Innovative methods for measuring adoption of agricultural technologies:
Establishing proof of concept and thinking about scaling up

Workshop Report[1]
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1. Introduction

As one of the activities under Objective 1 of the SIAC project, a workshop on "*Innovative methods for measuring adoption of agricultural technologies: Establishing proof of concept and thinking about scaling up*" was held on August 3-4 in Boston, USA. This event was jointly organized by Michigan State University, the Standing Panel on Impact Assessment (SPIA) of the CGIAR Independent Science and Partnership Council (ISPC), and the CGIAR Research Program on Policy, Institutions, and Markets (PIM). Forty-four participants from 28 public and private institutions participated in this workshop to share and discuss the results and lessons learned from various pilot studies recently implemented using new and innovative adoption measuring methods.

The program was designed to focus on technical aspects of the adoption measurement methods and their scaling-up potential in the developing world. A wide range of methodologies spanning the long-standing practices of expert opinion elicitation and farmer self-report in household surveys, to new methods of DNA fingerprinting, remote sensing, ICT-based rapid survey, and surveys at informal markets were included in the workshop program. Participants also brainstormed on the most appropriate mechanism for institutionalizing the adoption measurement and the scope of outsourcing data collection to the private sector. The workshop program and the list of participants are included in Annexes 1 and 2.

This document summarizes the main outcomes of the discussion of this workshop. It first provides an overview in terms of the motivation for this workshop, the importance of measuring technology adoption, and the scope/focus of the workshop in light of the motivating factors, challenges, and opportunities. This is followed by a summary of each workshop session that highlights the pros and cons and scaling up challenges associated with different methods of collecting technology adoption data in a developing country context. We conclude with some remarks on the general consensus that emerged, or suggestions made at the workshop on the next steps to advance professional practicein measuring agricultural technology adoption.

2. Workshop Overview

In the research-to-impact pathway that starts from the initiation of an agricultural research activity to the generation of outputs, outcomes and impacts, 'adoption' plays a critical role in achieving societal level goals such as reducing poverty, hunger, and malnutrition. Adoption, defined as the use and uptake of research outputs by the end users, is a necessary condition to achieving impact. In fact, the aggregated or system level impact of agricultural research is positively correlated with the level of adoption. If, along this pathway, research and dissemination efforts for a given output lead to high level of adoption, the overall impact is expected to be high; but if there is no adoption, there will be no impact. Thus, knowledge of the scale and magnitude of the adoption of a research output serves as an

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important metric for gauging the success and effectiveness of research and dissemination efforts. Adoption information provides a valuable source of feedback for planning publicly funded research. Knowledge on the level of adoption of a research output can also help guide subsequent research to uncover development impacts, if adoption levels are high; or it can inform the broader development community in shaping its thinking on a wider set of potential constraints to adoption, if adoption is low.

Despite these benefits that come from tracking adoption of research outputs, keeping abreast with this knowledge across time and geographical scales is a challenging task. Establishing a system for tracking and estimating the adoption of agricultural technology more frequently and at a representative scale is both time and resource intensive. There are methodological challenges in estimating the adoption of agricultural technology and practices by farmers spread across the country on a regular basis that give an accurate picture of adoption without incurring huge costs for the logistics of data collection. This explains the lack of up-to-date knowledge on aggregate-level adoption of research outputs generated from long-term investments by international and national research systems on crop germplasm improvement research, agronomic research, natural resource management, livestock improvement, fisheries and aquaculture, and water management.

The importance of tracking technology adoption and the challenges associated with it both provide an impetus for this workshop. The lack of up-to-date knowledge on the level of adoption by farmers of different types of technologies was also an impetus for the Strengthening Impact Assessment in the CGIAR (SIAC) program initiated by SPIA four years ago. How to measure technology adoption and generate understanding of who is adopting, the scale and magnitude of adoption, where and why (or why not) adoption is taking place, are also issues that many NARS, CGIAR Centers (hereafter referred to as 'Centers') and CGIAR Research Programs like PIM are grappling with. This workshop was organized to explore and learn about innovative methods of tracking and measuring technology adoption to address some of these challenges.

Within this broader context of the importance of tracking technology adoption and the challenges associated with it, the overall objectives of this workshop were to:

a. Take a stock of current and innovative methods for measuring adoption of agricultural technologies
b. Share and discuss results and insights from pilot studies and experiments conducted to establish proof of concepts to harness the potential of new methods for tracking adoption of agricultural practices and other types of technologies
c. Further the discussion on scaling up proven methods of measuring technology adoption

The two-day program was designed around the following themes of '**innovative** methods and approaches:'

a. Methods / approaches /**alternatives** that are **low cost** and provide **high accuracy** estimates at a **large scale**
b. **Institutionalizing** / integrating the collection of adoption data in existing public sector led efforts in many countries

The bolded words above emphasize the key themes of this workshop underlying the discussions and deliberations that took place over the two days: innovative methods, low cost–high accuracy–large scale adoption estimates, low-cost alternatives to conventional practices, and institutionalization of the collection of adoption data.

Before the start of the workshop, it was made clear that the workshop was NOT about assessments of constraints to technology adoption, determinants of adoption, or the benefits and impacts of adoption. Instead, the focus was on tracking and estimating adoption of agricultural technologies in developing countries as measured by area (geographic scale) and number of people (farmers, farm households, ‘endusers’). The outputs of such tracking efforts (i.e., the focus of this workshop) are expected to generate knowledge on: the scale and magnitude of adoption (spatial dimension), the speed and rate of diffusion (temporal dimension), and patterns of adoption (‘who’, where adoption is occuring) (social dimension). Below we present the summary of each program session, bearing in mind the workshop themes and the intended knowledge outputs in the spatial, temporal and social dimensions.

3. Current practice for large-scale varietal adoption studies: The expert opinion elicitation method

The workshop opened with this first session focused on sharing of experiences by Center participants with the expert opinion elicitation method for estimating country-level variety-specific adoption. This was the method used under the previous DIIVA (Diffusion and Impacts of Improved Varieties in Africa, 2009-2013) and TRIVSA (Tracking Improved Varieties in South Asia, 2010-2012) projects. The presentations and discussion in this session were mostly focused on experience in using this method under SIAC Activity 2.1 (addressing ‘large gaps in existing adoption databases for genetic improvement technologies’) to build a database of varietal adoption across 130 crop-country-combinations (CCCs) in the regions of South Asia, Southeast Asia and East Asia. Within the framework of ‘low-high-large’, this method is considered to be relatively low-cost (as measured by cost per CCC), large-scale (estimates are for the CCC level or sub-regions within a CCC only), but has low (or unknown level of) accuracy.

