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Learning selection revisited: How can agricultural researchers make a difference?

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ABSTRACT

Ten years ago we developed, and published in this journal, the learning selection model to describe the development and early adoption of researcher-developed agricultural equipment in Southeast Asia. In this paper, we update the innovation histories of the three main technologies upon which the model was based and carry out some mapping and analysis of the post-harvest research networks in three countries. We find that the evolutionary algorithm based on interactive experiential learning remains valid. However, in the case of the most successful technology – the flat-bed dryer in Vietnam – the R&D team did not withdraw once a critical mass of manufacturers and users were familiar with the technology, as the model says should happen, but rather continued to champion the technology. In the process they developed major improvements to the original design, and a new type of dryer. They achieved far greater impact than any other team. They were successful largely because they were able to work with the same networks of partners, in the same innovation trajectory, for 25 years. We find evidence of institutional support in working in this way. Their role was to make the major modifications while local users, manufacturers and promoters made local adaptations and 'bug fixes'. This way of working is similar to that of plant breeders working for the public sector and by many researchers in the private sector. However, current trends in international research towards 'projectization' on one hand, and the requirement to produce international public goods (IPGs) on the other means that researchers do not stay working for long enough with the same partners because funding keeps changing, nor do they work locally enough because of the expectation that they should generate new IPGs from scratch every one or two project cycles.

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1. Introduction

Ten years ago the two authors – Douthwaite and Gummert – worked together on a German-Government-funded Post-harvest Technologies Project that developed and promoted rice harvesting and drying technology in Southeast Asia. Gummert led the project which was based at the International Rice Research Institute (IRRI), Philippines.

Douthwaite subsequently based his PhD thesis on the work. The main output of the thesis was a model – called the learning selection model – that describes how successful grass-roots innovation processes begin. A paper describing the model was published in Agricultural Systems in 2001 (Douthwaite et al., 2002).

One of the thesis' main findings was that the most successful rice harvesters and dryers where the ones that had been most modified by local manufacturers and users. This ran contrary to the then dominant view that agricultural engineers, given their professional training, could and should design machines that worked without subsequent tinkering. The learning selection model described an evolutionary-like process in which scientists and engineers (the R&D team) work with interested manufacturers and farmers (the key stakeholders) to modify a technology, select what works, and spread the results. Douthwaite subsequently wrote a book called 'Enabling Innovation' in which he found that the model helped explain other grass-roots innovation processes such as the development of Linux and the Danish wind turbine industry (Douthwaite, 2002).

For the last 10 years Douthwaite has worked as an adoption and impact specialist, first at the International Institute for Tropical Agriculture (IITA) in Nigeria and then at the International Centre for Tropical Agriculture (CIAT – Spanish acronym) in Colombia. In his work, Douthwaite has continued to build theories of innovation, because, as Christensen et al. (2004) say in their book 'Seeing What is Next' "...the lenses of theories of innovation provide powerful insights not readily observable ..." (p. xv).

Gummert on the other hand worked as an IT consultant in Germany for 2 years before returning to Asia to lead IRRI's post-harvest work. While Douthwaite has been researching innovation processes Gummert has been working within them.

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In this paper, we use the opportunity of Gummert again working on post-harvest in Asia to revisit the three main cases upon which the learning selection model was based. We examine what has happened over the last 10 years through the lenses provided by the learning selection theory of innovation. In so doing we set out to evaluate the learning selection model and to generate insights into how researchers can play a part in enabling and fostering grass-roots innovation processes. This should be of wider interest because what we refer to as ‘grass-roots’ innovation is now more widely known as ‘open source’ innovation (Tapscott and Williams, 2006), or ‘democratic innovation’ (von Hippel, 2005). Both are being seen as the basis of powerful new business models with applicability far beyond agriculture.

First we begin by describing how the learning selection model and a 10-point guide to fostering open source innovation based on the model. We then describe what complexity science, particularly understanding of the dynamics involved in complex adaptive systems, can add to learning selection. Then we present our methodology and the findings followed by discussion and conclusions.

2. The learning selection model

The learning selection model is based on the analogy proposed by a number of writers between technological change and Darwinian evolution (e.g., Nelson and Winter, 1983; Mokyr, 1990). If this analogy is valid then technology change must be driven by a process analogous to *natural selection*. Learning selection is that analogue.

Natural selection consists of three mechanisms. These are:

2.1. Novelty generation

As a result of random genetic mutations and sexual recombination of differing genetic material, differences between individual members of a species crop up from time to time.

2.2. Selection

This is the mechanism which retains random changes that turn out to be beneficial to the species because they enable those possessing the trait to achieve better survival and breeding rates. It also rejects detrimental changes.

2.3. Diffusion and promulgation

These are the mechanisms by which the beneficial differences are spread to other territories.

As we said in the original Agricultural Systems article on learning selection, the analogy 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, 1986). 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” (Douthwaite, 2002, p. 115).

The learning selection model is depicted graphically in Fig. 1. It shows a technology, depicted as a cogwheel, beginning as a ‘plausible promise’ that motivates the key stakeholders to adapt and improve it over time, in an evolutionary-like process. The technology then increases in fitness by gaining knowledge and becoming ‘meshed in’ to existing systems through the adaptation and learning that takes place. Here, fitness is taken in the biological sense to mean improvements in the likelihood that the technology will be adopted and promulgated. The ‘meshing in’ of the technology is represented by the move from a single cogwheel to three interlocked ones as institutions around its use are developed. The increase in knowledge is represented by the increase in size of the cogwheel(s).

Learning selection is shown inside the black box in Fig. 1 and is responsible for the evolution. Learning selection is a process built

