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The Agricultural Technology Adoption Puzzle: What Can We Learn From Field Experiments?

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Abstract

The Green Revolution, consisting of using High Yielding Variety (HYV) seeds together with high fertilizer doses, has been widely adopted under irrigated conditions, but generally not in rainfed areas that are prone to stresses like drought and flooding. This puzzling lag in technology adoption is holding back the role of agriculture for development in extensive regions of the world such as Sub-Saharan Africa and Eastern India, with high aggregate costs in terms of economic growth and human welfare. Field experiments have been particularly useful in addressing this adoption puzzle. Significant lessons have been learned on the roles of farmer behavior and of mediating factors such as credit, insurance, markets, and policies in constraining adoption.

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…/… We use experimental field research in Eastern India to show that rainfed agriculture typically suffers from lack of effective supply of suitable HYVs, constraining adoption and resulting in low fertilizer use. Effective supply requires the existence of suitable HYVs (provided by research), the provision of information to farmers about these technologies (provided by extension services and social networks), and their local availability for adoption (provided by private agents in value chains). We consequently argue that solving the adoption puzzle for rainfed areas requires that governments and international donors increase investment in discovery-type agricultural research, support innovations in extension services, and promote the role of private agents in value chains. For donors this implies resolving a collective action problem in the provision of international public goods that remains pervasive.

The adoption puzzle

The Green Revolution, consisting in farmers using High Yielding Variety (HYV) seeds and high fertilizer doses, has occurred in irrigated areas of the world starting in the mid 1960s. By contrast, it has largely by-passed rainfed areas such as Sub-Saharan Africa where fertilizer use and cereal yields are distinctively low (Figure 1). In India, the Eastern and Central states of Orissa, Jharkhand, Madhya Pradesh, Maharashtra, and Chhattisgarh are rainfed, use low fertilizer doses, and achieve low rice yields, even though rice cultivation is very important in these regions as a share of total cultivated area (Figure 2). Stagnant yields have prevented agriculture from supporting a structural transformation, the move of labor from agriculture to employment in industry and services, and the reduction of rural poverty.

Figure 1. Low fertilizer use and low cereal yields in Sub-Saharan Africa (World Bank, 2016)