As per the guidelines prepared for SIAC Activity 2.1, the method consists of first collecting and putting together the historical information on varietal releases in a given CCC, collecting and reviewing evidence on recent adoption studies and variety-specific seed distribution and sales data, and synthesizing this evidence for use as resources/background materials in the elicitation workshops. The elicitation workshop serves as a platform to convene a panel of experts that are considered to be fairly knowledgeable about varietal adoption for the respective crop and country. Typically, these expert panels consist of National Agricultural Research Systems (NARS) and/or Center breeders, crop management scientists, extension workers, seed traders, seed company representatives, local agricultural officers, representatives of NGOs active in seed dissemination efforts, farmers, and other individuals knowledgeable about the particular crop production systems in the country by sub-region. During the workshop, participants are asked to share their ‘expert opinion’ judgements on variety-specific adoption for all the ‘sub-regions by season’ combinations identified as units of disaggregation for a given CCC. The individual-level opinions are then discussed and debated in the larger group to come up with a consensus estimate of adoption at a representative scale for a given sub-region × season combination. These sub-region level estimates are then aggregated to obtain the weighted average adoption estimates for each variety at the country level.

In the presentations made by different Center focal points for this Activity, it was clear that each Center had adapted this methodology to their crop and country settings, and there were slight variations in the way different steps were implemented and the workshops organized to elicit expert judgements on varietal adoption. Several pros and cons, and lessons learned were identified based on the experience of using this method by five Centers (CIMMYT, CIAT, CIP, IRRI and ICRISAT) in the past two years. These are summarized below.

Pros/what worked:

- Methodology is quick, cost-effective, not time consuming (relative to conducting representative farmer surveys)
- Composition of expert panel: Convening experts from various disciplines and organizations;
- Providing list of released varieties and overview of the sector at the elicitation workshops helped to faciliate the elicitation process
- Method is holistic: It incorporates information based on seed saving information, informal seed exchanges and farmers' own saved seeds as well as expert opinion from different institutions
- Captures adoption differences across the domains

Cons/challenges:

- Method gives biased estimates: Experts do not have accurate knowledge on varieties grown by farmers in all geographical regions. This will create biased estimates when deriving aggregate level estimates. Also, there is a tendency for experts to overestimate adoption of varieties released by their program or institution.
- Difficult for experts to come up with adoption estimates in the following settings:
    a. Large number of varieties, each with a small market share (experts have difficulty estimating adoption of varieties not widely grown)
    b. Private sector is an important player (they are not forthcoming in sharing their seed sales data or market share by varieties)
    c. cross-pollinated crops and hybrids
    d. Fear of contradicting official statistics
    e. Complex domains (large number of agro-climatic regions, seasons and production conditions requires lengthy discussions and leads to expert elicitation fatigue
    f. Varieties are known by different names in different locations within the CCC
    g. Farmers grow mixtures (e.g., lentils)
- Elite capture – some experts dominate discussions, which can lead to biased estimates

Lessons learned and guidance for future efforts:

- Workshop organization tips
    a. Pre-workshop preparation: prior understanding of the seed system, varietal preferences, past studies, etc., are important to get the most out of expert elicitation workshops
    b. Engage NARS partners in workshop planning and organization to increase their buy-in and ownership of the process and outcomes
    c. Include the right mix of experts representing different disciplines and organizations
    d. Good facilitator (preferably from the NARS partner) with knowledge about the crop and country is important
    e. Include domain maps: better visualization of geographical boundaries can help clarify the definition of domains and ensure consistency in understanding the denominator for which percentages of varietal adoption are elicited
    f. Avoid including experts from the same organization in one group
    g. Need to engage with right partners, they should be participative (NARS partners), should lead expert elicitation process
- Suggestions for improvements that can be made at the margin - to increase the confidence in results, the expert elicitation workshop method could be combined with:
    a. Field-level reconnaissance surveys or mobile phone surveys
    b. DNA fingerprinting of seed samples collected by experts from different geographic areas

c. Prior to the workshop, conducting representative farmer surveys on a small scale where varietal adoption is considered to be highest and using the results of this survey as a benchmark against which to estimate adoption of different varieties at a larger geographic scale

- To capture the interest of national partners and increase participation by experts combine or integrate the elicitation process as part of a broader workshop on research prioritisation
- More research could be carried out to identify the sources of bias in this method. For example, designing experiments to find what aspects of the workshop organization (e.g., size, composition) generates the bias in this methodology, which can be used to improve the methodology in future. However, given the inherently limited understanding that any group of experts could have of a heterogeneous set of production conditions in a country, these are not high priority for further research.

4. DNA fingerprinting for estimating varietal adoption: Taking stock of recent work

This session featured an introductory technical presentation by Dr. Marianne Bänziger on DNA fingerprinting methodology, followed by presentations from MSU, SPIA and Center representatives on their recent experiences of using the DNA fingerprinting method to estimate varietal adoption rates for different types of crops in different countries. These include: varietal identification of cassava in Ghana, Malawi, Vietnam, Colombia and Nigeria; rice in India, Bangladesh, Indonesia and Colombia; beans in Zambia; maize in Uganda; potato in China; sweet potato in Ethiopia; lentil in Bangladesh and India; and wheat in India. A summary of these recent studies using DNA fingerprinting-based varietal identification as presented by Dr. Bänziger is included in Table 1. They represent a good mix of clonally propagated crops (cassava, potato, sweet potato), self-pollinated crops (rice, wheat), partially cross-pollinated crops (beans, lentils) and cross-pollinated crops (maize).

