Under what circumstances and conditions does adoption of technology result in increased agricultural productivity?

A Systematic Review

Prepared for the Department for International Development

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Abstract

The review question

Under what circumstances and conditions does adoption of technology result in increased agricultural productivity?

Who wants to know and why?

New technology that enables sustainable and profitable production of food and fibre is critical for both food security and economic development. Whether framed in terms of modernisation, productivity enhancement, poverty reduction, social protection, environmental protection or adaptation to climate change, technical change is at the heart of most agricultural policy, programmes and projects. From a development perspective, a nagging question is why the benefits of new agricultural technology often appear to by-pass poorer farmers – even when they are the 'target' group.

Our review focuses on technology for food crop production in low and lower middle income countries (LLMIC) and the productivity gains farmers achieve when adopting them. It is also concerned with other impacts, positive and negative, that may accrue, for example with respect to health, food security or environmental services. Both individually and collectively managed technologies are considered.

This review is directed to an audience of policy-makers and practitioners in the agricultural research area and to development studies academics. It has two main objectives:

- Providing policy makers and practitioners a more realistic understanding of the outcomes that can be expected from technological change as well as of the opportunities to shape the innovation environment so as to favour a productive agriculture supporting broad-based livelihoods;
- Informing the academic community on key gaps in evidence and on the evolution of theory and its drivers in this field.

This appears to be the first systematic review of the conditions and circumstances under which productivity gains are achieved from the adoption of agricultural technology, either globally or by region.

Methods of the review

We use the methods of realist review, adapting elements of the meta-narrative approach. To make sense of the conditions and circumstances that studies claim affect the outcomes farmers achieve by adopting technologies, we hypothesize that it is necessary to recognize the distinct but evolving traditions of research that dominate this literature. We initially identified three traditions – the Diffusion of Innovation, Economic and Local Innovation traditions – expecting to refine this delineation through the review process. We also expected that while a given study would broadly align with a particular tradition, there would also be engagement with the concerns and concepts of other traditions. Whether cross-tradition engagement is increasing and whether from this a fuller understanding of the consequences of adoption is emerging are central to this review's objectives.

Our search of the literature was focused on the major food crops of LLMIC agriculture and ten technology groups including crop cultivars, biotechnology and the management of water, soil fertility and pests. We systematically searched several academic databases and repositories of grey literature. Our database search strategy was developed in consultation with information experts at the British Library of Development Studies and the EPPI Centre and refined through pilot searches. Additional papers were identified in consultation with researchers in the field, including several associated with one or the other tradition. We also searched the bibliographies of the papers they identified and the papers that cited those papers.

Papers thus identified were subjected to a two-stage screening, first for relevance to the study's topic, based on title and abstract. Those that passed were assessed against six criteria relating to conceptual clarity and methodological and contextual detail based on the full paper.

Results

A total of 20,299 papers were screened at the first stage, of which 214 passed through to the second stage. Only five of these papers passed and were candidates for in-depth review. Those not passing the second stage screening failed against two criteria: they did not clearly define technology "adoption" and/or they did not describe a clear and adequate method for assessing change in productivity.

The five papers were scattered across the ten technology groups. This is too small a body of studies on which to proceed to the final stages of systemic review: the in-depth review and synthesis of evidence.

A description of these papers (a "systematic map") can provide some though limited guidance to future efforts to review this area of research, which will have to use a different approach than employed here. We note that four of the five papers could be readily identified with the research traditions we had delineated while one stood apart. The two papers that aligned with the Local Innovation Tradition described multi-year studies that employed several research methods. They reported a number of non-productivity outcomes in addition to yield (output/area) and implicated several conditions and circumstances, the latter including processes and their interactions. The other three papers, two of which aligned with the Economic tradition, reported short duration studies based largely on a single cross-sectional survey. They described less diverse outcomes and implicated only static conditions in explanation.

Implications

The central finding of this systematic review is that from the screening of more than 20,000 citations, only a handful met the quality and relevance criteria we stipulated. This was the case across the ten technology groups we considered. It seems unlikely that our search missed a sufficient number of studies that would have permitted a meaningful synthesis of evidence. Neither does it appear that our standards were unrealistic: their importance has long been noted, guidelines have been disseminated and good practice taught in undergraduate and professional curricula.

The result is that our ability to derive clear, evidence-based guidance on the conditions and circumstances under which farmers achieve productivity gains when they adopt technology is undermined. Opportunities to support more effective policy and program management have been lost and, it would appear, a good deal of research time and money wasted.

In the final section we consider why the quality of evidence in this area is so poor and why the demand for it appears to be so ineffectively expressed**.**

Acronyms

3ie	International Initiative for Impact Evaluation
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
DFID	Department for International Development
DIT	‘Diffusion of Innovations’ Tradition
EPPI	Evidence for Policy and Practice Information and Co-ordinating (Centre)
ET	‘Economic’ Tradition
GMO	Genetically Modified Organism
IDS	Institute of Development Studies
IFPRI	International Food Policy Research Institute
IPM	Integrated Pest Management
IV	Instrumental Variables
LDC	Less Developed Country
LIT	‘Local Innovation’ Tradition
LLMIC	Low and Lower Middle Income Countries
OPV	Open-Pollinated Varieties
SRI	System of Rice Intensification

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1. Background

New technology that enables sustainable and profitable production of food and fibre is critical for both food security and economic development, and consequently, the dynamics of technical change in agriculture has been an area of intense research interest since the early part of the 20^{th} century. Research has focused around three inter-related questions:

1. What are the characteristics of farmers who adopt new technology; and how do these characteristics explain the intra-population dynamics of adoption?

2. What are the drivers of technical change?

3. What are the impacts of technology change?

The policy interest in these questions stems from the central place that technology development (agricultural research) and promotion (agricultural extension) have traditionally played in agricultural development. Convincing farmers of the benefits of new technology has been the mainstay of agricultural programmes and projects throughout the developing world.

Over the decades, approaches to agricultural research, extension and rural development more broadly have evolved considerably. Strong commodity and productivity orientations within agricultural research were softened to some degree by sequential waves of interest in farming systems (Collinson, 2000), farmer participatory research (Okali et al., 1994) and rural livelihoods (Scoones, 2009); while extension broadened from 'master farmers', demonstrations and 'training and visit (Hulme, 1991), to 'farmer-to-farmer' approaches (Alene and Manyong, 2006) and 'social learning' through farmer field schools (Van den Berg and Jiggins, 2007).

Nevertheless, the preoccupation with technology and technical change has remained constant. Whether framed in terms of modernisation, productivity enhancement, poverty reduction, social protection, environmental protection or adaptation to climate change, technical change is at the heart of most agricultural policy, programmes and projects. From a development perspective the nagging question is why the economic and environmental benefits of new agricultural technology often appear to by-pass poorer farmers – even when they are the 'target' group.

This systematic review seeks to shed light on this question by addressing the link between the use of new agricultural technology and increased productivity. Specifically it focuses on the evidence of how conditions and circumstances in Low and Lower-Middle Income Countries articulate the relationship between technology use and productivity outcomes.

Definitions and theory of change

Key definitions are given in Box 1. These definitions provide the foundation for the theory of change that underpins this systematic review (Figure 1). This theory posits a dynamic interaction between technology on the one hand and conditions and circumstances on the other. Changing conditions and circumstances (e.g. increasing land pressure, changing policy, markets or climatic conditions) stimulate the development of particular technologies or whole classes of technology, or make existing technologies more or less relevant or attractive. The use of new technology can in turn change some of these conditions and circumstances.