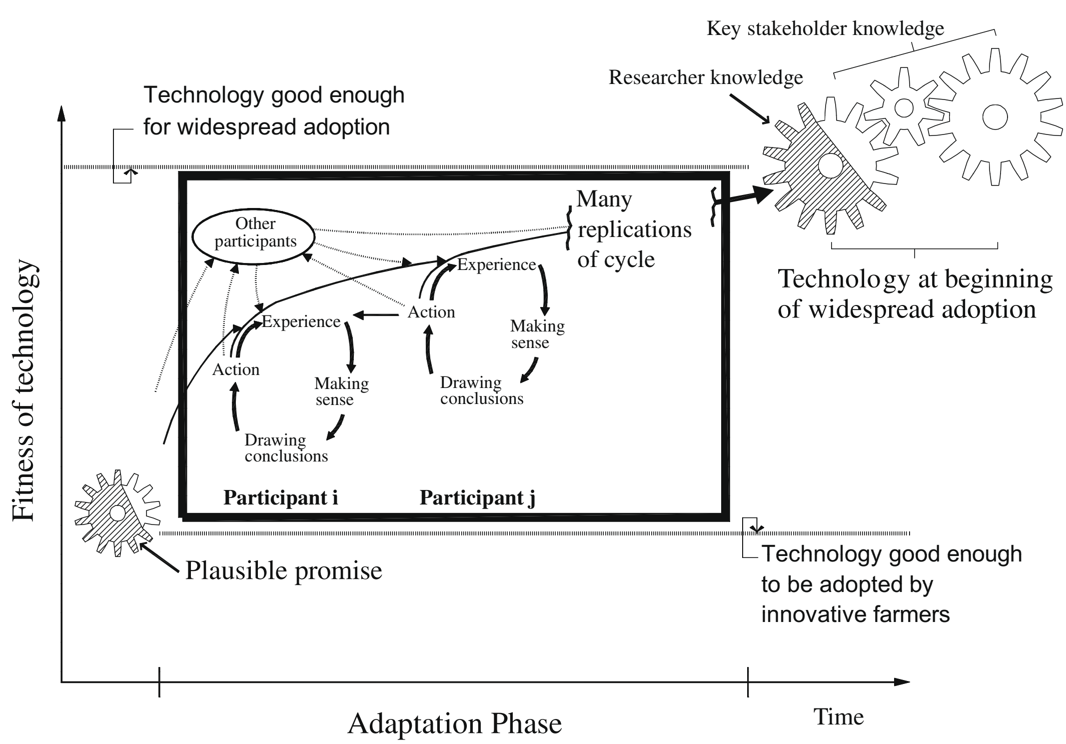

Fig. 1. The learning selection model.

on Kolb's (1984) experiential learning cycle, and is perhaps best explained using an example.

2.4. 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.

2.5. Making sense

She reflects and makes sense of the experience. She realizes that uneven drying is losing her money and that it might be sensible to try and improve the dryer's performance.

2.6. Drawing conclusions

She then develops personal explanations of what happened from her own or others previous experience or theories. She hypothesises that if she reduces the amount of paddy she loads into the dryer then drying will be more uniform.

2.7. 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 now 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. 1 then the miller represents participant *j*.

So far the third component of the evolutionary system – the promulgation and diffusion mechanism – is missing. In the example, promulgation of the novelty occurs when the farmer tells people in her social network, represented in Fig. 1 by the 'other participants' box, about the benefits of her novelty and they choose to experiment with it themselves.

The farmer, the miller and the people they are connected to through their social networks will be going through their own learning cycles creating the conditions for the recombination of differing observations and experiences that can lead to further adaptation. 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. The evolution can be understood as a 'social construction' in which the selection decisions made and the institutions that grow up surrounding its use are influenced by social context or its 'social construction' as it might also be termed (Pinch and Bijker, 1984).

The research found that the learning selection model is most useful when key stakeholder 'learning by using' and 'learning by doing' are important in the early adoption phase. 'Learning by using' is learning during manufacturing that leads to improvements in the manufacturing process while 'learning by doing' is learning during the use of the technology (Rosenberg, 1982). The learning selection process works best when users are able to modify the technology, and if there are ways of evaluating changes.

3. A 10-point guide to fostering innovation

As mentioned above, Douthwaite wrote a book in which he used the learning selection model to shed insight into four innovation histories: Danish windturbines, Linux, local economic trading systems and the world's crops. All four were chosen because, as with agricultural machinery, users played a major role in their

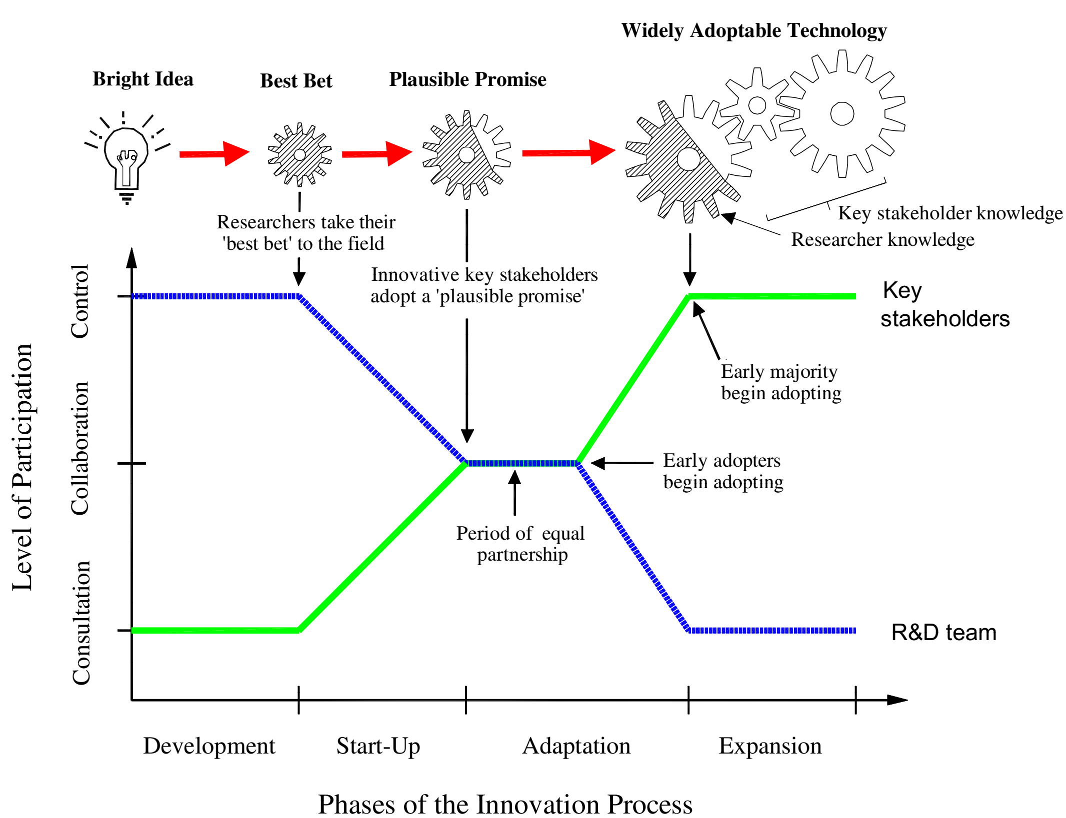

Fig. 2. Stages and participation in a learning selection innovation process in which a new technology is developed and adopted in a territory.