This recent body of work can be divided into two types—1) pilot-scale studies to test the effectiveness of alternative methods for tracking the adoption of improved crop varieties against the benchmark of DNA fingerprinting; and 2) adoption studies conducted at a representative scale that use DNA fingerprinting-based methods as part of farm household surveys to estimate varietal adoption. The impetus for the first types of pilot studies conducted in recent years (for e.g., cassava in Ghana, Malawi and Colombia; beans in Zambia; maize in Uganda; and sweet potato in Ethiopia), mostly through support from SPIA and CGIAR centers, has been the desire to find cost-effective approaches to estimate varietal adoption in a developing country setting where it has been recognized that the reliability of farmers' responses to questions about technology adoption such as 'what varieties of crop X do you plant in your fields?' can be problematic. This is because of several confounding factors such as: a) the inability of farmers to identify the varieties by name; b) inconsistency between the names of varieties as identified by farmers and what is in the variety registration list (or as identified by the breeders) (i.e., identification may be incorrect or varieties may have local names); c) varieties for some open-pollinated crops (such as maize, sorghum, millet) losing their genetic identity if seeds are recycled for many seasons and farmers may still be referring to them by the original variety name.

The results of the pilot studies indicate large measurement errors associated with farmer elicitation and expert elicitation based methods of both type I (i.e., improved varieties identified as local varieties by farmers) and type II (i.e., local varieties identified as improved varieties). In most cases, farmers were not able to identify the varieties by name and there was high variability in estimates of adoption across the different methods tested. For some crops visual-aid protocols (a series of questions related to observable phenotypic characteristics) performed better that self-reported about variety name, but still gave estimates for the class of improved varieties in aggregate that were either far below (as in the case of sweet potato) or far above (beans) the DNA fingerprinting benchmark.

The emerging consensus from these recent pilot studies is that if accurate identification of specific varieties is the goal of studies tracking adoption by farmers, then the only method that can meet this goal is DNA fingerprinting. Other studies presented in this session were examples of adoption studies that have used DNA fingerprinting as the method of tracking variety-level adoption estimates at a representative scale. Several of these studies were still ongoing and results of DNA analysis of samples collected during the farm surveys were not available. Details on the methods and results of each study (where available) were included in the two-page handouts prepared by each presenter prior to the Workshop. In the framework of 'high-low-large', this method uniquely represents the potential for obtaining high accuracy compared to other methods traditionally used for varietal identification. Potentially, DNA fingerprinting can also be applied on a large scale, but implies some constraints on the timing of field surveys, more survey enumerator training, and the costs associated with collection, processing and sequencing the samples from both the reference library of varieties and the field samples.

Table 1. Overview of recent studies using DNA fingerprinting for varietal identification *(summarized by M. Bänziger based on handouts prepared by each study presenter)*

Author	**Labarta et al**	**Hareau et al**	**Maredia et al**	**Maredia et al**	**Maredia et al**	**Stevenson et al**
Crop	**Cassava**	**Potato**	**Cassava**	**Lentil**	**Wheat**	**Maize**
Multiplication	Clonal	Clonal	Clonal	Self-pollinated, with cross-pollination vectored by insects	Self-pollinated (> 95%)	Cross-pollinated
Area (ha)	500k + 30k					
Region	Vietnam & Colombia	Yunnan, China	Ghana	Bihar, India	Bihar, India	Uganda
Sample #	3500 + 434	141 out of 615 HH	917 from 495 plots	880	3,162	416
Markers	SNP	SSR	GBS >> 56,849 SNPs	GBS	GBS	
Cost	US$ 15-20	US$ 50-70 >> US$ 10-20	US$ 30	US$ 50	US$ 50	
Conclusion	Clear identification as vegetatively propagated crop	Why genotyping if visual identification is 97% accurate	11 varietal cluster	No results yet	No results yet	All samples lost
Objective	Confirming adoption	Confirming adoption	Identification	Identification	Identification	Identification

Author	**Stevenson et al**	**Yamano et al**	**Veettil et al**	**Aw-Hassan**	**Maredia et al**	**Kosmowski et a**
Crop	**Maize**	**Rice**	**Rice**	**Lentil**	**Beans**	**Sweet potato**
Multiplication	Cross-pollinated	Self-pollinated	Self-pollinated	Self-pollinated, with cross-pollination vectored by insects	Partially cross-pollination (10-50%)	Clonal
Area (ha)						
Region	Uganda	Bangladesh	India	Bangladesh	Zambia	Ethiopia
Sample #	550	1,289	2,797	Samples from dealers	402	259
Markers	140 SNPs; 10,000 DArT	6k SNP chip	6k SNP chip	ISSR & SSR	66 SNP markers	DArT
Cost					US$ 34	
Conclusion	Different resolution between different number of samples	Distinct allele (Sub1) is easy to recognize, a variety not; what is same what is different	Role of reference library; What is same what is different	8 out of 9 samples matched with reference samples	4-71% of datapoints (or samples) were identified as IVs	Accurate variety identification; large reference library
Objective	Identification	Varieties with a particular trait	Identification	Identification	Identification	Identification

During the Workshop, presenters focused on sharing their perspectives on lessons learned from these recent experiences (pilot studies and representative scale adoption studies) and the potential issues that need to be tackled in scaling up the use of this method for varietal adoption. These are summarized below under the major categories of issues discussed.

Accurate DNA–fingerprinting-to identify crop varieties used by farmers depends on a) the quality and comprehensiveness of the respective reference library, and b) the type and density of the specific assay used.

Type of assay used in fingerprinting

The following diagnostic factors are important to consider when deciding on the density (which is correlated with cost) of the specific assay / platform to be employed in DNA fingerprinting:

a. *How many varieties are we looking for?* Are there many varieties (released and/or landraces) that need to be identified or only a few?
b. *Extent of out-crossing:* Is the crop clonal, self-pollinated, or cross-pollinated? Are there hybrid varieties?
c. *Many sources of impurity in seeds that farmers purchase:* When the seed system is not able to maintain genetic identity of varieties—esp. early generation seeds (breeders seed and foundation seeds), and may even apply to samples collected for the reference library
d. *Heterogeneity within a plot*: Is there purposeful mixing of mulitple varieties in farmers' plots? Do we expect significant mis-labelling / mis-selling / counterfeiting of seed?

In general, the more complex the responses are to these diagnostic questions, the denser the assay should be (i.e. the specific DNA fingerprinting method should examine a greater number of alleles in the genome). A comparative review of the specific sequencing methods employed in these studies was outside the scope of this workshop, and is not explored in detail in this report. This is the kind of guidance that the CGIAR Excellence in Breeding platform and other initiatives can provide to CRPs over the coming years.