The conditions and circumstances of interest include environmental (soils, water availability, climate variability etc), institutional (markets, tenure regimes etc) and personal (age, gender, education level etc). Also important are the circumstances in which farmers are exposed to and come to learn about a technology: how to access, employ and draw profit from it. None of these are static although they change at very different rates; they are differentially susceptible to external shocks and to the influence of policy, programmes, projects and farmer agency. As Figure 1 indicates, agricultural technologies are both shaped by and shape these various conditions and circumstances. Feedback effects can be reinforcing for example where expanding adoption of a technology by farmers increases the pool of knowledge on how to gain the most from it. Negative effects can occur from technologies that undermine ecological services, for example where pesticides deplete the natural enemies of crop pests. Such situations can create "treadmills" where the environmental or economic changes produced by the technology induce farmers to use increasing levels of it and make disadoption difficult.

Agricultural technology includes the means and methods of producing crops and livestock. For reasons of feasibility explained below, this review is not concerned with post-harvest technologies such as storage and processing; nor is it primarily concerned with livestock technologies. Within arable agriculture, our main focus, the most common areas of technology development and promotion comprise new varieties and management regimes (planting date, spacing etc), soil and soil fertility management, weed and pest management and irrigation and water management. Some technologies are incremental e.g. the substitution of a new variety in an otherwise unchanged production system, while others such as integrated pest management (IPM), agroforestry or the System of Rice Intensification (SRI) involve radical change. The manner in which varieties are produced and marketed can significantly alter the scope for farmer decision making: hybrid varieties or those produced by genetic modification and the proprietary rights these varieties may enjoy preclude the local crossing and selection that farmers have long practised. Some technologies can be applied at the field or sub-field scale (e.g. varieties and fertiliser) where decisions and associated costs, risks and benefits rest with an individual or household; while others such as certain types of irrigation may only be appropriate and viable at a much larger scale, necessitating different institutions and greater level of organisation and collective action.

Farmers' decisions about whether and how to adopt new technology are conditioned by the dynamic interaction between characteristics of the technology itself and the array of conditions and circumstances. However, this review is <u>not</u> primarily concerned with how the interaction of technology and conditions and circumstances influences the process or speed of adoption (pathway 1 in Figure 1): this is being covered by another systematic review. Rather, our focus is on how that interaction affects what happens <u>as a result</u> of adoption (pathway 2 in Figure 1): the outcome that is the central concern of this review is that an increase in productivity is realised. Adoption is important as the base from which change in productivity is assessed.

Whether productivity increases or not, other benefits in relation e.g. to health, the environment or risk management may be also realised. These benefits may be valued and sought after in their own right – competing with productivity – or, probably more commonly, are seen as important in conjunction with it. For example, farmers may favour a technology option that promises a reasonable but not the largest yield advantage if they feel it helps them avoid market or environmental risks. In collectively managed technologies, equity in the distribution of productivity gains and not only their mean level may be an objective.

Central to our review is the understanding that traditions of research can be distinguished by their characteristic but evolving theories of change linking processes of technology generation, adoption, spread and use. Recognizing these traditions is important because they are likely to privilege different suites of circumstances and conditions in explaining the outcomes of technology adoption. These traditions are described in the following section.

Box 1. Key definitions

Agriculture: crop and livestock raising activities and the management of natural resources and inputs necessary to sustain them.

Farmers: people whose livelihoods depend to some degree on agriculture and who pursue it primarily with their own and/or their family's labour.

Technology: the means and methods of producing goods and services, including methods of organization as well as physical technique. **New technology** is 'new' to a particular place or group of farmers, or represents a 'new' use of technology that is already in use within a particular place or amongst a group of farmers .

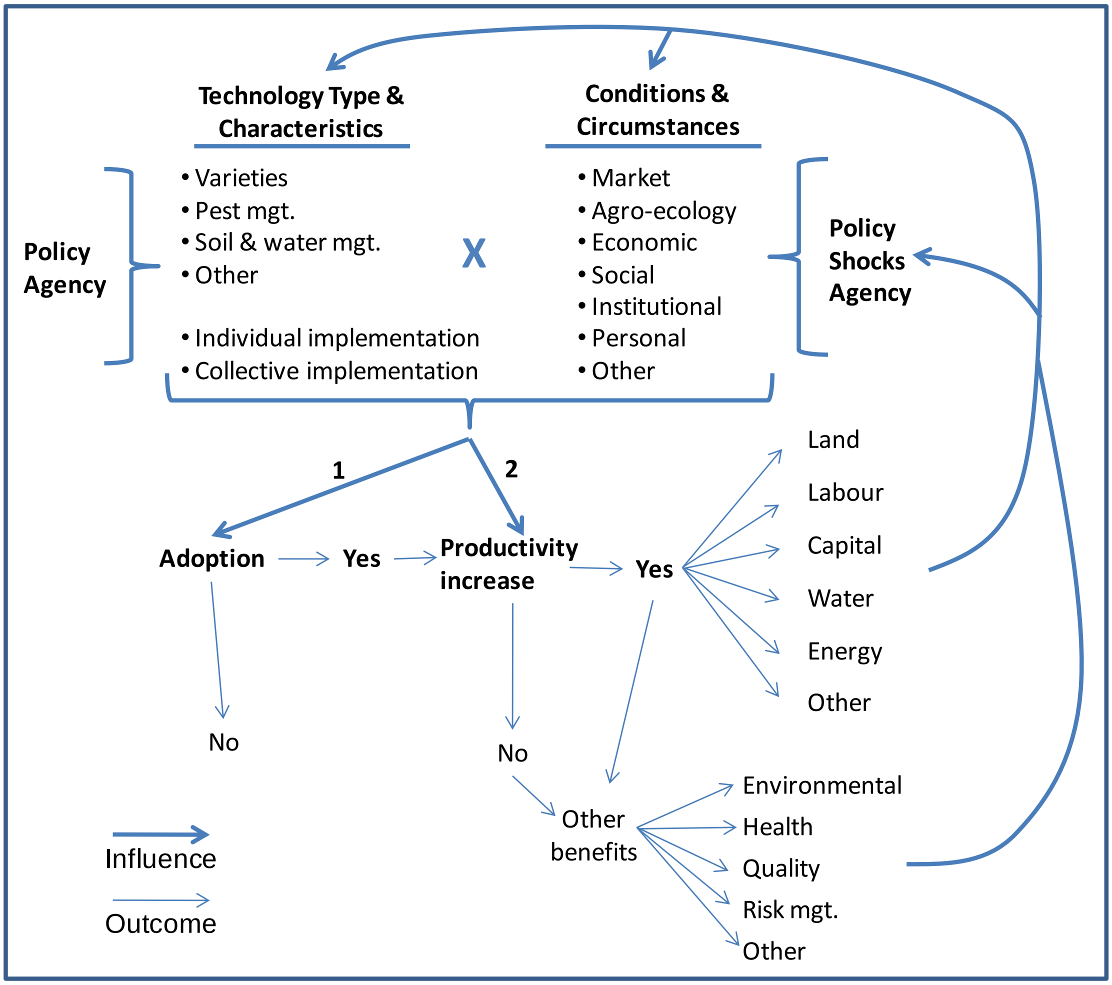
Adoption: the integration of a new technology into existing practice; usually proceeded by a period of 'trying' and some degree of adaptation. **Dis-adoption** refers the process of reversion to the pre-existing technology following a relatively short period of adoption.