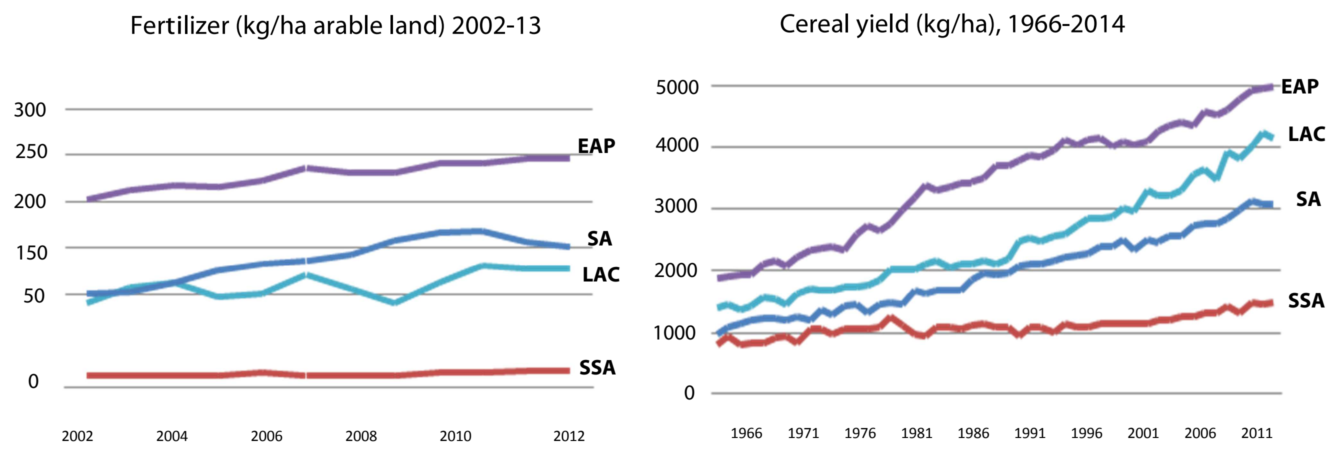
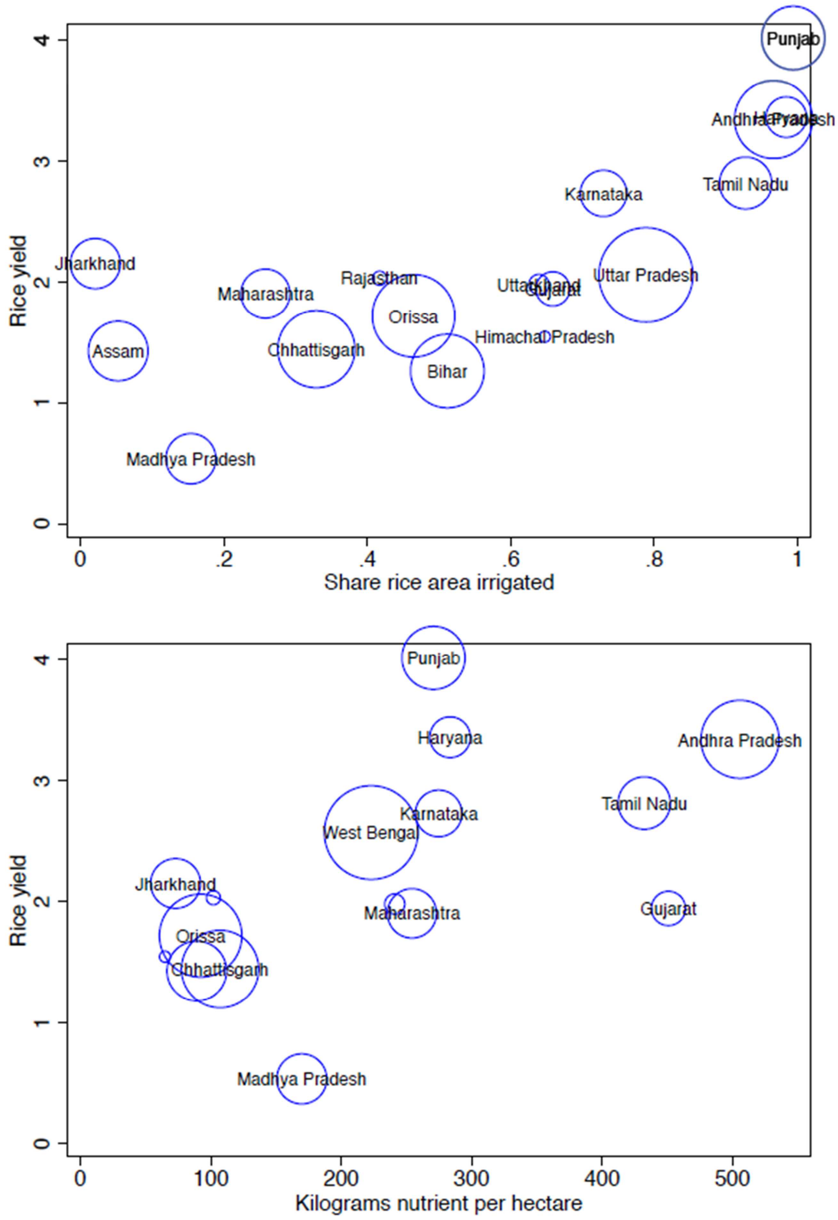


Figure 2. Low fertilizer use and low rice yields in India's rainfed states in spite of importance of rice cultivation

Bubble size is rice area as a share of cultivated area (ICRISAT, 2016)



In focusing on rainfed areas, we distinguish three categories of agro-ecological conditions. Good potential-low risk areas where the technology developed for irrigated areas applies; good potential-risky areas where varieties resilient to abiotic shocks such as droughts, floods, and extreme temperatures are necessary; and low potential areas where the solution to low yields is not to be achieved through improved seeds. The lagging adoption puzzle we consider here applies to the intermediate category that characterizes the vast majority of rainfed areas.