Size and scope of the reference library

How big or small should the reference library be? Should it include local varieties? If so, where/how to collect reference samples for local varieties? Who should own/maintain the reference library? These are some of the potential issues that need further discussion and general guidelines should be developed. On the issue of sourcing the materials, there are broadly two options – use CGIAR Centers' global genebank accessions, or develop a reference library based on location-specific materials collected / maintained by partners. If you only use Center genebank accessions in the reference library, the information may not always be what partners are looking for. On the other hand, local materials collected or maintained by national partners may be prone to errors and require going through the national administrative and logistical procedures (which could be time and resource intensive) to access materials for the reference library.

Cost

DNA fingerprinting is a higher cost method of varietal identification. The costs include not only the marginal cost of field sample collection, but also the cost of establishing the reference library, DNA extraction, genotyping and data analysis. The cost of DNA fingerprinting quoted by presenters of different case studies ranged from $15-20 per sample on the lower end to as high as $50-70 per sample (Table 1). These differences are a function of the techniques used for DNA fingerprinting (SNP markers vs. SSR vs. GBS vs. DArT), partners involved, and where the analysis was done (in-country vs. abroad). However, there was a consensus that the cost of genotyping across these different methods is rapidly declining and the total cost of high volume DNA fingerprinting per sample are projected to come down, especially with initiatives such as the Excellence in Breeding Platform.

Presenters also highlighted the logistical costs and challenges of including sample collection as part of the farm/household surveys. These challenges include timing of the survey vis-à-vis the type of sample that needs to be collected for DNA analysis; time and coordination costs of training enumerators, and coming up with an error-proof system of labelling as the samples move from one step to the next between the time they are collected in the field and when reaching the lab, and how the samples are coded when the data/results are transmitted back to the researchers. Depending on the type of samples collected, there are also risks of sample quality deteriorating during the time lapsing between sample collections to sample analysis (for e.g., leaf samples can get mouldy or seed samples can get infested with storage pests).

Sampling

Presenters highlighted several challenges associated with sampling. These include issues related to the type of sample to be collected (leaf vs. seed vs. grain vs. tubers) which has implications on the timing of sample collection and method of sample collection, and the number of samples per data point. The latter issue relates to the appropriate sample size to be collected and subjected to DNA fingerprinting per variety as identified by farmers. The number of samples per variety (or per plot) relates to seed purity and heterogeneity, which is a different but related issue that needs careful consideration on a case-by-case basis and depends on the type of crops (cross pollinated vs. self-pollinated crops), farming practices (e.g., farmers deliberately growing mixed varieties), and seed system characteristics (counterfeiting of seeds, seeds sold as mixtures, etc).

The issue of what should be the sampling frame also needs careful consideration. For example, should the samples of the same variety (as identified by the farmer) be collected from each household or at the community level? There is a need to continue to explore the inter- and intra- village varietal variations to come up with cost-reducing strategies when using DNA fingerprinting based varietal identification.

Scaling up

The corpus of studies conducted in the recent years has shown the potential application of DNA fingerprinting in varietal identification beyond the proof of concept. It has also been used as a validation method in several representative level adoption studies conducted in the last year or so. There are several issues identified that need careful consideration in assessing the potential for scaling up this methodology as part of household surveys. These are:

a. National or regional capacity to conduct high volume DNA fingerprinting. Outsourcing genotyping services to labs abroad may not be sustainable, and sometimes biodiversity protection acts and national regulatory systems may not allow it (e.g., teff in Ethiopia; all crops in India)
b. Cost: Although costs are coming down and may be marginal if this method is integrated as part of household survey, they are still significant, when one includes the cost of establishing the library, data analysis and interpretation. Given the significant costs, the question is: What are the potential ways to reduce cost and make logistics more manageable?
c. Precision: What should be the threshold to declare whether two samples are the same /different variety? It may be easier to identify varieties more precisely for clonal, self-pollinated crops and mono-genetic traits (e.g., sub1) but it is more difficult for cross pollinated crops and polygenic traits. These complexities exist regardless of the methodology, but only the DNA fingerprinting brings them to light.

5. Remote sensing for tracking adoption of NRM practices and other types of technologies

This session focused on opportunities for using remote sensing (RS) to evaluate the adoption and impact of agricultural technologies. This is an example of an innovative method that is expanding and advancing rapidly. The spatial resolution of RS data is increasing, which means good quality data can now be captured at smaller pixel size. The temporal resolution (frequency) of such data is also increasing which allows time series analysis to develop specific signature of vegetations at different growth stages.

RS methods have the potential to provide adoption estimates on a large scale, more frequently, and at relatively lower cost than field based survey methods. However, huge challenges remain regarding the 'accuracy' of estimates derived using remote sensing. This session was thus aimed at discussing the scope and scale of this method in tracking adoption of agricultural technology, types of technologies best suited and lessons learned from some recent experiments on the potential for scaling up.

Three presentations featured in this session focused on the following topics: 1) Harnessing the potential of remote sensing for tracking adoption of agricultural practices (by Glenn Hyman); 2) Vietnam study on utilizing RS (Soil Moisture Oceanic Salinity [SMOS] and Advanced Spaceborne Thermal Emission Reflection Radiometer [ASTER] imagery) for estimating AWD adoption (by Jenny Lovell); and 3) Ethiopia study on landsat 8 satellite imagery and drones for estimating crop residue retention on soils (for conservation agriculture) (by Frederic Kosmowski).

Application of this RS and GIS method in the context of agriculture and technology adoption can be grouped into ex ante and ex post applications. Ex ante applications are the most common applications. An example of this application includes the use of spatial analysis of land cover or land use derived from remote sensing to target genotypes. Global crop distribution models often combine land use derived from RS with production statistics and other spatial data to help in projections and foresight analysis. RS combined with data on salinity and saltwater intrusion, drought and water scarcity, and other land use information, as well as digital elevation model-based (DEM) watershed analysis can allow to determine suitable areas for adoption of NRM practices, such as in this case AWD or water harvesting technologies.

Examples of RS and GIS tools and methods for evaluating ex post adoption and impact include: IWMI's work on Moderate Resolution Imaging Spectroradiometer (MODIS) data to see where irrigation has been developed and being used; IITA's work on mapping residues on the surface to assess the adoption of conservation agriculture; and in Honduras/Nicaragua the use of MODIS data to evaluate the spread of slash and mulch agroforestry. The latter study is also an example of challenges in using this method given its inability to differentiate between a phenomenon that occurs as a result of farmers' intent(i.e., a result of adoption decision) or something occuring naturally, for example, vegetation growing back on farms and rural areas abandoned by people). Because of these challenges in knowing the 'intent' just from the images obtained through RS, this field is heading in a direction where RS is combined with household surveys.