Condition: a prerequisite, something that must be present if something else is to occur.

Circumstance: a factor that influences or modifies an event; a circumstance is more variable or transient than a condition.

Productivity: output per unit of input. In agriculture, output is most commonly measured as weight of harvested crop produced; the most common inputs of interest are land and labour, although capital, water and energy may also be of interest.

Figure 1. Conceptual framework / theory of change.
The study's concern is with the consequences of adoption and the conditions and circumstances that influence them (pathway 2), not with the influences on adoption itself (pathway1).



Contending traditions in the study of technology change

The literature on the dynamics of technology change in agriculture is dominated by a handful of identifiable and evolving traditions. Recognizing the existence of these traditions is critical because research that follows one or the other starts with different understandings of farmers' aims and objectives; defines technology and adoption differently; measures different outcomes; and emphasizes different constellations of conditions and circumstances.

The most prominent of the traditions are the sociological 'diffusion of innovations' tradition (DIT) associated with E. M. Rogers, which seeks to explain adoption behaviour in relation to personal characteristics and endowments (Rogers, 2003); the 'economic' tradition (ET) which focuses on the role of changing factor prices in 'inducing' innovation and on productivity and income outcomes (Koppel, 1994); and the 'local innovation' tradition (LIT) which adds a focus on agency, social learning and development and adaptation of technology with and by farmers (Chambers et al., 1989).

It is important to note that these traditions do not represent mutually exclusive or competing theories of technical change within agriculture. Indeed they share many concerns and concepts, and can in principle work quite well together: the Economic tradition seeking to explain the factors that stimulate farmers to respond, and the Diffusion of Innovations tradition seeking to explain how they respond, and why some respond more quickly than others. In other words, the traditions are about differences in emphasis and perspective. However, it is in the nature of traditions that researchers more frequently refer to and build on the concepts and questions that define a tradition than to those characteristic of others. The extent to which researchers in fact engage with the concerns of other traditions, whether cross-tradition engagement is increasing and whether from this a fuller understanding of the consequences of adoption is emerging are central to this review's objective.

Table 1 outlines key features of the principle traditions: how they choose to assess adoption and its outcomes and the conditions and circumstances they privilege. We will use this table to map individual studies to traditions. Both the delineation of traditions and the characterization of their features will be refined through the review process. It is clear that concerns within these traditions have changed over time: for example, textual analysis reveals that the concept of dis-adoption has grown in prominence in the agricultural literature in recent years but barely figured there before 1995.

We have been unable to identify any previous systematic reviews of productivity outcomes resulting from the adoption of agricultural technology either globally or by region. There is a vast literature that touches on the conditions and circumstances associated with the adoption of individual technologies in specific settings (for relevant reviewes see, Feder et al., 1985; Feder and Umali, 1993). There are also reviews of the impacts, including productivity-related ones, of agricultural research undertaken by particular institutions. Raitzer and Kelley (2008) carried out a meta-analysis of the costs and benefits of investments in technologies, primarily cereal varieties and biological pest control, developed by CGIAR centres. However because their analysis is at an aggregated geographic level it provides little insight into the conditions and circumstances in which productivity gains are realized. Distribution of benefits among poorer and women farmers could not be assessed.

The World Bank undertook an extensive literature review on the determinants of adoption and impacts of land management technologies in the Ethiopian highlands from which it drew several generalizations concerning the profitability of different technologies by environment (Yesuf and Pender, 2006). However, the review examined studies focused either on the adoption or the impact of these technologies: none appears to have considered both aspects together. As we discuss at several points in this review, the productivity and other outcomes that can be expected from a technology depend on farmers' relationship to it: how long they have known and used the technology, how widely they employ it on their farms and what proportion of it they implement or how intensively they apply it. In a broad but not systematic review, Doss (2006) critically appraised the literature on agricultural technology adoption and, to a lesser extent, productivity outcomes, drawing a number of conclusions notably on how studies could be designed to yield more pertinent insights for policy. The lack of clarity in what authors meant by "adoption" was one of the principal weaknesses she identified.

Table 1. Key features of the principal traditions

	Tradition		
	Economic	**Diffusion**	**Local Innovation**
Major emphasis	What drives technical change?	What are the personal characteristics and endowments that allow people respond to these drivers more or less quickly? How does the adoption process unfold?	How do agency, social processes and networks affect the dynamics of technical change?
Adoption – treated as:	A dichotomous choice; less commonly a linear sequence of decisions (whether to adopt, where to employ it, how much of it to use).	An essentially linear process, affected by individuals' relative advantage; degrees & stages of testing, adaptation, use & dis-adoption are recognized	A complex process with different degrees & stages of testing, adaptation, use & dis-adoption; farmer agency and knowledge/skill are emphasized
Exposure – emphasis on:	Access to relevant information	Access to relevant information and networks	The context & process of exposure & the importance of social learning
Farmers – emphasis on:	Individual characteristics & circumstances	Individual characteristics & circumstances	Groups & social networks; women's role highlighted
Wider context – emphasis on:	Policy, price & institutional contexts	The nature and effectiveness of diffusion channels	The enabling/dis-enabling environment for farmers' testing/ experimenting, adaptation and spread
Consequences of adoption – emphasis on:	Generally technology-specific, single outcomes, productivity-related. Negative outcomes seldom considered	Generally technology-specific, sometimes multiple outcomes, productivity + others. Negative outcomes sometimes considered	Technology often in relation to farm/ livelihood systems; multiple outcomes – productivity + other concerns – common. Negative outcomes sometimes considered

Objectives

The primary question addressed by this review is: **Under what circumstances and conditions does adoption of technology result in increased agricultural productivity?**

We address this question in relation to:

- The most common agricultural technologies: new varieties and management regimes (planting date, spacing etc), soil and soil fertility management and weed and pest management; irrigation and water management

- Crops (with only a secondary focus on livestock)

- Production (as opposed to post-production) technology

- Low and Lower-Middle Income economies (as defined by the World Bank)[3]

The primary question can be broken down into four subsidiary questions:

1. What outcomes result from the adoption of different types of technology?

2. What are the relationships between these different outcomes?

3. How are these different outcomes valued by farmers?

4. What conditions and circumstances affect which outcomes result from adoption of different types of technology?

Review team

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[3] http://data.worldbank.org/about/country-classifications/country-and-lending-groups#Low_income

User Involvement and Policy Relevance

This review is directed to an audience of policy-makers and practitioners in the agricultural research area and to development studies academics. The review has two main policy objectives:

- Providing policy makers and practitioners a more realistic understanding of the outcomes that can be expected from technological change as well as of the opportunities to shape the innovation environment so as to favour a productive agriculture supporting broad-based livelihoods;
- Informing the academic community on key gaps in evidence and on the evolution of theory and its drivers in this field.

Policy advisors from DFID have been involved in refining the objectives of the review and will peer review its main outputs. Other policy-makers and practitioners have been reached via contacts in agricultural policy networks, in particular the IDS-coordinated, DFID-supported Future Agriculture Consortium[4] and through participation in training courses, seminars and conferences.

The findings will be disseminated in full report form as well as in shorter, more accessible policy briefings. These will highlight the key findings, conclusions and recommendations to policy-makers. We will also contribute to academic debates by preparing a paper for publication in a peer reviewed article.