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development. On the basis on the insights generated he came up with a 10-point guide to fostering a grassroots-based innovation process. The guide is replicated below in some detail because it contains insights that we will test against the findings.

3.1. Start with a plausible promise

Begin an innovation process with a 'plausible promise'; something that convinces potential stakeholders that it can evolve into something that they really want. The plausible promise does not need to be refined or polished; it can be imperfect and incomplete. In fact, the less final it is, the more scope there is for the stakeholders to innovate and thus gain ownership of the technology. The more problems there are, then the greater the chances that the key stakeholders will give up in frustration. A delicate balance must be maintained. The plausible promise come from anywhere, not only from research.

3.2. Find a product champion

The next step is to identify the innovation or product champion. He or she needs to be highly motivated and have the knowledge and resources to solve problems. The product champion needs both the necessary technical knowledge and the motivation; it always helps if the product champion already has a stake in the technology. He or she must also have good people and communication skills because, to build a development community, it will be necessary to attract people, interest them in what is going on, and keep them happy working for the common cause. The product champion's personality is therefore crucial.

3.3. Keep it simple

A plausible promise should be simple, flexible enough to allow revision, and robust enough to work well even when not perfectly optimized.

3.4. Work with innovative and motivated partners

Participants in an incipient innovation process should select themselves through the amount of resources they are prepared to commit, in particular their time. On the other hand you should be prepared to offset some, but not all, of the risk they are taking working with you.

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

Your co-developers will be influenced by their environment. Their motivation levels will be sustained for a longer period if they live or operate in an environment where your innovation promises to provide great benefits. In addition, they are more likely to receive encouraging feedback from members of their own communities.

3.6. Set up open and unbiased selection mechanisms

During early adoption, the technology should evolve and become 'fitter' through repeated learning selection cycles. This requires setting up efficient and unbiased ways of selecting what works and abandoning what does not. The product champion can often acts as a selector. An effective selector must be able and prepared to recognize good design ideas from others. They must be prepared to work for the good of the technology rather than the furtherment of their own ideas. This means that, when this person is also the inventor, he or she must be suitably receptive and thus able to accept that others might have better ideas.

3.6.1. The product champion/selector

As soon as you have the key stakeholders working with you and generating novelties, you need ways of selecting and promulgating beneficial changes. Initially, the product champion usually plays this role. However very few people are capable of effectively championing their products and selecting novelties at the same time. This is because, to be good at the former, it is necessary to believe deeply in the product's benefits and be able to defend it against criticism. An effective selector, on the other hand, must keep an open mind and be able to work with others to question fundamental design decisions. If a product champion defends the technology too strongly or shows bias, then "forking" occurs, and the disaffected person or group branches off to do what he or they felt prevented from doing by the selector. It is good to have people test alternative design paths, but, if it is done in frustration or spite, then cliques form, making any comparison and subsequent selection between rival branches difficult. Creative talent is split, and energies can be dissipated in turf wars.

3.6.2. Alternative selection mechanism

Even if the product champion can be open-minded and unbiased, he or she may have problems convincing others. One option is to set up a review mechanism that is well respected by the key stakeholder community. There are a number of ways of doing this. Three that work are review by an independent organization, peer review, and the provision of enough information to potential adaptors that they can make informed selection decisions themselves.

3.7. Do not release the innovation too widely too soon

When people show enthusiasm for a prototype it is very tempting to release it as widely as possible but this should be resisted. The technology will always be less perfect than one initially thinks.

3.8. Do not patent anything unless it is to prevent someone else privatizing the technology

In learning selection, people co-operate with each other because they believe that all will gain if they do. The process is, therefore, seriously damaged if one person or group tries to gain intellectual property rights over what is emerging. Patents are monopolies that immediately reduce the novelty generation rate and thus slow down future development and the flow of ideas.

3.9. Realize that culture makes a difference

Culture can influence the degree to which knowledge is guarded within a particular group, or spread around.

3.10. 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 go on flogging dead horses long after it has become clear to everyone else that the technology is not going to succeed. Equally, project champions can continue trying to nurture their babies long after they have grown up and market selection has begun. It is, therefore, a good idea to put a time limit on the product champion's activities.

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4. Complexity science and learning selection

In recent years a number of authors have incorporated insights from complexity science into theories of innovation (e.g., Sherman and Schultz, 1998 and Ekboir, 2003). A conceptualization of complex adaptive systems (CAS) that resonates well with learning selection is provided by Axelrod and Cohen (1999).

A complex adaptive system consists of one or more populations of **agents**, along with the **artefacts** (e.g., things, technologies, databases, etc.) and **strategies** (including norms) that they use. An agent is an entity, such as an individual or organization, which has agency, i.e., can make thing happen. In a CAS, the agents use strategies in their **interactions** with other agents and with artefacts. The agents evaluate the subsequent results of these interactions and as a result **select** to copy strategies or artefacts, or recombine or invent new ones. Copying itself is error prone. This evolutionary process of selecting what works, copying, recombining and inventing constantly introduces novelty. Over time, the evolutionary process changes the frequency and **variation** of types of agents, strategies and artefacts as the populations of "fitter" agents, strategies and artefacts increases in relation to others.[1]

CAS theory adds to learning selection in two important ways. Firstly it helps us see that grass-roots innovation processes such as Linux are an emergent property of human systems (see Antonelli (2008) who comes to a similar conclusion). Emergence is a fundamental characteristic of CAS that results from the continuous and multiple interactions of agents, strategies and artefacts. A common example of an emergent property is the shape of a flock of birds. The shape is a property of the whole flock and results from each individual bird keeping close but not crashing into its neighbours. The shape is influenced by environment (e.g., nearby obstructions, wind) and past events (e.g., attack by a bird of prey).

Seeing innovation as an emergent property of human systems has profound implications for how scientists in particular see their role in fostering innovation. It implies that an R&D team can only foster innovation if they interact with other agents, and that they should see themselves as one of many agents with their own agenda. Many scientists prefer to see themselves as somehow apart and apolitical and their technologies (i.e., prototype artefacts and the strategies to use them) as neutral.