The study currently ongoing in Vietnam through SPIA support provides another example of RS method to estimate the adoption of AWD practices by rice farmers. AWD is a water saving technology that doesn't reduce yields. It requires monitoring the water level by way of an installed pipe and making the irrigation decision based on the water level observed. This is an example of a complex technology where a great variety of methods have been used for reporting adoption with inconsistent results, which makes it difficult to assess the true extent of AWD adoption. This study plans to use a RS based classification system to estimate adoption of AWD and then validate/calibrate the model results with soil moisture sensors installed on the ground. One of the limitations of this RS based methodology is that other practices (such as System of Rice Intensification) could simulate false positives, which can overestimate the adoption of AWD. The study will differentiate between random access to irrigation water and purposeful non-continuous flooding through its GIS model building approach (verified by field checks) by comparing pixels/plots with neighbouring ones. Thus, if non-continous is observed while surrounding paddies are flooded, this could indicate likely AWD adoption. This model and its assumptions will be tested and verified by field checks and ground-truthing.

The Ethiopian study provided an example of the use of Landsat 8 satellite imagery and drones for estimating crop residue retention on soils, which is a key element of conservation agriculture. A minimum level of 30% residue cover is recommended. But estimating adoption of this technology is complex, and most studies have relied on self-reported farmers' perceptions in agricultural surveys. Aerial-based methods as used in the Ethiopia case study represent an improvement over survey-based methods. The objective of this study was to identify low-cost, reliable methods for measuring crop residue coverage, and estimate the measurement errors associated with each method. Six measurement methods were used on each plot and data were compared to a line-transect reference method. Two of these methods were aerial based—one used drones and the other used RS data (Landsat 8 TM). Results of this study indicate that survey-based methods tend to underestimate crop residue coverage. In continuous analysis, best estimates came from the visual-aid protocols, and in categorical analysis, visual-aid protocols and RS performed equally well, despite the coarse resolution (30 m). The drone method was difficult to implement in practice. The camera sensors were sensitive to light conditions and proved fickle in maintaining function, possibly prone to damage by field dust. More sophisticated drones could possibly perform better and should be considered for future studies. However, it was pointed out that the routine application of the drone technology for tracking agricultural technololgy adoption may be constrained by government regulations and the need for obtaining legal authorization for their use.

In summary, this session pointed out several potential applications of RS and other aerial-based methods for evaluating technology adoption. Irrigation, conservation agriculture, no-till agriculture, crop rotations, and AWD are key applications. RS can also be applied to estimate total cropped area, a parameter used as the denominator in estimating adoption rates. These applications of this tool is made possible because of the high resolution images being captured by RS. However, such image analysis cannot capture the human intention (or lack thereof) underlying the patterns observed from the sky (e.g. agroforestry). Capturing the human intention, which is key in evaluating adoption, might require combining image analysis with field surveys. Demonstrating the presence or appropriate "status" of the natural resource in question is a necessary, but not sufficient, condition for demonstrating adoption of any related research-derived natural resource management practice.

6. Using appropriate Information and Communications Technology (ICT) for surveys

This session focused on the use of mobile phones for surveys and collecting data on farmer practices. Short Messaging Service (SMS) is the most common use of phone in developing countries. It is estimated that 70% of people in Africa and 90% in Asia can be reached via SMS. With the use of mobile phones expanding rapidly, this method offers a cost-effective way to reach people and collect data from them through SMS or IVRS based surveys.

There are many innovative business models that are taking advantage of the mobile phone revolution. GeoPoll is an example of one such private-sector led model that is active in the application of this innovative method. They operate in 26 countries and have ~300 million mobile subscribers in their database that can be approached to carry out surveys either through SMS or Interactive Voice Recording

Service (IVRS) method. Examples of ways in which this service has been used by research organizations, NGOs and donors include the use of mobile surveys to assess the adoption of new seed technologies among smallholder maize farmers, understanding nutrition and hygiene practices in relation to childhood stunting, evaluating perceptions of barriers to getting agricultural loans, and understanding the economic, food security and other types of impacts of disasters and crises.

One of the applications of GeoPoll's suvery based research study presented in this session was the research conducted by IFPRI on understanding the linkage between market access and hybrid maize seed use/purchase by farmers in Tanzania. This study used SMS based survey responses from 1000 farmers over two time periods to understand the purchase and recycling decisions related to hybrid maize seed adoption.

Another example of the application of mobile phone based survey method was the study in India recently conducted by CIMMYT to track the adoption of NRM technologies. This study was a pilot study funded under the SIAC program to develop an innovative mobile phone based data collection model and validate it with alternative methods. This pilot study used the IVRS method to collect the information on adoption of selected NRM technologies and practices. This method consists of contacting the farmers on their mobile phone and asking questions using a voice interface. Farmers record their responses to each question by pressing the numbers on the mobile phone dial pad. These responses are converted into data that gets transferred to data worksheets automatically. Unlike the SMS based surveys, the IVRS application is considered to be more user friendly and literacy neutral.

In addition to the mobile phone applications for collecting data (remotely), this session also included discussion of some examples of using modern 'technology' to conduct traditional personal interview based surveys. TechTracker, was cited as an example of a mobile app that is used by organizations like ASARECA and IITA to capture data on smart phones for M&E purpose. Survey Solutions is another example of a web based, open source survey program developed by the World Bank (and used by the Living Standards Measurement Study [LSMS] team) to make the field data collection more efficient and less prone to data recording errors. It helps researchers design Computer Assisted Personal Interviewing (CAPI) questionnaires that can be installed on computers/tablets and doesn't require Internet connection to use in the field.

In summary, the expansion of mobile network infrastructure has opened up new opportunities for almost real time and less costly data collection. SMS surveys can complement, and help refine other methods (e.g., expert opinion elicitation, household survey) of tracking adoption data. This method can be used to implement once-off surveys to conduct real-time research and M&E studies, or to collect panel-based, longitudinal, and/or pooled cross-sectional surveys. They are ideal for tracking custom metrics such as use, uptake, adoption of some practices / nputs / technologies on a high-frequency basis (e.g. daily, weekly, monthly). Both the SMS and IVRS mobile phone platforms support various question types - multiple choice, "select-all-that-apply", and skip patterns. The SMS based surveys can also support open-ended questions.