[4] http://www.future-agricultures.org/

2. Methods

We approached the primary and secondary questions identified above through a realist review (Pawson et al., 2005; Jagosh et al., 2011), adapting elements of the meta-narrative approach of Greenhalgh et al. (2005). We employed the initial delineation of traditions – Diffusion of Innovation, Economic and Local Innovation – to identify and categorise the theory informing each study that was reviewed, refining the categories and their features in light of the emerging evidence, as discussed below.

Inclusion criteria

We included in our review studies that:

- Were written in English or French, without limitation as to date;
- Were based on primary data, without limitation as to study design;
- Dealt with family farmers – those whose livelihood derives primarily from agriculture which they pursue mostly with their own and family labour;
- Concerned Low and Lower Middle Income countries[5];
- Assessed outcomes farmers achieved from adoption of the major agricultural production technology types:
    - Crop varieties and their management regimes (e.g. planting date, spacing);
    - Soil, soil fertility, pest and disease management;
    - Water and irrigation management – implemented by individuals or groups;

  Our primary focus was on agricultural technologies involving the major food crops of low and lower middle income countries: maize, rice, wheat, millet, sorghum cassava, banana and bean. We searched for these specifically.

  We focused secondarily on technologies involving other crops and livestock and their management i.e. while not searching for them specifically, we included studies involving them that were identified in the searches;
- Clearly described how “adoption” was defined;
- Assessed outcomes in terms of change in productivity of a specified input (e.g. land, water, chemical inputs, labour); some of these studies also assessed non-productivity outcomes (e.g. income, health, risk). How outcomes were assessed was clear and appropriate; and
- Documented how specific conditions and/or circumstances influenced the outcomes achieved.

[5] As defined by the World Bank http://data.worldbank.org/about/country-classifications/country-and-lending-groups#Low_income. These countries are also listed in Appendix 1.

We found it essential to specify crops by name, otherwise an impossibly large number of papers, many irrelevant, emerged from the database searches. The crops we specified represent 95% of the area devoted to cereals in LDCs, 59% of the roots and tubers area, 62% of the fruit area and 42% of the pulses area. They are, moreover, crops for which there are active and significant research programs oriented to small farmers (the focus of our review). The crops specified do not include some regionally important pulses e.g. cowpea and pigeon pea and potatoes among the roots and tubers but studies involving them may have been caught through the abstract searches.

Search strategy

Our search strategy had four components:

1. Systematic search of academic databases
2. Snowballing
3. Consultation with professionals
4. Systemic search of depositories of grey literature

Academic databases

Our database search strategy is detailed in Appendix 2.

Consultation with key professionals and "snowballing"

We consulted with researchers associated with the traditions to identify what they considered to be key studies and papers. We also searched the bibliographies of key papers and the papers that cited these key papers (a process known as backward and forward "snowballing") to identify additional academic and grey literature. Literature identified in this way was assessed against the same standards as the papers that which emerged from the database or grey literature searches.

Search of grey literature depositories

We searched the holdings of the British Library for Development Studies (BLDS), the databases IDEAS[6], JOLIS[7,] and key institutional websites, including: IFPRI, World Bank, and 3ie (International Initiative for Impact Evaluation) to identify relevant unpublished studies. By far the largest store of relevant material was found in the archives of the Africa Rice Centre which contain studies on rice technology adoption by farmers across Africa.

6 http://ideas.repec.org/
7 http://jolis.worldbankimflib.org/e-nljolis.htm

Screening strategy

We employed a two-stage screening strategy (Figure 2). In the first stage, research assistants reviewed the title and abstract of each article for its relevance to the study's topic. Approximately 10% of the articles were checked by a reviewer. They applied the following five exclusion criteria:

1. The study is not written in English or French;
2. It is not based on primary data;
3. It does not concern family farmers;
4. It is not about or relevant to Low or Lower-Middle Income countries;
5. It is not about or relevant to the impacts of adopting crop or livestock production technology.

As explained in the previous chapter, we had sought a compromise in the design of our search strategy between feasibility and comprehensiveness. However, in the event, the number of citations identified by Web of Science and AGRIS for several of the technology classes was still too large for us to screen in the time available. In these cases, we had the database rank the output by relevance and then screened the citations until there had been several hundred without one passing the first stage criteria.

Papers that passed the first stage screening were subjected to a second, more detailed screening by a research assistant and at least one of the reviewers. Here, the objective was to exclude those papers that did not provide sufficient conceptual clarity, methodological and/or contextual detail. The exclusion criteria at this stage were:

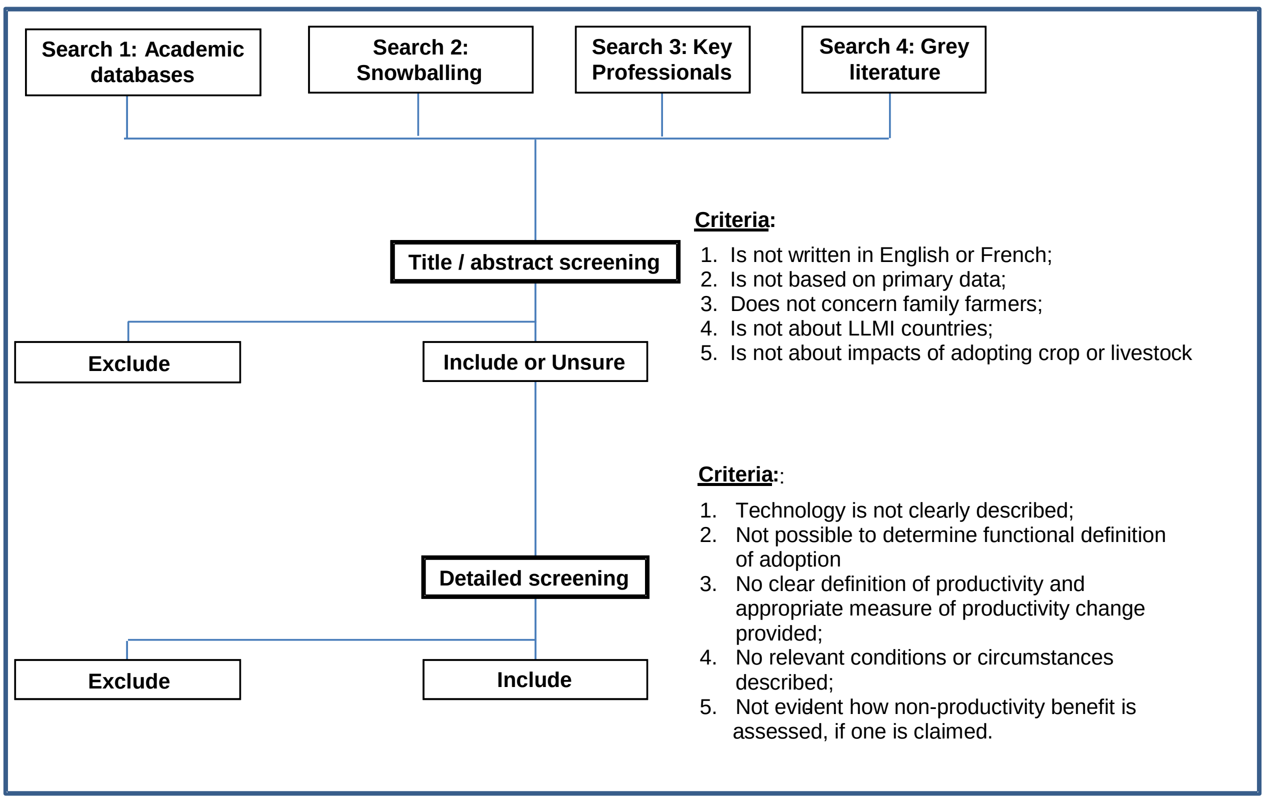
1. The technology is not clearly described;
2. It is not possible to determine the functional definition of adoption. We looked for clarity on three dimensions of use that affect the productivity and other outcomes that can be expected from a technology:
    - **How long** have farmers known or used the technology?
    - On what **area** or proportion of their fields are farmers using the technology?
    - What **proportion** or which elements of a complex technology such as conservation agriculture are farmers using? For technologies like fertilizers and pesticides, the relevant dimension is the intensity with which they are applied, typically measured in the number of applications or the quantity applied. For technologies such as varieties the question does not generally apply.
3. A clear definition of productivity and appropriate measure of productivity change are not provided;
4. No relevant conditions or circumstances are described;
5. A non-productivity benefit from adoption is claimed but it is not evident how it was assessed.