Secondly, CAS theory suggests a broad range of interventions beyond developing new technology that can foster positive change. The Axelrod and Cohen framework identifies three important sets of interventions:

(1) Changes to the **variation** in a system of types of agents, strategies and artefacts (e.g., by introducing novelties).
(2) Changes to **interaction** patterns between agents, strategies and artefacts (e.g., influencing social networks).
(3) Changes to **selection** processes by which the "fitness" of an agent, strategy or artefact is assessed and their variation subsequently changes (e.g., the selection in learning selection).
(4) The framework helps understand learning selection as working to change the variation in the system by championing a new technology and making improvements to it (usually an artefact together with use strategies). Championing the technology (product championing) involves changing interaction patterns amongst agents, by proactively linking people up (e.g., linking potential manufacturers to potential buyers, farmer exchange visits). A big part of it involves setting up unbiased selection mechanisms so that real improvements to the technology are selected upon, and detrimental adaptations are killed off.

The framework also helps us understand that fostering innovation through introducing and nurturing 'plausible promises' is just one of a number of approaches that can foster change in human-based CAS. Others include changing interaction patterns and selection processes through changing policy.

5. Methodology

Douthwaite used case study methodology (Yin, 1989; Sechrest et al., 1996) in the original PhD thesis. He wrote the cases up as innovation histories – narrative descriptions of the early adoption and adaptation of the stripper harvester, flat-bed dryer and low-cost dryer in the Philippines and Vietnam. Writing innovation histories involves analyzing and writing data up so as to identify the main events in the order they happened together with narrative that identifies and explains causal mechanisms. Our method in this paper was to briefly remind key informants of the respective innovation histories and adoption status 10 years ago before asking them to describe what had happened in the last 10 years. In this way, with the very limited resources available to us, we attempted to fill in the gaps.

The questionnaire asked the following open-ended questions:

- What has happened to sales of the technology since 1997?
- What have been the main developments in the technology since 1997? In which countries?
- Please describe the main novelties or modifications from the original design.
- Why do you think the development has gone in this direction?
- Who was motivating these developments? Was there a clearly identifiable product champion? Who?
- What external trends/drivers were they responding to?
- What were the main constraints to innovation, production and marketing?

We received four responses including one from the main informant in the original research. We also used Gummert's own knowledge and written records from his work in post-harvest in Asia over the last 5 years that works with the same drying technologies is the same countries.

Our other approach was to compare and contrast maps of the post-harvest sectors for three countries drawn by participants in three workshops. The method for drawing the maps is described in Douthwaite et al., 2008 and at http://boru.pbworks.com/Draw+network+maps. The workshops were held in December 2008 and April 2009 to launch the second phase of a project funded by the Asian Development Bank, and led by Gummert. The maps represent a form of institutional analysis and allow us to measure the extent to which research organizations are linked with other types of organizations including manufacturers, farmers' groups and the government sector. We then attempt to correlate the institutional analysis with the other findings.

[1] Adapted from Axelrod and Cohen's summary of their framework, p. 154.

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6. Findings

We now look at the three technologies in turn to see how their development in the last 10 years supports or challenges the understanding of how successful grass-roots innovation unfolds provided by the learning selection model in general, and the 10-point guide in particular.

7. Flat-bed dryer

In the flat-bed dryer, a fan blows hot air through a bed of rice. In 1997, flat-bed dryers in the Philippines and Vietnam typically had a capacity of 4–6 tonnes and could dry one batch in 7–8 h. About 1500 dryers had been installed in Vietnam, made by a large number of small-scale manufactures. In contrast, less than 100 dryers have been sold in the Philippines, largely through the promotional efforts of the Philippine Rice Research Institute (PhilRice).

8. Vietnam

There are now approximately 6200 flat-bed dryers installed in Vietnam. A major factor in the fourfold increase was the strong championing of flat-bed drying by Dr. Phan Hieu Hien, who had designed and installed the first flat-bed dryers in Vietnam in 1983. Since 1983 the pattern has been that Hien and his Nong Lam University (NLU) team release a new design of dryer which is copied, modified and improved by local workshops and the users. NLU monitors these modifications and comes up with major design changes and improvements. This cycle has repeated for nearly 25 years.

In 1998 Hien led a DANIDA-funded project that provided financing for about 2000 dryers. The project was able to link technical expertise in NLU with extension services and credit. In 2001, NLU, in response to user requests, increased the capacity of the dryer to 8–10 tonnes by increasing the size of the drying bin and fitting a higher capacity blower. In 2004 they further modified the dryer so that the airflow is reversed half-way through the drying process, thus reducing moisture variation in the dried rice and allowing for shorter drying times. NLU took the lead role in developing efficient dryer fans. Its focus on dryer fan design was because poor performance fans had nearly killed off flat-bed drying in the late 1980s. NLU transferred design and fabrication technology to 15 manufacturers in the Mekong Delta, seven of whom have built fan test ducts according to industry standards.[2] NLU developed simple blower testing equipment including a pitot tube and airflow meter and a solar collector for supplementary heating. IRRI played a role in some of the improvements made, including the introduction of an automatic rice hull furnace.

On the demand side, adoption and adaptation of dryers was driven by increasing quality consciousness of the export-oriented rice sector. The main constraint was a lack of support to manufacturers from the extension service in provinces where the technology was new, and lack of financing to purchase dryers.

9. The Philippines

The number of flat-bed driers used in the Philippines has increased from 100 to 200 in the last 10 years, mainly due to the efforts of PhilRice engineers who have provided technical assistance to interested farmers and cooperatives. Some modifications have been made to the design, but fewer than in Vietnam. In early 2007, the Secretary of the Department of Agriculture was impressed when he saw a PhilRice-designed flat-bed dryer working in a farmers' cooperative and initiated a program to install roughly 1000 units nationwide, following the PhilRice design, but to be implemented by the Bureau of Post-harvest Research and Extension (BPRE). Similar machinery programs in the past have failed because farmers groups were supplied with poor quality equipment due to lack of technical support from the implementing agency. There is a risk that this will be repeated given that BPRE will implement the program, not PhilRice who have more experience with flat-bed drying in the Philippines.