The objective of this paper is to show how field experiments can be used to help explain the continuing low adoption of technological innovations by smallholder farmers in rainfed areas where agriculture is under-performing relative to potential. While low adoption has numerous determinants, we argue that it can importantly be explained by a pervasive deficit in effective supply of technology for smallholder farmers in rainfed areas. We define effective supply as the joint occurrence of the existence of, information about, and local availability of technology.

Facts about missing technological revolutions

It is well known that agricultural productivity growth is generally essential for the structural transformation, industrial development, and welfare improvement of low-income countries (WB, 2007). For historians such as Bairoch (1973), an agricultural revolution has been a pre-condition for an industrial revolution. This has been the case not only in 18th century England, but also throughout the "Western Experience" with industrialization stretching from Belgium and France starting in 1820, to the United States in 1860, and Japan in 1880, and later the successful "Asian experiences" following WWII in countries with land endowments such as Taiwan and South Korea. Growth theory also tells us that technological

change in agriculture is important for industrialization. This can happen through the contribution that productivity growth in agriculture makes to availability of a financial surplus (Kuznets, 1966), the release of labor (Jorgenson, 1967), the production of a low-priced food surplus (Lele and Mellor, 1981), and the creation of effective demand for industrial non-tradable goods (Adelman, 1984; Mellor, 1998). Only in the Lewis (1955) dual economy model does surplus labor in agriculture allow industrial growth through labor transfers without technological change in agriculture, but this only for as long as surplus labor persists.

Recent empirical studies show that the role of technological change in agriculture as a determinant of industrialization remains valid. In Brazil, labor-saving technological change in soybeans contributed to national industrialization through the release of labor (Bustos, Caprettini, and Ponticelli, 2016) and the transfer of a financial surplus (Bustos, Garber, and Ponticelli, 2016). Locally, however, land-augmenting technological change in agriculture can produce the opposite effect if it crowds-out the growth of non-agricultural sectors on the labor market (Foster and Rosensweig (2004) for India, and Hornbeck and Keskin (2015) for the United States Plains). That productivity growth is an important source of growth for agriculture is also well established. Evenson and Fuglie (2010) have shown that, in all developing countries, 2/3 of agricultural growth originated in productivity growth and 1/3 in factor deepening.

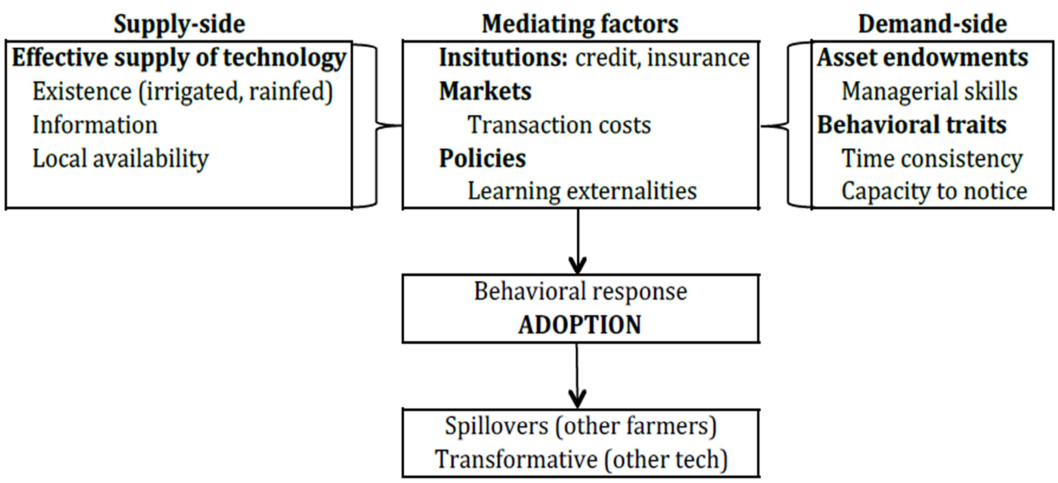
Beyond supporting a structural transformation, productivity growth in agriculture is also necessary to create income gains for a majority of the rural poor. With some 2/3rd to 3/4th of word poverty rural, GDP growth originating in agriculture is, relatively to other sectors, the most effective for poverty reduction (Ligon and Sadoulet, 2016). This is all the more important in a context where labor absorption in industry is being reduced by labor-saving technological change and repatriation of manufacturing plants toward the industrialized countries (Rodrik, 2015).