We used EPPI-Reviewer4 software to store and organize bibliographic details of the papers screened and reviewed. The following data was recorded for each paper:

For papers passing Stage 1 screening:
- Bibliographical reference
- Country or region of the study
- Technology studied
- Description of the adoption definition employed
- Productivity and non-productivity outcome(s) studied and description of how assessed
- Conditions and circumstances considered and description of the relationship between them and the studied outcomes.

Plus, for papers excluded at Stage 2 screening:
- The criterion against which it failed

Figure 2. Screening strategy



Methods of data analysis

As explained in the following chapter, the number of studies that passed the screening process was too few to allow us to apply most of the methods outlined in these final two sections. In particular, we could not carry out a synthesis of evidence from the screened studies. These two sections thus largely describe what we had intended to do which may be of interest to researchers considering whether and how to review this literature.

The outcomes of interest to us were the conditions and circumstances under which farmers realize a change in productivity when they have adopted a technology. Also of interest were non-productivity benefits realized by adopters, either together with or independent of increased productivity. Studies were to be assessed by two reviewers for evidence bearing on these outcomes. The weight of a study in the synthesis of findings was to be determined through an appraisal of its:

- **Relevance** – key here is the detail and clarity with which conditions and circumstances were described and assessed in relation to the outcomes of adoption. Of particular interest were to be papers that clarified understandings within a tradition and that serve as key references for later work; and

- **Quality**, was to be assessed in terms of the standards of qualitative or quantitative research, depending on the approach used. We intended to draw on checklists that have been employed in other studies e.g. Munro et al. (2007) for qualitative research and Raitzer and Kelley (2008) for quantitative research. We paid attention to evidence of bias, a particular risk in light of the frequent lack of arm's length evaluation in this area.

Papers that passed the screening were to be assigned to one or the other of the traditions on the basis of the features highlighted in Table 1. We intended to examine the accumulating papers for tradition-specific key words that might have been missed, using these to refine our search.

Data synthesis and presentation

We intended to follow an interpretative approach to the synthesis of the findings (Dixon-Woods et al., 2005). Heterogeneity of results was to be assessed in relation to the circumstances and conditions influencing adoption and resultant productivity and non-productivity outcomes in relation to different technology types e.g. crop variety vs. soil/water management and individually vs. collectively managed and to adoption by farmers differing in gender, wealth and social exclusion.

We anticipated that we would present a structured empirical narrative alongside several mapping and summary tables (presenting descriptive details of each study included in the review). All studies selected were to be summarised in some form in the final report, whether in one of the tables or in the narrative synthesis. In the event, we were only able to carry out a relatively limited mapping based on the handful of studies available.

The synthesis was to be structured according to the subsidiary research questions that fall out of the main review question. Within this structure, evidence from the different traditions relating to each of the subsidiary questions was to be analysed within and then compared among the traditions. Summary tables and possibly diagrams were to lay out the evidence by technology type, and, if sufficiently dense, by region, stratifying by tradition. Other tables or diagrams were to present the trends apparent in how the traditions have understood the important conditions and circumstances shaping the outcomes of technology adoption, thereby highlighting evidence of convergence, divergence or independent development.

Implications and conclusions were to be derived from discussions among the reviewers and refined through dialogue with policy makers, practitioners and researchers. We expected that one important strand would be the reciprocal relationships between policy, the research traditions and the evidence they provide.

3. Identifying and describing studies: results

Figure 3 summarizes the results of the search and screening process. From the various sources, 214 citations passed the first stage screening. Of those that were excluded at the second stage, the vast majority (202) failed because they did not provide a functional definition of adoption (Table 2). Of those that met this criterion, a further 7 were excluded because they failed to provide a clear basis for assessing productivity and change in productivity. Only five studies passed the second stage screen and were candidates for in-depth review. Two of these originated from the key references and three from the database searches. None emerged from our search of the Africa Rice Centre’s archives or the other grey literature sources.

Table 3 documents the screening process by technology. After “cultivars”, the largest number of studies passing the first stage screening related to the “multiple technologies” category. These had not been searched for *per se* but emerged along with the technology-specific results and were identified during the second stage screening. The five studies that passed the second screening were evenly distributed across the 12 technology groups: no group had more than one study. Table 4 characterizes the five studies.

We cannot go much further: five studies is too small a body of literature on which to base a meaningful synthesis of outcomes. Our reading of systematic review methodology has uncovered very little guidance to inform this judgment. Reviews based on an aggregation across studies of a quantitative outcome variable can draw on statistical theory. Fu et al. (2011), developing guidelines for the assessment of clinical interventions, propose as a rule-of-thumb a minimum of 6-10 moderate to large size studies for a continuously-distributed main outcome variable and at least four studies for any categorical sub-group. Although the outcomes we are concerned with are qualitative – conditions and circumstances – it can be helpful to think in a similar way about confidence: any pattern one might hazard to identify on the basis of five studies would be vulnerable to the appearance of a single contradictory study.

However, as discussed in Chapter 1, we expect that the conditions and circumstances affecting productivity and non-productivity outcomes of adoption will vary by technology type and by the research tradition authors follow. Indeed, the three traditions we identified are distinguished by the different constellations of conditions and circumstances they emphasize. Many more than five studies would be required to test these hypotheses.

While an in-depth review and synthesis is not possible, it is worthwhile to consider some features of these five studies, along the lines of what is often referred to as a systematic map (Gough et al., 2012). A map draws on a sample of the studies identified in order to describe the literature and often serves to guide the subsequent synthesis of findings. In this case, the map is the endpoint of our systematic review but may provide guidance to future efforts to review this literature, which clearly will have to take a different tack than ours. Based on just five studies, the caveat above concerning confidence applies.

In the next chapter, we consider the implications of our findings: these relate primarily to why so few studies emerged from the thousands we screened.