10. Indonesia

The flat-bed dryer first reached Sumatra, Indonesia, in 1982/1983 when 500 units of various sizes were distributed to village cooperatives in South Sumatra through a presidential grant. The project was terminated because of unsatisfactory results. In 2004, the South Sumatra Forest Fire Management Project (SSFFMP) financed one flat-bed dryer with 3.3 tonnes capacity, designed by the Indonesian Centre for Rice Research (ICRR). The dryer was installed with a farmers group (UPJA) in the tidal swampy areas of South Sumatra. Local manufacturers copied the dryer and increased the drying bin capacity to 8–10 tonnes, but using the same blower and furnace with the result that drying time increased from 8 h to 24 h. Unlike in Vietnam, manufacturers have not yet received the technical support they need to match the fan and dryer design to the dryer capacity. Nevertheless, local manufacturers have installed about 40 units, and adoption is increasing. Sales are driven by difficulties in drying and selling wet paddy. The main constraint to a more rapid increase in sales is the quality and performance of the dryer itself. Manufacturers lack technical assistance that would help them improve quality, unless there is a well-funded project like the SSFFM Project. The national extension system, that could provide technical support, has been decentralized to the sub-district level so that extension workers are unable to source specialist technical information, such as data on dryer fan design, and often do not have resources to go to the field. As a result there is no continuous upgrading and improvement of the design, as in Vietnam.

11. Other countries

In 2004 IRRI organized a dryer manufacturing training course held at NLU in Vietnam. As a result, versions of the NLU dryer have been installed in Myanmar, Laos and Cambodia. A Myanmar manufacturer and the head of the Myanmar Rice and Paddy Traders Association (MRPTA) participated and MRPTA subsequently installed 24 dryers. They were successful in part because they remained faithful to that design, rather than immediately trying to develop their own 'improvements', as many engineers tend to do. This is perhaps because, being millers and traders, they wanted something that worked quickly to improve the poor quality of milled rice. The installation was championed by the Executive Secretary of MRPTA, a former medical doctor, whose own family owns a rice mill. The main constraint to further adoption is the limited capacity the MRPTA has to install dryers and train users.

A Lao participant also attended the 2004 dryer training course in Vietnam and in 2005 installed a 4 tonnes dryer, with a bamboo rather than perforated screen floor to the drying bin. In 2006/2007 he developed an even smaller 1 tonnes dryer with a metal bin and using two small-capacity blowers (developed for the low-cost dryer). In 2007 he reported that the 4 tonnes dryer was better suited to Lao conditions and replaced the bamboo floor with perforated steel sheet, thus reverting to the original Vietnamese design.

An IRRI project installed one dryer in Cambodia in 2007 at a farmers group. The national counterpart from the public sector

[2] Japanese Industrial Standard B 8330-1962.

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tried to build the blower to save money, but it fell apart after 2 h of operation. In collaboration with a manufacturer, who also attended the training in Vietnam, the project replaced the faulty blower and furnace and conducted a series of confidence building activities including training and demonstrations to restore the reputation of the technology. The dryer is now being used by farmers groups and is frequently being visited by rice millers, who want to invest in drying technology.

12. Low-cost dryer

The low-cost dryer, also called the SRR dryer, was first developed by Hien and the NLU team in 1994. They sold 670 dryers to farmers from 1995 to 1997. The original design used low-temperature, could dry 1 tonnes in 48 h without mixing, and appealed to farmers who needed to dry their paddy before selling it. NLU shipped low-cost dryers to the Philippines, Bangladesh, Myanmar and Indonesia for evaluation.

13. Vietnam

Sales increased to about 1000 a year by 2000 but dropped since then to a few hundred a year in 2007. The fall is due in part to the success of the flat-bed dryer. Rice traders and millers have become increasingly willing to buy wet paddy at a good price, so farmers themselves do not need to invest in their own dryer.

The NLU team developed a second model with a faster drying time by increasing the temperature of the blown air and reducing the grain bulk depth. However, this required the use of two bins, instead of one, and manual mixing of the grain. Hence it costs more and requires more labour to operate it.

14. Other countries

In the Philippines a low-cost dryer was tested and modified by the Bureau of Post-harvest Research and Extension (BPRE), loaned to a farmer but found to be too loud by his neighbours. The project was dropped. In Indonesia a dryer was tested by the ATIAMI project in West Sumatra and South Sulawesi, but with no adoption. One constraint was that using the dryer meant farmers had to upgrade their electricity supply to a more expensive category. In Cambodia, the Cambodia IRRI Australia Project (CIAP) and the Support Program for the Agricultural Sector in Cambodia (PRASAC) project tested them but also with no adoption. Cambodia still does not have a proper power grid. Electricity is still mostly supplied by old United Nations Transitional Authority in Cambodia (UNTAC) generators and where available is too expensive. Most villages do not have electricity at all.

15. Stripper harvester

The first stripper harvester was built at IRRI in 1990. By 1997, 139 units of a much-modified version had been built and sold in the Philippines and units had been shipped to farmers and manufacturers in 14 countries. Sales in the Philippines peaked in 1995 (Douthwaite, 1999).

16. Philippines

In the Philippines, sales of the stripper harvester have fallen to zero. According to Dr. Lito Bautista, an engineer at PhilRice, this was due to the poor performance of the machine in soft wet fields, and high losses. In 1998 PhilRice attempted to build a small stripper combine harvester, which was never finished. A few farmers who bought machines are still using them on their own fields, although they have stopped servicing other farmers' fields. PhilRice subsequently put their efforts into developing a combine harvester.

17. Indonesia

The only country where there is any reported uptake of stripper harvesting is Indonesia, where over 200 machines of various types have been sold.

The first prototype stripper harvesters were shipped to Indonesia in 1994 and 1995 by the IRRI Post-harvest Technologies project. One machine went to the ATIAMI Project in West Sumatra and the ATIAMI Project carried out field demonstrations in Sumatra and South Sulawesi. The project lent a prototype Chandue Workshop for copying. No sales were made because almost immediately the manufacturer tried to develop a complicated track system for the stripper harvester, to overcome mobility problems, but got nowhere and gave up in 2001. Then, in 2005, Chandue Workshop began marketing six models of stripper harvester (Table 1) and produced 210 machines (see Fig. 3).

In 2006, IRRI and the second author became aware that Chandue Workshop was suing a competing workshop owner, who is related to him, for patent infringement. Mr. Paisal, the owner of the Chandue Workshop, claimed he had invented the stripping mechanism. Despite IRRI going to some lengths to provide evidence that stripper harvesting was originally patented in the UK, Mr. Paisal continued to pursue his case and as of March 2010 it still had not been resolved. In the meantime the manufacturer being sued complained he had spent a lot of money fighting the court case against him.

There are several factors that explain why stripper harvesters are being sold in South Sulawesi. Firstly, asynchronous planting

Table 1
Stripper harvester models built by the Chandue workshop, South Sulawesi, Indonesia.