In seeking an explanation to the adoption puzzle, we note a number of common features to the context where it happens. Agriculture is dominated by smallholder farmers. They cultivate foodgrains under good potential but risky rainfed conditions. In this context, decision-making in agriculture is highly complex, with considerable exposure to risk and a great deal of heterogeneity in farmer circumstances.

Hypotheses

In formulating hypotheses that could explain the lack of adoption of technological innovations, we note that it can come from the demand side, from constraining mediating factors, or from the supply side (Figure 3). On the demand side, farmers may have insufficient asset endowments such as managerial skills to adopt, or display behavioral traits that deter them from adopting such as time inconsistency (procrastination) and lack of ability to notice what matters in explaining yields. Mediating factors include credit and insurance constraints, high transaction costs on markets, and policy deficiencies such as learning externalities that are not internalized. On the supply side, technology must exist for rainfed areas, be known to and understood by farmers, and be locally available for adoption. Adoption can in turn create spillovers on other farmers, inducing them to adopt, and be transformative on adopting farmers in the sense of inducing further adoption of other technologies and use of more factor-intensive production methods such as higher doses of fertilizer and labor-intensive agricultural practices. Field experiments can be uniquely useful to establish causalities between these potential determinants and adoption outcomes.

Figure 3. Determinants of technology adoption



Field experiments in agriculture

It is well known that statistical identification of causalities in adoption decisions using observational data is particularly difficult. This is due to omitted variables, endogeneity, and selection biases. When they can be done, and are well implemented, randomized control trials (RCTs) allow to establish strong internal validity (that is causality for the conditions under which the experiment applies) (Athey and Imbens, 2016). They have the advantage of producing results that are logically convincing and simple to explain: all you need is calculate a simple difference in average outcomes between units of analysis in the treated and control groups. Setting up field experiments is demanding, but extensive use of the approach has helped develop practice (Glennester and Takavarasha, 2013). Today, on average some 20% of papers published in the *Journal of Development Economics* use an RCT approach, up from virtually zero ten years ago. Practice includes establishing a working partnership with an implementation agency interested in the results, designing experiments to avoid ethical problems in defining controls, reducing the risks of selection in accepting to be treated, running experiments large enough to achieve sufficient statistical power for hypothesis testing, and if desirable specifying experimental designs that help identify causal channels behind reduced form results. Practice has also helped set up experiments with faster turnaround of results so they can serve as management tools. They have contributed to the emergence of a culture of evidence-driven innovations in public agencies and development organizations that is now widespread (Gueron, 2016).

A major critique of the experimental approach to research in development has been inadequacy in dealing with external validity for policy recommendations (Deaton, 2010). The critique has been taken seriously. Banerjee, Chassang, and Snowberg (2016) thus recommend carefully recording the contextual conditions of each experiment for use by others in assessing external validity. Institutions such as Innovations for Poverty Action (IPA) and the International Initiative for Impact Evaluation (3ie) have been created to engage in widespread replication of experiments across different contexts. Experiments can also be conducted directly on causal channels rather than on particular policies/programs, allowing greater control over context (Kling et al., 2016).

Another critique has been smallness of the experiments, relative to the type of policy and program initiatives necessary to deal with global poverty (Ravallion, 2012; Rosenzweig, 2012). Having enough degrees of freedom to do statistical testing of presumed impacts requires dealing with small and numerous units of analysis. Students or schools, and patients or clinics are thus easier to experiment with than units of governance and country policies. This critique has also been taken seriously. Much new RCT work has been directed at working with governments and at addressing policy issues, either directly or through the channels of causation involved.