Figure 3. The search and screening process

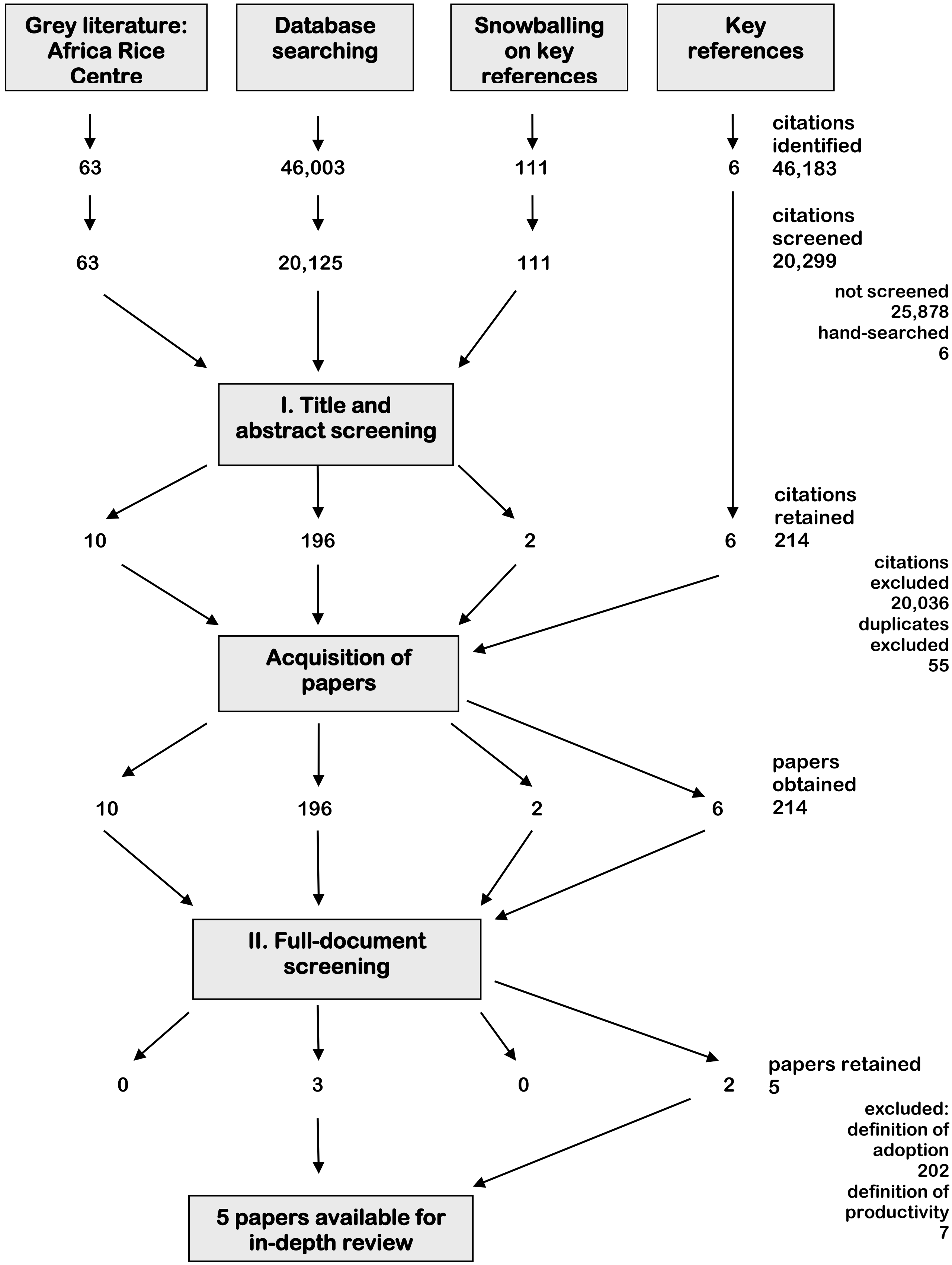


Table 2. Fate of the 214 studies that were screened at the second stage

Criterion	Number of studies excluded	Number of studies retained
1. The technology is not clearly described	0	214
2. A functional definition of adoption cannot be determined	202	12
3. A clear definition of productivity and appropriate measure of productivity change are not provided	7	5
4. Relevant conditions or circumstances and a link between them and the impact on productivity are not described	0	5
5. If a non-productivity benefit from adoption is claimed, it is not evident how it is assessed	0	5

Table 3. The screening process by technology

Technology	Citations searched	Retained after 1st stage screening	Retained after 2nd stage screening
Fertlization	7502	16	0
Pesticide	1920	3	0
Biotechnology/ GMO	1723	14	1
Hybrid seed	558	3	1
Agroforestry	822	11	0
IPM	2512	8	0
SRI	218	11	1
Irrigation and water management	1532	17	1
Organic agriculture	1379	2	0
Conservation agriculture	112	24	0
Cultivars	2022	54	0
Multiple technologies[1]	_	51	1
Total	20299	214	5

[1] Studies identified in one of the technology searches that were found to relate to more than one technology.

Table 4. Characteristics of the five studies that were candidates for in-depth review

Study	Technology	Study population	Functional definition of adoption	Calculation of productivity and change	Relevant conditions and circumstances	Non-productivity impacts
Stone (2011). Field versus farm in Warangal: Bt cotton, higher yields, and larger questions. *World Development*	Bt cotton (proprietary hybrids) and associated pest control, esp. insecticides	4 cotton growing villages in Adhra Pradesh; partial panel study in 2003 and 2007, sample stratified by land-holding. Mean farm area/household 2.0 ha, 16-59% planted to cotton, by village	**Time and area**: Compares last year of no farmers using Bt cotton (2003) and first year of virtually all doing so, on all fields (2007). **Proportion**: Apparently all aspects taken up, by all farmers	The mean increase in farmers' reported cotton yield between 2003 and 2007 was 18%.	**Institutional**: limited seed or insecticide regulation; **Social**: village ethnic/caste composition, social learning, information connectivity; **Personal**: commitment to cotton; **Economic**: unstable cotton prices; **Agro-ecology**: soil type, changing insect ecology	Reduced insecticide use (at least initially); changing insect ecology; agricultural de-skilling
Loevinsohn et al. (1994). Cooperation and innovation by farmer groups: scale in the development of Rwandan valley farming systems. *Agricultural Systems*	Options for intensifying highland valley farming systems: rice, green manures, fish culture. Rice (the most widely used option) was a new crop and required innovation both individually (e.g. varietal selection) and collectively (e.g. irrigation)	68 farmers, (expanding to 99 by the end of 2 years) in 4 groups farming in 3 valleys. Mean area of valley land managed/ household: $250m^2$ - $430m^2$. A partial panel was repeatedly sampled.	**Time**: Groups followed over 2.5 years from introduction. **Area**: By year 2, rice occupied 25% -100% of valley land by group. **Proportion**: Groups took up all aspects of rice cultivation, varying in how they integrated rice into their farming systems	Rice yield was measured on 50% of fields: 2 t/ha in the first season, 3-4 t/ha in following 4 seasons. Farmers reported rice was more productive than cereals previously grown. It also permitted 30% more land to be cultivated and, in one valley, an additional cropping season/year	**Institutional**: farmer-led research, group governance; **Social**: extreme land scarcity; access to information; **Personal:** varying market orientation; **Economic**: relative crop prices; **Agro-ecology**: altitude and cold, topography	Income; food security (by conserving key crop diversity)