Within the framework of "low-high-large", these ICT based methods represent a low cost method that can be applied on a large scale. However, there are still many challenges on the front of accuracy that need to be tackled. Some of these challenges relate to sampling issue such as biased sample (one can only reach people who own mobile phones), selection bias (large non-response rate, attrition rate), and the issue of internal and external validity. There are also limitations related to the technology itself, such as 160 character limit in SMS based surveys, phone literacy on the part of the respondent, language literacy for the SMS surveys, and understanding the technical concepts and terminologies (content of the survey) without any explanation or help of an enumerator.

The general consensus of the workshop participants was that given the cost and time benefits, it makes sense to try this method even with the selection bias and the limitations noted above, as no method is entirely free of selection bias, including the traditional household survey. However, more research should be designed to test the bias in surveys using ICT approaches by comparing it with methods that are grounded in a representative sample of the population.

7. **Adoption data from markets: Surveys of input or output market participants to estimate adoption of technologies**

A major cost of collecting technology adoption data (or any type of data) from the farmers is the cost of reaching the respondents in remote villages across a wide geographic scale. These costs of *last-mile* logistics of doing farm household surveys have been a major reason why such surveys are infrequent or not done at a large representative scale. Thus, as part of this workshop, we wanted to explore innovative approaches that can avoid such last-mile costs of doing farm household surveys, such as doing surveys of input or output market participants or doing farm surveys in a central location.

Two examples were presented in this workshop that shared the experience of collecting data from the markets. One of these examples used the market place as the location to interview the farmers. The idea behind this approach taken in a study in Rwanda was to talk to farmers from different villages at a central location, such as a market, rather than going to all the remote locations to interview them. There are obviously cost savings in using this approach. However, there are also concerns about the bias inherent in this method of selecting the sample of farmers for the study. Farmers going to the market may not be representative of all the farmers (for example, the sample may only include market-oriented farmers and not subsistence farmers). So depending on the objectives of the survey or the type of technology adoption questions that are focused, this approach may not give a representative picture of technology adoption. This was a major criticism of this approach.

The other example presented in this session used data from agro-dealer surveys conducted in Bihar, India. Rice seeds from 200 agro dealers across the state of Bihar were collected as part of this study, along with some information on each of these varieties. These seed samples were genotyped using the SNP marker technology to identify varieties being sold in the market, and to assess what types of rice varietal technologies are available to farmers. Although the purpose of this study was not to estimate varietal adoption by farmers in Bihar, this approach can potentially be used for such a purpose in a setting where farmers mostly rely on purchased seeds through a formal sector (i.e., agro-dealers).

Another market based approach mentioned (but no examples exist of the application of this approach) was the possibility of estimating varietal-level adoption in a setting where all the crop production/output (grains, tubers) is sold in the market after harvest in a relatively small time period. If such a scenario existed, where the produce is mostly sold in the local/domestic market and there is no cross-border commodity trade (import/export) or food aid (in the form of grain) for that crop, then it is possible to estimate variety-specific adoption rates based on analysis of materials moving through markets, mills, or collection points in centralized locations. This might include identification based on color, size, shape and other characteristics; or it might include DNA-based identification.

More research and pilot studies are needed to understand the issues of sample bias and representativeness of estimates derived from these market based methods, before they can be promoted as scaled up approaches for tracking adoption of technologies in developing countries.

8. Institutionalizing Collection of Adoption Data through Household Surveys

Unlike the previous sessions that were focused on innovative methods and approaches, this session focused on partnerships and relationships between national government agencies, CGIAR centers, and other international organizations such as the World Bank and FAO, and the practice of agricultural survey management in developing countries. Underlying this focus on relationships is the exploration of the question of how to institutionalize the routine use of some of the innovative methods discussed above as part of a system that is self-sustaining through government support and partnerships with international or local organizations.

Presenters representing different sides of these relationships and partnerships shared their experiences and expertise on this issue based on their involvement in conducting representative surveys in Zambia, Uganda and Ethiopia. In Zambia, the focus was on sharing the experience of the annual crop forecast and post-harvest survey conducted by the Ministry of Agriculture. The survey covers approximately 13,600 households representing small and medium scale farms, and about 1,600 large scale farms. The survey is representative at the national, provincial and district level and each household is interviewed in March (post-planting) and in October (post-harvest stage). A fresh household sample is drawn each year from within the same clusters. A methodological innovation they have recently adopted is the use of CAPI, which has significantly reduced the time for data cleaning and analysis, which is critical for generating time sensitive information for the government on crop forecasting.

For Ethiopia, the focus was on the Socioeconomic Survey, which is a panel survey conducted by the Central Statistical Agency. The survey covers 5,262 households from both rural and urban areas selected using a two-stage random sampling method. The sample is representative at the national and five regional levels. The data are collected from September (post-planting) to February (post-harvest) by CSA enumerators who reside in the communities assigned to them. In terms of innovative methods being used, all the plots surveyed are georeferenced, and yield estimates for some major crops are estimated using the crop-cutting methodology (which is applied on 15-30% plots). The survey team in Ethiopia is already engaged with the SurveySolutions team at the World Bank and are planning to use CAPI for the future rounds of the socioeconomic surveys. Through collaboration with SPIA, plans are also underway to integrate questions and visual-aid protocols that will allow collection of technology adoption data on treadle pumps, motor pumps, crop residue cover, weather index insurance, crop rotation with a legume in previous three years, and other technologies.

Lastly, the session also highlighted the experience of the World Bank LSMS team in supporting the Uganda National Panel Survey (UNPS) conducted by the Uganda Bureau of Statistics (UBOS). The survey is nationally and regionally representative and covers a sample of about 3,200 households across 320 enumeration areas over five waves from 2009/10 to 2015/16. The surveys involve two post-harvest visits to each household to capture agricultural production for two agricultural seasons. The field work is done by 9 mobile teams, each has a team leader, 3 enumerators and 1 driver). For the past 3 waves the UNPS has fully transitioned to CAPI platform. More methodological innovations in collaboration with SPIA in the implementation of the UNPS 2017-21 work program are currently being negotiated with

UBOS. Overall, this partnership and collaboration has given the World Bank and SPIA team opportunities to showcase the importance of statistics and push for implementation of innovative methods at scale.