Model number	Description
DP 4000	Very similar to the original IRRI design shipped to Indonesia
DP 5000	Also walk-behind, with two star-wheels
DP 6000	Walk-behind, three wheels, collection box in front
DP 7000	Operator sits on top, otherwise similar to original IRRI design
DP 8000	Operator sits on top, two engines, one driving each side, can turn on the spot, 8 ft width (i.e., width of one metal sheet)
DP 9000	Walk behind like the original IRRI design, but 8 ft width, that is 2.4 m wide rotor compared to 0.8 m for the original

Fig. 3. The DP 7000 stripper harvester *(Note the prominent display of the patent number and the seat for the operator).*

means that there is harvesting all year so a mechanical harvester can be used nearly all the time, thus paying for itself quickly. Mechanical harvesting is needed because there is labour shortage and there are no competing harvesters on the market as yet. The ATIAMI project carried out a systematic assessment of 26 manufacturers and lent a prototype stripper harvester for copying to the most capable and interested. Finally, the manufacturer, Mr. Paisal, is an archetypal inventor/tinkerer who was clearly motivated to develop the technology for the sake of pursuing novelty.

18. Network analysis

Network maps of the post-harvest sectors in Cambodia, Vietnam and the Philippines were drawn in three workshops (see Table 2 for details). In each workshop participants were split into four groups who drew maps that showed who are funding post-harvest work, carrying out research, promoting post-harvest technologies and providing political support to sector. The maps were entered as text files and entered into the network mapping software NetDraw (Borgatti, 2002), allowing us to draw one composite map for each country (see Fig. 4).

Table 2
Postharvest project inception workshops in which participants drew network maps of the post-harvest sectors in their respective countries.

	Cambodia	Philippines	Vietnam
Date of workshop	15–19 December 2008	27–30 April 2009	21–24 April 2009
No. of end users	4 (13%)	13 (35%)	3 (6%)
No. of intermediaries	9 (29%)	9 (24%)	16 (32%)
No. of researchers	8 (26%)	8 (22%)	20 (40%)
No. of govnt. staff	10 (32%)	7 (19%)	11 (22%)
No. of participants	31	37	50

Vietnam and the Philippines have roughly the same populations and have similar sized post-harvest network maps. Cambodia, with a smaller population, has a smaller network (Table 3). The biggest difference between the three countries is the number of research links drawn in Vietnam (30% of total) compared to the Philippines (11%) and Cambodia (10%). Fig. 5 shows the research networks in each country (the organizations that research organizations are directly linked to, and the links between these organizations, known as an Egonet (Borgatti, 2002)). It shows that the Vietnamese post-harvest research network is bigger (includes 55% of organizations in the entire Vietnam post-harvest network, compared to 37% in the Philippines and 36% in Cambodia) and contains many more links. In short, we can conclude that research is better integrated into the Vietnamese post-harvest sector than in either the Philippines and Cambodia.

Dr. Phan Hieu Hien explained the results as follows:

> "Yes, the Vietnamese post-harvest network is much bigger and much more complicated than the Philippines and Cambodia, because we are the second/third largest rice exporter [in the world]. Before one can trade something, he/she has to process it, that is post-harvest! That's why I always say that in Vietnam it is not a matter of introducing one dryer, one harvester, or one any piece of equipment. Post-harvest here needs an integrated or systematic approach".

The Vietnamese post-harvest research network is different to the Philippines and Cambodia largely because universities are much more involved. According to Hien, the mandated national post-harvest research institute is in the North of Vietnam, 2000 km away from Vietnam's main rice bowl in the Mekong. Many universities are found in the Mekong Delta and train agricultural engineers. Because of the importance of rice production and

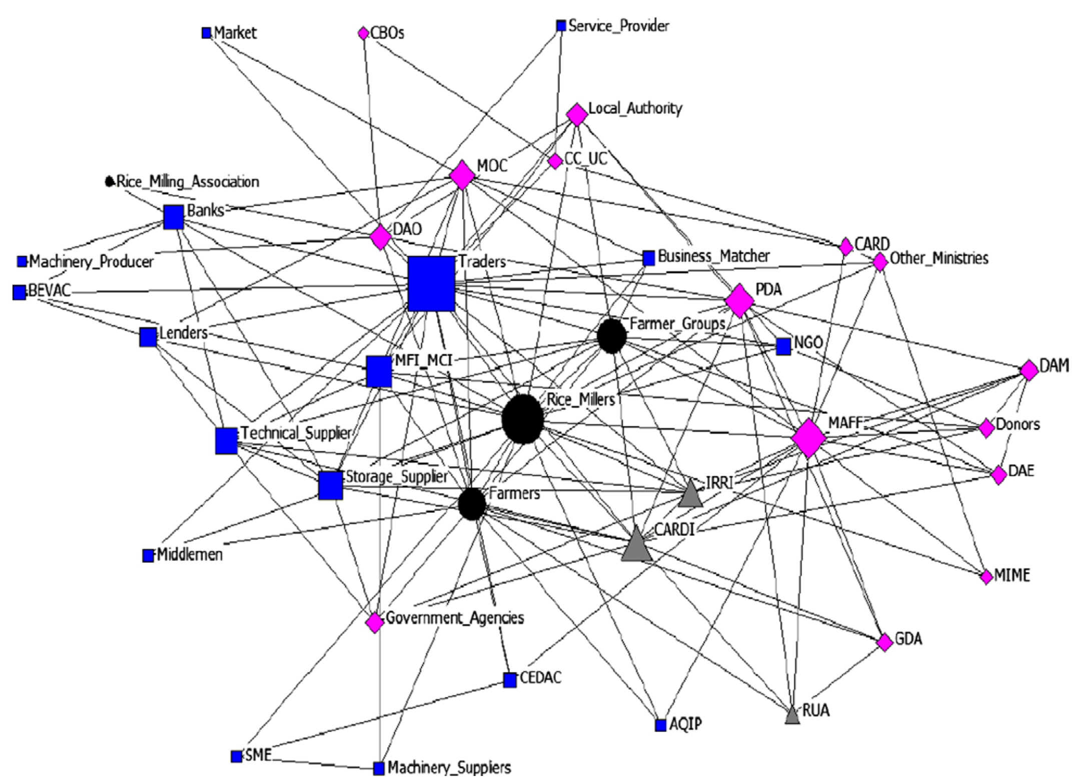

Fig. 4. Network map of the Cambodian post-harvest sector, drawn by participants in post-harvest project inception workshop, December 2009 *(Note that circles = end users, triangles = research organizations, diamonds = government, squares = intermediary organizations).*

Table 3
Comparison of post-harvest networks.