Matuschke et al. (2007). Adoption and impact of hybrid wheat in India. *World Development*	Proprietary hybrid wheat, bred for semi-arid conditions	Survey in 3 Maharshtra districts, oversampling hybrid wheat users; mean farm area: 1.5 ha. Study took place 2 years after the hybrid was introduced: planted on 1.5% of the state's wheat area.	**Time**: Adopters are farmers who planted hybrid wheat in 2003-04. **Area**: Hybrid wheat plots average 0.5 ha (but many small ones) vs. 0.9 ha for conventional (OPV) wheat; **Proportion**: Not applicable	Farmers' reported yields in hybrid and OPV plots were analysed by instrumental variables (IV). Estimated yield increase due to hybrid wheat was 20%	**Agro-ecology**: access to irrigation, soil quality	Increased income
Noltze et al. (2013). Impacts of natural resource management technologies on agricultural yield and household income: The System of Rice Intensification in Timor Leste. *Ecological Econonomics*	System of Rice Intensification; 4 principles: early transplanting, single seedlings, wide spacing, intermittent irrigation	Stratified sample of farmers (159 adopters, 238 non-adopters) in 2 districts where SRI was promoted beginning in 2007. Mean rice area/household: 1.2 ha	**Time**: Two years after SRI introduced; **Area**: Adopting farmers manage at least 1 SRI plot (mean area 1.1 ha); **Proportion**: they employ all 4 SRI principles	Adopting farmers' reported yields in SRI plots were compared to yields in conventional plots of non-adopters. Using IV and endogenous switching regression, SRI's yield effect in SRI plots (+46%) and in conventional plots (+11%) were estimated. Effects greatest in initially low yielding plots.	**Social**: local information networks; **Personal**: age of household head; **Agro-ecology**: good water control; soil quality; proximity to homestead	Increased income, especially in small farm households that specialize in rice.

Posthumus et al. (2010). To terrace or not: the short-term impact of bench terraces on soil properties and crop response in the Peruvian Andes *Environment, Development and Sustainability*	Bench terraces	46 farmers' fields sampled (22 bench terraces, 24 sloping fields) in the Apurimac department.	**Time**: 2-4 yrs after terrace construction; **Area**: Terracing applied to whole field; **Proportion**: Not applicable	Yields were measured in 2002-03. IV were used to estimate effect of terracing on yield. Positive yield effect was nullified by the loss in crop area from terrace construction.	**Agro-ecology**: slope, access to irrigation	None identified

Characteristics of the included study: the systematic map

1. Two of the traditions that we had initially identified can be recognized in these studies. Concern with the role of farmer skills and social learning in shaping technologies, a hallmark of the local innovation tradition, is prominent in two studies (Loevinsohn et al., 1994; Stone, 2011). The institutional context is shown to support local innovation in the first case and to undermine it in the second. Two studies (Matuschke et al., 2007; Noltze et al., 2013) pay particular attention to farmers' personal characteristics, the physical features of their farms and input and output prices in explaining both adoption decisions and their consequences, as is characteristic of the economic tradition. The fifth study (Posthumus and Stroosnijder, 2010) is concerned largely with environmental conditions that influence the uptake and impact of the technology. It sits uneasily within any of the three traditions we delineated. It and other studies we have seen that did not pass the screening suggest that it may be necessary to distinguish a fourth tradition.

2. The studies that align with the economic and local innovation traditions describe different kinds of non-productivity impacts of the new technologies: the former report only income effects whereas the latter describe a range of farm-level effects and impacts on the local environment. Loevinsohn et al. (1994), one of the local innovation tradition papers, describes the different choices farmers made among the technological options, reflecting the values they placed on the non-productivity impacts of food security and income. Stone (2011), the other local innovation tradition study, describes a negative impact of the new technology: the introduction of a plethora of poorly-regulated Bt-cotton hybrids overwhelmed farmers' ability to test and compare, leading to varietal "fads" and contributing to what Stone calls agricultural de-skilling.

3. Loevinsohn et al. and Stone were able to discern these broader impacts because both were multi-year studies, relying on several research methods. The other three studies had little chance of detecting such impacts, even had they been looking out for them, because they were short term, each based largely on a single cross-sectional survey. This distinction also affected the studies' relative abilities to discern the conditions and circumstances influencing the productivity and other impacts of technology adoption. Recall that we defined "condition" as a prerequisite, something that must be present if something else is to occur; "circumstance" was defined as a factor that influences or modifies an event – more variable or transient than a condition. Farm acreage, household income or the head's educational attainment were conditions that a survey could readily document. However, in-depth interviews and repeated observations were required for example to understand the circumstances of farmers' responses to the inadequately characterized Bt cotton hybrids that flooded the market in Andhra Pradesh, in which social learning and regulatory processes Interacted. This suggests that it is not just the conceptual orientation of the traditions that influences the impacts, conditions and circumstances they are likely to highlight but also the research methods they typically rely on.

Doss (2006) and Smale et al. (2006) found the prevalence of short duration studies based on a single cross-sectional survey in one site a major impediment to understanding the factors affecting the adoption of technology and the benefits gained from it.

4. The two local innovation tradition studies determined changes in productivity (crop yield) differently than the other three studies. Those two studies calculated the difference in the yields measured or reported by farmers over the period of technology adoption on a panel or partial panel of fields. The three other studies inferred the effect of the technology on yield with the instrumental variables (IV) method, drawing on the yields of adopters and non-adopters

recorded in a single cross-sectional survey. The IV method can help to avoid the endogeneity of explanatory variables (i.e. they may be influenced by some of the same forces e.g. technology adoption as yield) by substituting other variables, known as instruments, that are correlated with the explanatory variables but thought to have no association with yield. The method is now commonly used in impact evaluation and guidelines for reporting statistical results have long been available (Bound et al., 1995). It is striking that none of the three studies that used IV met these standards, making it impossible for readers to judge whether the results are unbiased. The problem may well be widespread: a recent survey (Davies et al., 2013) of clinical intervention evaluations that relied on IV found that only 28% met one of the key information requirements (reporting appropriate tests of the strength of the association between instruments and exposure). Future reviews in this area should pay attention to this aspect of quality.

4. Implications

The central finding of this systematic review is that from the screening of more than 20,000 citations, only a handful met the quality and relevance criteria we stipulated. In what follows, we consider possible explanations and the implications for policy and research.

Did we miss relevant studies?

No search strategy can be guaranteed to find all pertinent studies. Ours was developed in consultation with experts at the British Library of Development Studies and the EPPI Centre and refined through repeated trial. The strategy we settled on was as comprehensive as possible while still being feasible to implement. As described above, we were obliged to sample the large number of citations identified by the databases (overall, we screened 43.7% of those citations) after they had been ranked by relevance. While the databases' definition of relevance may differ from ours, it seems unlikely, given the sampling proportion, that we would have missed more than a few additional papers that would have made it past the second screen.

We screened one large repository of relevant grey literature – that held by the African Rice Centre – which yielded no studies that passed the second screen. We cannot exclude the possibility that other such sources that we did not identify might yield some.

Were our standards unrealistic?

Most of the papers that were excluded at the second stage screening failed because they did not specify what they meant by "adoption" (or a synonym if they had not used the term itself) of the new technology. We specified that the study should provide information on three dimensions of use that affect the productivity and other outcomes that can be expected from a technology:

- **How long** have farmers known of or used the technology? Farmers experiment with and learn from others about a new technology, gaining more from it with experience. With time, farmers also abandon or dis-adopt technologies because circumstances change, they become aware of drawbacks and other technology options appear.
- On what **area** or proportion of their fields are farmers using the technology? Initially, farmers typically experiment with a technology on a small plot, often relatively fertile and near the home where its productivity may be greater than elsewhere. Gaining experience, they may employ it on a wider area or restrict it to a part of their holding where they find conditions favour it.
- What **proportion** of a complex technology are farmers using? Farmers often use only certain elements of what may be presented to them as a package, possibly using more of them with time but sometimes finding that some are not practicable or profitable in their conditions and circumstances and that they cannot achieve the same synergy among the elements that the package's proponents held out to them.