Some of the challenges and lessons gleaned from these experiences and highlighted by the presenters include:

- The importance of having full support from the upper management. They need to know the costs and benefits of integrating innovative methods. Someone needs to champion the cause, use leverage points and long-term relationships at the top levels in the government to be able to institutionalize the changes in the data collection system
- What methods and approaches get integrated in the ongoing data collection efforts at a country level depends on:
    - Country's policies and priorities vis-à-vis research priorities and interests
    - What can be measured with reasonable accuracy
    - Mandate and capacity of the national partner
- The importance of enumerator training in the use of CAPI and new modules and protocols to implement innovative methods for capturing technology adoption. More time and resources need to be budgeted for training. Also one should be cognizant of the fact that more questions means more time, more respondent and enumerator fatigue, which has implications on data quality. Thus there is a need to focus not only on which new and innovative methods to integrate in existing surveys but also which questions and modules need to be dropped from large surveys to balance this tradeoff between the length of a survey and quality of data

9. **Outsourcing to private sector: Perspective from service providers and researchers.**

Conventional wisdom states that when it comes to adoption of farm practices, information elicited from the farmers is more accurate than any other method. However, the cost of collecting this information from a representative sample of farmers is much higher than other methods because of the logistical costs (i.e., enumerators, training, transportation, supervision, coordination and management) associated with large sample surveys spread across a wide geographical scale. As a result, these surveys are carried out less frequently than they should be, leading to out of date information on agricultural technology diffusion.

Thus, questions worth addressing are:

- *Ceteris paribus*, are there options that are both low cost and provide accurate results?
- Does a research center necessarily have to do the surveys themselves (and invest time and resources in managing the logistics) or can they outsource this to private sector?
- Is there a market for 'information goods' such as adoption data where the demand and supply curves intersect?
- Can research centers focus on doing research and rely on tracking adoption of research outputs at the farm level by accessing such data at a price from the private sector?
- Is the private sector willing to collect data routinely and make them available for a fee and still earn profits? (marginal cost for information goods)

This session was motivated by these types of questions. It included three sets of presentations / perspectives—one from the Innovations for Poverty Action (IPA), a not-for-profit research and policy organization promoting effective solutions to global poverty problems by creating high quality evidence (through surveys), and helping turn that evidence into better programs and policies for the poor. IPA has offices around the world, but in each country they operate on a vertically integrated model, whereby they work closely with the client through all the stages of an evaluation—project development, including conceptualization and fund raising, executing the experiment (RCTs), data collection, analysis, paper writing, publishing, and policy impact. It adheres to high ethical and academic standards, and their research staff are motivated by publications rather than profits. This business model has attracted top talent for their field research staff, and earned them a good reputation in doing quality field work (including data collection) but without extensive salary cost.

The second set of presentations included sharing of experiences by three private sector firms that participated in a pilot study in India as part of a SIAC iniative to test innovative models for tracking and documenting technology adoption data that are both low cost and provide accurate results. Each firm implemented a variation of the local enumerator approach that was proposed as an example of a low-cost approach. They focused on tracking a specific set of NRM technologies associated with the two districts they selected to pilot their approach. Input on the types of questions and information to be collected was provided by MSU and the CGIAR Centers. All the aspects of data collection (including sampling, enumerator selection, training), CAPI software development, survey coordination, and management were the responsibility of the survey firms.

The third set of presentations gave researchers' perspectives on the results of this pilot study in India both from the cost and quality perspective. The average cost per surveyed household through the local enumerator approach was $27, ranging from $12-43/household across the three firms. This is in the comparable range of the cost of the conventional approach that was used for validation purpose. Thus, the cost advantage of this approach was questionable. On the effectiveness side of things, simple mean comparison of adoption rates as measured by percentage of households using a technology show statistically significant difference in the estimates derived from the local enumerator based approach and the conventional approach for several technologies. However, it is not clear if the differences in the adoption estimates is due to differences in the two approaches or the nature of the technologies focused on (i.e., most of the technologies included in the study were practices and not tangible products or kits that farmers can easily recognize or identify with). Theoretically the local enumerator approach can be valuable for relatively simple, longitudinal surveys, but this was not tested. It was difficult to identify the causes of measurement differences between the different approaches tested as there could be many confounding factors (i.e., enumerator quality, technology, app, management, wording, etc) that could be influencing the measurement based on enumerator reported farmer responses.

Overall, the experiences and perspectives shared in this session highlighted several issues and emerging lessons. First, these presentations and discussions confirmed that doing survey-based tracking of technology adoption is resource and management intensive. But to get useful information, investment in quality always pays off. For academic research purpose, taking a hands-off approach to data collection may lead to an output for which the quality will be unknown. Thus for a 'research' organization to rely completely on a market based approach of accessing the data for a fee collected by a survey firm may not be a viable approach, unless there are mechanisms in place for quality checks (that are low cost).

10. Conclusion

Over the past few years, through efforts by SPIA under the SIAC program, and by IFPRI and its partners under the PIM program, researchers have implemented many pilot and proof-of-concept studies to test innovative methods for tracking adoption of different types of technologies and agricultural practices. For some of these methods, there is now sufficient pliloting and evidence base to be able to scale them up. For example, DNA fingerprinting, georeferencing to validate RS data, and integrating adoption questions and modules in LSMS-ISA. For others, there is still a need for more pilots to address the accuracy question before they can be scaled up or become routine as a methodological option in estimating adoption of technologies.

This two-day workshop was organized to provide a platform for experts, practitioners, researchers and donors to discuss and learn from these different experiences gained in recent years through the lense of cost (is it low cost?), accuracy (does it give highly accurate results?) and scale (can it be applied at a large scale?). The workshop brought together participants from a wide range of backgrounds and affiliations, and gave an opportunity to reflect on a range of topics related to methodologies (e.g., sampling), modalities (in-house, out-sourcing, or integrating with ongoing efforts), and other challenges (e.g., cost, quality, accuracy, practicality) associated with collecting technology adoption data. The presentations, discussions and sharing of experiences from different partners generated a lot of learning and excitement about using innovative new methods for estimating and tracking adoption of different types of technologies and practices. The workshop also provided an opportunity for both presenters and the audience to critically examine each method's pros and cons and potential caveats to apply those in various settings. Overall, participants agreed that "innovation" *per se* is not a panacea – regardless of the specific data collection method used, a focus on data quality that pays attention to all sources of bias, will continue to be needed. There is scope for many more trials in order for the research community to fully take advantage of some of the methodological innovations discussed. Methodological experiments of this kind are certainly a public good for the research community more broadly, and the results from them should be written up and made as accessible as possible, even when the methodology failed.Ultimately, there was a strong demand expressed from the participants for SPIA to continue convening this type of workshop in the future.