	End users	Intermediaries	Research	Govnt.	Total
Cambodia					
No. of organizations	4	17	3	15	*39*
No. of links	49	102	29	98	*278*
Average no. of links	12.25	6.00	9.67	6.53	*7.13*
Philippines					
No. of organizations	12	46	4	6	*68*
No. of links	70	255	48	82	*455*
Average no. of links	5.83	5.54	12.00	13.67	*6.69*
Vietnam					
No. of organizations	5	36	10	11	*62*
No. of links	57	230	161	92	*540*
Average no. of links	11.40	6.39	16.10	8.36	*8.71*

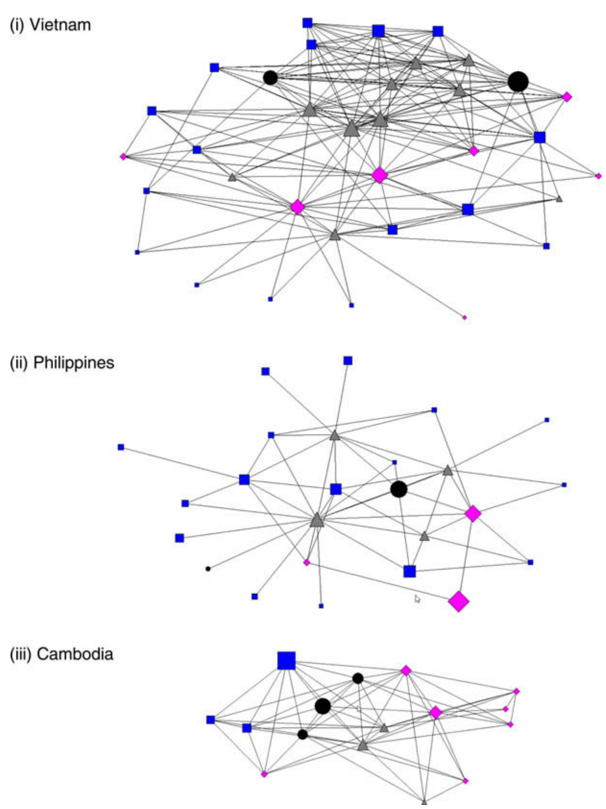

Fig. 5. Research egonets for the post-harvest sectors in three SE Asian countries *(Note that circles = end users, triangles = research organizations, diamonds = government, squares = intermediary organizations).*

export in Vietnam, together with a culture of universities allowing staff to take on consultancy, universities have become engaged in post-harvest research and development with links to intermediaries such as millers, dryer owners, combine manufacturers, etc. Such integration is not found at the same scale in the Philippines and Cambodia.

19. Discussion

We begin this section by examining how the respective innovation histories of the past 10 years confirm or contradict the learning selection model, the 10-point guide and the insights from complexity science. We then examine the implications for science and technology policy.

20. Does the learning selection model hold up?

Of the three technologies – flat-bed dryer, low-cost dryer and stripper harvester – the flat-bed dryer is clearly the most successful. There are about 6000 units installed in Vietnam and the technology has been exported to five other Southeast Asian countries. Its success in Vietnam is in part due to its continuing development in response to changing market requirements. This seems to confirm the basic evolutionary algorithm upon which the learning selection model is based.

The findings largely confirm and add insight to the 10-point guide to fostering a grass-roots innovation process. The low-cost dryer failed to prove itself a *plausible promise* in the Philippines, Cambodia and Indonesia for different reasons. As a result co-development of the technology with users did not start.

A *product champion* proved crucial to the success of the flat-bed dryer in Vietnam. The same R&D team championed the flat-bed drying for 25 years in which time they made major improvements to the technology and strove to maintain quality through, amongst other things, developing and providing blower test kits. They also linked to extension services and helped provide credit.

Interested and motivated individuals were crucial for the success of stripper harvester and flat-bed dyer in Indonesia, and the flat-bed dryer in Myanmar. In all three cases they were motivated by the need for the respective technologies in their areas and the fact they appeared to make a 'plausible promise' of meeting that need. The individual characteristics of the adopters themselves made a big difference. Some were motivated to make major changes before properly testing the original design and improving on that (e.g., flat-bed dryer in Laos; stripper harvester in Indonesia). This tendency appeared in engineers and manufacturer who wanted to make the design their own. While this reduced the 'fitness' of the technology and slowed progress, it also led to major innovations (e.g., stripper harvester in Indonesia).

Staff from the IRRI post-harvest technologies project played an important role in helping *select beneficial modifications* and spread them. An important example of this was the training course they organized for manufacturers from different countries to learn how to build the Vietnamese design of the flat-bed dryer. The technical expertise required to both suggest and evaluate modifications was largely missing in the flat-bed dryer development in Indonesia, and was initially lacking in Laos. Perhaps closer contact between dryer researchers and innovating manufacturers and engineers may have helped them avoid early mistakes. The fact that certain types of people are more likely to behave in a certain way showed that at least professional *culture makes a difference*. The network analysis suggests that the innovation systems in which researchers are embedded has a profound influence on how they operate and their effectiveness.

Politically-motivated government machinery supply programs still risk *promoting equipment too widely*.

The *patent* battle in Indonesia showed that patents taken out to stop others privatizing a technology must be taken out country by country to be effective. It also showed the serious damage that a struggle over intellectual property rights can do to an innovator's motivation and cash-flow.

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The biggest insight from the findings is to the 10th point – *knowing when to let go*. According to the learning selection view of early innovation (Fig. 2) the R&D team should withdraw after a couple of years of co-development to become 'consultants' on the new innovation trajectory they have established and then repeat the process with a new invention. In Vietnam the flat-bed dryer R&D team went through a number of learning selection processes that began with bright ideas, but they were all within the same innovation trajectory.

A software industry analogy can help understand what seems to have happened in the flat-bed dryer innovation history in Vietnam. Some software companies work with three product states, the current version (e.g., version 3.1) on release which has known bugs, the next release (e.g., version 3.2) with bug fixes and minor new features, and the longer-term next version (version 4) with major new features. What we see in Vietnam is that once manufacturers become familiar in a territory with the flat-bed dryer they were able to fix bugs and develop minor new features. They were not, however, able to develop major new improvements in response to likely market changes. This was carried out by the NLU team who developed major modifications such as reversible airflow. In one case the NLU team did start a new innovation trajectory with the low-cost dryer but it built on their flat-bed dryer experience and networks.