The importance of these dimensions of the adoption process has long been discussed, beginning at least with the work of Rogers (Rogers and Shoemaker, 1971; Rogers, 1995; Rogers, 2003) and reviewed in the context of LLMIC agriculture by Feder et al. (1985), Smale et al. (1995), and Doss (2006). A guide prepared by CIMMYT provided practical advice for the design of technology adoption studies (Byerlee, 1993). Concern with these issues has not been restricted to particular traditions or disciplines such as economics and sociology. Agronomy has a long-standing interest in the size of plots in which technologies are assessed: yields are often found to be higher in small plots due to edge effects (Langton, 1990). Indian entomologists have examined the factors influencing the extent of pigeon pea farmers' adoption of IPM i.e. the number of insect control measures they employ, comparable to our term "proportion", and the impact on their practices of the introduction of new insecticides (Rama Rao et al., 2011). Being clear about where a group of farmers is situated with respect to their use of a technology is neither an arcane concern nor an insuperable methodological challenge.

The second most common criterion at which studies failed in the second stage screening was the lack of a clear definition of productivity and an adequate measure of the change in productivity associated with the technology. Yield (output per unit area) was almost invariably the productivity indicator evaluated.[8] A common weakness was to calculate the difference in yields between farms or fields on which the technology was and was not being used in a simple cross-sectional comparison, leaving the conclusions vulnerable to bias due to self-selection by farmers or to non-random placement of the technology with respect to the characteristics of their fields.

Again, acceptable practices in impact evaluation are well described in text books and taught in many undergraduate and professional curricula. The standards we required were by no means unrealistic.

We conclude that the assessment of productivity change as a result of technology adoption in much of the published literature and that part of the grey literature we reviewed is methodologically flawed. This appears to be the case across the technology classes we considered. As a result, our ability to derive clear, evidence-based guidance on the conditions and circumstances under which farmers achieve productivity gains when they adopt technology is undermined. Opportunities to support more effective policy and program management have been lost and, it would appear, a good deal of research time and money wasted.

The demand for quality in evaluation

The question that remains is why the quality of evidence on this issue is so poor. Why, for example, is it still common for articles to refer to farmers' adoption of a technology as if it were a simple yes/no decision?

This wasn't the question our systematic review was designed to answer but our familiarity with the literature may permit us to pose more specific questions that can be pursued in further research. We examined closely several of the studies that were excluded at the second screen to identify modifications that would have enabled them to pass. What was required was often relatively modest, for example asking the same questions or making the same measurements in both experimental and control groups (those with and without access to the technology) or establishing a baseline before the technology was introduced. The generally experienced researchers carrying out the studies would have known how to make these changes. Some additional cost as well as forethought would have been required.

[8] Some studies assessed other productivity indicators alongside yield. For example, two of the mapped studies (Loevinsohn et al., 1994; Posthumus and Stroosnijder, 2010) documented changes in the proportion of land area cultivated on a seasonal basis. The former also assessed changes in the number of cropping seasons per year made possible by the technology.

Why weren't such changes made? Why did the evaluation of the technology's impact often appear to be an afterthought?

- Was there demand for quality evidence[9] in this area from stakeholders at national policy level? If there was, what prevented it from being effectively expressed and influencing research planning and design decisions?

- Did research funders express a demand for quality evidence in this area? If they did, what prevented it from influencing research planning decisions?

- What incentives or disincentives were there for researchers to design and implement evaluations that would have provided quality evidence in this area? Did these operate differently when the evaluation was at arm's length from the implementation as when it was done in-house or by implementers themselves?

- Were weaknesses in the evaluation picked up by peer reviewers when papers were submitted for publication? If they were, what prevented improvements being made?

- The need for quality evidence would seem to be greatest at the level of implementation and as the technology is being introduced to farmers, to support program improvement and adaptation. One would expect that the conditions of those who access the technology and who gain or lose from it and the circumstances under which this occurs would be very much a local concern. What prevented that concern from being translated into effective demand from communities, civil society or local government?

It may be possible to pursue such questions in case studies of evaluations, some better and some worse. These could provide insight into where problems lie and suggest means to overcome them. It seems self-evident that quality evidence will only be produced where there is effective demand for it. That does not appear to have been the case in the area we reviewed.

[9] Evidence that would have met the standards we set in our review.

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Appendix 1

Low and Lower Middle Income Countries

Afghanistan, Angola, Armenia, Bangladesh, Belize, Benin, Bhutan, Bolivia, Burkina Faso, Burundi, Cambodia, Cameroon, Cape Verde, China, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, DRC, Djibouti, Ecuador, Egypt, El Salvador, Eritrea, Ethiopia, Gambia, Georgia, Ghana, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, India, Indonesia, Iraq, Ivory Coast, Jordan, Kenya, Kiribati, Korea, Kosovo, Kyrgyzstan, Laos, Lesotho, Liberia, Madagascar, Malawi, Maldives, Mali, Marshall Islands, Mauritania, Micronesia, Moldova, Mongolia, Morocco, Mozambique, Myanmar, Nepal, Nicaragua, Niger, Nigeria, Pakistan, Papua, Paraguay, Philippines, Rwanda, Samoa, São Tomé, Senegal, Sierra Leone, Solomon Islands, Somalia, Sri Lanka, Sudan, Swaziland, Syria, Tajikistan, Tanzania, Thailand, Timor-Leste, Togo, Tonga, Tunisia, Turkmenistan, Tuvalu, Uganda, Ukraine, Uzbekistan, Vanuatu, Vietnam, West Bank and Gaza, Yemen, Zambia, Zimbabwe

Appendix 2

Database search strategy

Our search method was developed in consultation with information experts at the British Library of Development Studies and the EPPI Centre and refined through several pilot searches. We searched the following databases: AGRIS, CAB Abstracts, JSTOR, Web of Science, Science Direct, GREENFile, African Journals Online, Asia Journal Online, Latin American Journals Online and Econlit.

In the Web of Science we searched the following databases: Science Citation Index Expanded (SCI-EXPANDED); Social Sciences Citation Index (SSCI); Arts & Humanities Citation Index (A&HCI); Conference Proceedings Citation Index- Science (CPCI-S); Conference Proceedings Citation Index - Social Science & Humanities (CPCI-SSH).

We employed the following English search terms:

First term – agricultural context:

(agricultur* OR crop OR farm or farm*) AND (maize OR rice OR wheat OR cassava OR manioc OR millet OR sorghum OR banana OR bean)

Results filtered by technology:

fertiliz* OR fertilis*
pesticid* or herbicid* or insecticid*
cultivar*
biotech* OR GMO OR GMOs OR “genetically modified”
hybrid OR hybrids
agroforestry
IPM OR “integrated pest management”
SRI OR “system of rice intensification”
irrigat* OR “water management”
“organic agricultur*” OR “conservation agriculture”

Results filtered by outcome:

impact OR benefit OR productivity OR yield OR income OR health OR welfare OR market OR “food security” OR risk

We searched on “topic” (title, abstract and key words) in Web of Science and ScienceDirect; “abstract” and “title” and “subject” in CAB Abstracts; “abstract” and “title” in AGRIS, JSTOR, GREENFile, Latin American Journals Online and EconLit, and “full text” in African Journals Online and Asia Journals Online.

Google Scholar search

A second search was performed using Google Scholar with the following search terms:

(impact OR productivity OR yield) AND (/technology – as above/) AND (agricultur* OR crop)