Experience shows that choice of methods can be pragmatic and opportunistic according to the particular problem at hand, data availability, and opportunities to experiment. RCTs can in particular be combined with sources of secondary data, game-in-the-field approaches (e.g., to study willingness-to-pay), and natural experiments (e.g., using a program rollout or a regression discontinuity design on which an RCT is constructed. See for example de Janvry, McIntosh, and Sadoulet, 2010). Clearly, choice of methods must follow conceptualization of the research question, assessment of data availability, and design of an identification strategy, rather than precede them.

Results from Field Experiments: Role of Demand-Side and Mediating Factor Constraints

Results on the demand side

On the demand side, experimentation has analyzed the role of behavior in deciding on fertilizer use. With seasonality and long lags between harvesting and planting, results show that procrastination in putting money aside to purchase fertilizers for the next season is pervasive. The risk is that all available liquidity will be gone by the time fertilizers have to be applied. Procrastinators need nudges to decide to set money aside at harvest time to buy fertilizers at planting time. Behavioral incentives can also drive additional demand for credit. In their experiment in Kenya, Duflo et al. (2011) find that help to decision-making can increase fertilizer uptake by up to 75%. While this effect is large, it still leaves only 26% of farmers using fertilizers.

Experiments have also been used to show that many farmers fail to notice what matters in using information available to them to improve yields, leaving them far inside the efficiency frontier (Hanna et al., 2014). In this case, seaweed farmers fail to give importance to pod size while only focusing on pod spacing on the seaweeds they grow. Helping them focus attention on important dimensions of the data they have can induce them to decide on adoption of better technology. How important increased attention can be in reducing the adoption gap is still to be established.

Results on mediating factor constraints

Extensive research has also been done on mediating factor constraints, particularly credit, insurance, markets, and policy.

Credit: One such mediating factor is liquidity constraints in acquiring technology due to lack of access to credit. It is well known that most smallholder farmers do not have access to credit, and do not qualify for commercial bank loans as currently offered. Helping them overcome this financial market failure could thus be important for costly technology adoption. But experimental results show that credit alone is unlikely to be the main constraint on adoption (Karlan et al., 2014). In an experiment in Ghana, they show that once farmers are insured, they are able to find the necessary liquidity to invest more and plant more risky crops, while cash grants make little difference on these outcomes. When superior technology is available, such as flood tolerant rice, farmers respond by increasing the use of credit from available sources (Emerick et al., 2016a). Likewise, Kenyan farmers who are contracted to produce high-value export crops are able to find credit for their operations (Ashraf et al., 2009). Crépon et al. (2014) show that there was low take- up for credit when made available in Morocco, and Carter et al. (2014) that only 50% of farmers took up fertilizer vouchers in Mozambique. RCTs have been useful not only to identify the role of credit constraints, but also to experiment with ways of relaxing these constraints. They have thus shown that there exists much room for improvement in available credit schemes for agriculture. This includes customization of repayment schedules to seasonality (Matsumoto et al., 2013, for Uganda; Beaman et al., 2015, for Mali), availability of post-harvest loans to help farmers postpone selling a harvest time and wait for better prices (Burke, 2014, for Kenya), flexible collateral arrangements (such as using stored crops with warehouse receipts as loan guarantees), providing lenders with information on borrowers (through a credit bureau, scoring, and fingerprinting), access to pre-approved credit lines (as with the Kisan Credit Card from the National Bank for Agriculture and Rural Development for Indian farmers), and IT services in nudging financial transactions (with for example SMS reminders to make payments on loans and saving deposits).

Insurance: RCTs have been useful in showing that risk is a major constraint on technology adoption and factor use. Experimentation has focused on the use of index-based insurance for better risk coping and risk management by smallholder farmers. Results show that this index insurance can be effective when used (Cole et al., 2014, for the production of cash crops in India; Cai, 2016, for the production of tobacco in China; Elabed and Carter, 2015, for the production of cotton in Mali). But they also show that there is very low uptake without high subsidies. Here again, RCTs have been used to explore product improvement. This includes reducing basis risk with better data such as satellite measurement of area yields (Carter, 2012), risk layering with other financial instruments such as savings and borrowing (Clarke, 2016), and displacing insurance contracts from individual farmers to the institutional level such as producer organizations, banks, or public social safety nets (Dercon et al., 2014). Experimentation with improved technology in weather and yield measurement, and with improved contract design could help make index insurance a viable financial product for smallholder farmers, boosting their adoption of Green Revolution technologies in risky rainfed contexts.