The learning selection view of innovation (Fig. 2) was originally developed to show the production of international public goods, or IPGs. IPGs are 'research outputs of knowledge and technology ... that are applicable internationally to address generic issues and challenges' (Harwood et al., 2006, p. 6). In Fig. 2, researchers come up with a good idea, convince potential manufacturers and users in one or more pilot sites that it is a 'plausible promise', co-develop it with them for awhile before withdrawing to go on and seed the next innovation trajectory. The model assumes that from bright idea to co-development should be done within the time period of two project cycles – in other words about 6 years. The assumption is that once established in a pilot site and under the control of the key stakeholders (the people who manufacture, promote and use the technology in the territory), the technology will become widely adopted and eventually spread to other territories in other countries, thus justifying the label of IPG. The researchers are not responsible for this 'extension'. The researchers should go off and seed the next innovation trajectory with the next IPG.

The flat-bed dryer innovation history challenges this conceptualization. It suggests that to really make a difference, the R&D team should not jump ship, but seek to generate their bright ideas within the same innovation trajectory. It suggests that once researchers are embedded in a successful innovation network they should stay there because it keeps them relevant and responding to real need.

The network analysis found that research organizations, especially universities, were much more embedded in the Vietnamese post-harvest sector than in two other countries (Philippines and Cambodia). Links in the network maps in Fig. 4 represent interaction between people, hence it is reasonable to conclude that post-harvest researchers in Vietnam are likely to be better linked to other post-harvest actors than in either the Philippines and Cambodia. Therefore it is probably not by chance that the most successful R&D team came from Vietnam: the network analysis is suggesting they received institutional support in the secret of their success – maintaining and building relevant networks over an extended period of time.

21. Implications for science and technology policy

The idea that more public sector research should be carried out within networks that link researchers to information about need, use and future trends has major implications for the CGIAR system. The previous Science Council Chairman said that CGIAR Centres should not undertake location-specific research because of the high opportunity costs involved (Ryan, 2006). But if CGIAR scientists are not involved in location-specific research then they may not be located within a network of individuals and organizations who are responding to a real need, in a real *locality*. The flat-bed dryer story shows that researchers can generate IPGs while carrying out location-specific research as they respond to needs that are not location-specific. It shows that within an existing innovation trajectory research can generate IPGs that begin new innovation trajectories (e.g., the low-cost dryer). Hence probably only a small percentage of research should be 'blue sky' i.e., research that attempts to establish new innovation trajectories without being embedded in an existing one. The innovation literature suggests this should be between 5% and 20%, which would seem reasonable.

In fact, the CGIAR's most successful research in terms of its impact – breeding of improved crop varieties – is carried out within established innovation trajectories, in well integrated and relatively dense (i.e., networks rich with links) networks. In the case of rice, the core 'IPG' was the idea of breeding semi-dwarf varieties that could yield more without the plants falling down. For the last 40 years IRRI has been breeding semi-dwarf varieties with resistance to different pests and adapted to different conditions within an evolving network of partners. Advanced research centres like IRRI are responsible for major modifications while bug fixes and minor modifications are dealt with locally.

The plant-breeding model is similar to that of much of the private sector. Here, researchers work to develop improvements to existing product lines and every now and then spin-off 'plausible promises' that seed new product lines. They are part of integrated network that identifies customer needs, provides feedback on performance under different conditions and predicts future trends. We can hypothesize that IRRI's plant-breeding network would more closely resemble the Vietnamese post-harvest research network than those of the Philippines or Cambodia.

'Projectization' of research, together with the emphasis on production of IPGs, makes it increasingly difficult for Centre scientists to embed themselves in this way. More often than not, a coalition of partners comes together to meet the donor's requirement, work together (or not) for 3 years to develop an IPG and then dissolve. If they are lucky they will get an extension. Project proposals are rarely evaluated on the track history of the network of people proposing them, and whether that network does link the researchers to the key stakeholders. Instead donors want to be associated with something new because history means they might have to share credit with a competing agency. We are setting up a straw man here, we realize, but it rings true to our own experiences.

Innovation systems behave as complex adaptive systems (Ekboir, 2003). If the networks are rigid and unchanging then they are unlikely to be innovative (Burt, 2005). Equally if networks are constantly forming and breaking up then the system is in a state of 'eternal boiling' and also will not be able to respond to a changing external environment (Axelrod and Cohen, 1999). The twin trends towards working in projects and the necessity of producing IPGs creates conditions of 'eternal boiling', as do funding decisions made for short-term political reasons. Under such conditions part of the role of a product champion can be understood as smoothing out turbulence by managing to keep working on coherent sets of ideas and technologies with a network of people over time and across institutional boundaries and jealousies.

A challenge in fostering innovation processes therefore is how to strike the correct balance between network rigidity and eternal boiling, between continuity and change. The innovation histories suggest that this is most likely to happen when researchers are embedded in a network that makes them aware of emerging needs and links them to users with whom they generate solutions. Public–private partnerships are one way of doing this. Hien and his team, while employed by a university, constructed dryers in a family-owned businesses, and then moved the production to a private arm of the NLU, which was specifically founded to generate profit by producing equipment. Network analysis suggests that they received institutional support to work in this way as they were embedded in an innovation system where universities link more to other post-harvest actors than in the Philippines and Cambodia.

22. Conclusions

Ten years ago the learning selection model was developed to describe the development and early adoption of agricultural equipment in Southeast Asia. The updated innovation histories of the three main technologies confirm the evolutionary algorithm upon which the model was based. However, in the case of the most successful technology – the flat-bed dryer in Vietnam – the R&D team did not withdraw once a critical mass of manufacturers and users were familiar with the technology, as the model says should happen. Rather the R&D team continued to champion the technology and go through learning selection cycles on it. In the process they developed major improvements to the original dryer design. They achieved far greater impact than any other team. They were successful largely because they were able to work with evolving networks of partners, in the same innovation trajectory, for 25 years. This finding challenges the conventional wisdom of much of the international research system that researchers should avoid carrying out adaptive location-specific research and rather develop so-called international public goods (IPGs) that have broad applicability. Rather it suggests a research-for-development approach that ensures researchers are solving real needs of real people in real localities, for extended periods of time. IPGs that spin off new innovation trajectories will likely emerge in the process. While researchers do not need to be physically in each locality working with every farmer or manufacturer they do need to be embedded in networks through which they become aware of need, opportunity, how the technology is being promoted and used and what the market is likely to demand in the future. This structure is similar to that enjoyed by plant breeders and by many researchers in the private sector. It is a way of putting the dictate to 'act local, think global' into practice.

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