficiary stakeholders know enough to carry out *learning selection* themselves, and the participation of the R&D team can be reduced to consultation. This is the point where market selection starts to work. The technology will continue to improve and thrive if there is a critical mass of sufficiently motivated beneficiary stakeholders. This is an end point for which the R&D team can strive.

Application of the LS model to participatory technology development (PTD)

The LS model describes a process by which beneficiary 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 PTD, as described by van Veldhuizen *et al.* (1997). Therefore, the LS model may also help understand PTD by focussing attention on the fundamental process by which rural technology occurs, interactive experiential learning, or *learning selection* as we call it. 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.

Conclusions

The scientific paradigm suggests that agricultural researchers can and should be able to develop, under their control, technologies that work well enough not to require significant modification after release. This is not the case, at least in agricultural engineering in the Philippines and Vietnam. *Learning selection*, a process analogous to natural selection in biological evolution, can help provide a model of the early adoption phase that is a better approximation to reality. In so doing it can help research management and hence increase impact. The LS model could also help provide a theoretical underpinning to participatory technology development.

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