Annex 1: Workshop program

Innovative methods for measuring adoption of agricultural technologies:
Establishing proof of concept and thinking about scaling up
3rd - 4th August 2016, Boston Marriott Copley Place, 110 Huntington Ave, Boston, MA 02116, USA
(Meeting location: 4th Floor, Provincetown Room)

Workshop Objectives

1. Take a stock of current and innovative methods for measuring adoption of agricultural technologies
2. Share and discuss results and insights from pilot studies and experiments conducted to establish proof of concepts to harness the potential of new methods for tracking adoption of agricultural practices and other types of technologies
3. Further the discussion on scaling up proven methods for measuring technology adoption

Agenda

Wednesday 3rd August 2016		
07:30 Breakfast, Coffee and Registration		
08:30	**1. Welcome, introductions, workshop objectives**	**Doug Gollin, Jawoo Koo**
08:45	**2. Tracking and estimating adoption of agricultural technologies in developing countries:** Importance, challenges and need for innovative methods. *Brief overview presentation*	**Mywish Maredia**
09:00	**3. Current practice for large-scale varietal adoption studies: The expert opinion elicitation method**	**Mywish Maredia (Chair)**
	Experience from Asian CCCs in SIAC	**Alice Laborte, Kumaracharyulu, Ricardo Labarta, Marcel Gatto, Pavithra Srivinavasamurthy**
	Experience from African CCCs in DIIVA	From the floor
10:15	Health break	
10:30	**3. DNA fingerprinting for estimating varietal adoption:** Taking stock of recent work *4 slides on lessons learned and potential for scaling up based on each of the following case-studies. 2-page handouts to be prepared on methods, results of each study.*	**Richard Caldwell (Chair)**
	Introduction and overview	**Marianne Banziger (via WebEx)**
	Cassava: Ghana, Malawi, Vietnam, Nigeria	**Mywish, James, Ricardo**
	Rice: India, Bangladesh, Indonesia	**Takashi, Mywish**
	Beans: Zambia	**Byron**
	Maize: Uganda	**James**
	Potato: China	**Guy**
	Sweet potato: Ethiopia	**Frederic**
	Lentil: Bangladesh	**Aden**
	Wheat and lentil: India	**Mywish**
	Discussion: Scaling up and implications for impact assessment	
12:45	Group Lunch (outside the meeting room)	
1:45	**4. Remote sensing for tracking adoption of NRM practices and other types of technologies**	**James Stevenson (Chair)**
	Harnessing the potential of remote sensing for tracking adoption of agricultural practices	**Glenn Hyman**
	Bangladesh study on hyperspectral signature analysis for estimating AWD adoption	**Parvesh Chanda**
	Vietnam study on Soil Moisture Oceanic Salinity (SMOS) and Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER) for estimating AWD adoption	**Jenny Lovell**

	Ethiopia study on landsat 8 satellite imagery and drones for estimating crop residue retention on soils (for conservation agriculture)	**Frederic Kosmowski**
	Discussion on: Scope and scale of this method in tracking adoption of agricultural technology; Types of technologies best suited; Lessons learned from pilot experiments, Cost, limitations	
3:45	Health break	
4:00	**5. Using appropriate ICT for surveys**	**Jawoo Koo (Chair)**
	Potential of ICT tools for collecting data and tracking adoption of agric ultural practices	**Katy Money (GeoPoll)**
	India study on cell-phone based IVRS method for collecting data on farmer practices	**Mywish** on behalf of Surabhi Mittal
	Tanzania SMS-based mobile phone surveys	**Beliyou Haile**
	Tablet-based CAPI methods: lessons for technology adoption surveys ■ Experience of using TechTraker ■ Experience of Survey Solutions	 **Moses Odeke** LSMA-ISA **(James)**
	Discussion on pros and cons of using this method for technology adoption data; Challenges of sampling; Cost; Potential for scaling up	
6:00	CLOSE (Dinner on your own)	
Thursday 4th August 2016		
08:00	Breakfast, coffee and networking	
09:00	**6. Adoption data from markets:** Surveys of input or output market participants to estimate adoption of technologies	**Doug Gollin (Chair)**
	Introduction	**Moses Odeke**
	Agro-dealer survery at informal markets in Rwanda	**Jawoo Koo**
	Bihar agro-dealer surveys	**Takashi Yamano**
	Discussions to focus on: • *Reliability of these methods in estimating farm level adoption* • *Challenges of sampling (to derive representative adoption estimates)* • *Potential for scaling up* • *Under what conditions/types of technologies this method can be used/not used*	
10:30	Health break	
10:50	**7. Institutionalizing collection of adoption data through household surveys** *How can we institutionalize the routine use of these new methods?*	**James Stevenson (Chair)**
	Partnerships with national statistical agencies on specific surveys: Cases of Zambia, Ethiopia, Uganda and India	**Dingiswayo Banda** (Zambia) **Frederic Kosmowski** (Ethiopia) **Talip Kilic** (via WebEx - Uganda) **Mywish Maredia** (India)
12:15	Group Lunch	
1:15	**8. Outsourcing to the private sector**	**Lakshmi Krishnan (Chair)**
	Perspectives from service providers, clients (CGIAR centers, donors) and researchers *Can data collection be outsourced?* *Cost vs. benefits* *Is there enough demand to sustain and institutionalize private sector led data collection to track technology adoption in developing countries?*	Innovations for Poverty Action **(Prathap Bhavani)** Background, overview of the pilot in India (**Mywish)** Perspectives from private sector: **Muthu Raman, Meeta Mehta, Sunil Kumar, Chris Root**
15:00	Health break	
15:20	**9. Wrap-up**	**Chair: Mywish Maredia**
	PIM future plans on these issues	**Jawoo Koo**
	Plans for a future SPIA program to institutionalize these methods	**Doug Gollin**
	Output plans from this workshop	**Mywish and James**
17:30	CLOSE	

Annex 2
Participant List

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