Markets: High transaction costs in accessing markets may make technology adoption simply not profitable. Results show that poor infrastructure makes technology such as hybrid maize in Kenya unprofitable for many, explaining differential adoption across farmers (Suri, 2011). Creating IT platforms to more effectively bring supply and demand together can be effective in improving prices received and creating rewards to quality improvements (McIntosh, 2016). Experimentation is important in designing alternative ways of organizing these platforms and formulating contracts. Providing price information to farmers is typically not sufficient to allow them to obtain better prices without direct access to markets or greater bargaining power (Fafchamps and Mirten, 2012). Contracts between producer groups and commercial partners such as agro-processors, agro-exporters, and supermarkets are essential for the adoption of high value crops. These contracts can easily suffer from side sales on the part of the producer group, and from hold-up behavior on the part of the commercial partner, eventually leading to contract failure (Ashraf et al., 2009). Innovative contract design can interlink product and insurance transactions, potentially creating efficiency gains relative to separate transactions and helping solve the insurance take-up problem (Casaburi and Willis, 2015).

Policies: Subsidies are needed when there are learning externalities or social benefits from adoption. Potential early adopters under-adopt because they do not capture the full benefit of their initiatives. Subsidies are however difficult to implement as they are costly, difficult to target, prone to corruption, and politically sensitive to remove once introduced. Experimentation with the design of subsidies to adoption has for this reason been extensive, in particular to find out whether a one-time subsidy can have persistent effects on adoption or not. Carter et al. (2014) find that one-time subsidies to fertilizers and improved seeds in Mozambique induce short-term adoption and that demand persists over time and creates learning by others. RCTs have also been used to experiment with the design of cost- minimizing subsidies in China when there is stochastic learning due to weather events and recency biases in learning from these stochastic events (Cai et al., 2016). In this case, subsidies to achieve a desirable uptake objective need to be permanently recalibrated to the occurrence of past weather shocks and to observation by farmers of insurance payouts.

Important progress has thus been made in identifying the role of demand and mediating factors in adoption, and in experimenting with potential solutions to these constraints. But it leaves the adoption puzzle still only partially resolved. This suggests that the assumption that beneficial technologies are sufficiently available for adoption may need to be scrutinized. Direct field observations in Eastern India and Bangladesh indeed vindicate T.W. Schultz' (1964) assertion that smallholder farmers are "poor but efficient" with the assets they have and the technology available to them. They continue to use the same seed varieties over decades for lack of better alternatives. They use them efficiently for what they can do, but yields are low. A complementary hypothesis is thus the need to increase the effective supply of Green Revolution technology suitable for adoption, where effective supply is defined as the combination of existence, information, and local availability. We turn for this to research done on abiotic shock-tolerant rice in Eastern India.

Results from field experiments: Role of supply-side constraints

Existence: Case of flood-tolerant rice in Odisha

Here the new technology is a flood tolerant rice variety for rainfed environments called Swarna-Sub1 that reduces downward risk. The research questions are: (1) what is the risk-coping value of Sub1, as measured by the yield resilience effect in bad years, and (2) what is the risk-management effect of Sub1 as measured by the yield effect in normal years. The first effect is agronomic, the second behavioral. The research strategy consists in the randomized distribution of Sub1 seed minikits of 5 kilograms to farmers in the Indian state of Odisha (Dar et al., 2013; Emerick et al., 2016).

Results show that adoption of Green Revolution technology for good potential-risky rainfed areas increases with the existence of technologies adapted to smallholder farmers. In this case, not only are yield losses in bad years reduced, but yields increase in normal years due to behavioral responses to reduced downside risk and the corresponding adjustments in risk management. Farmers can now take more risks with their investments in normal years knowing that they are less exposed to risks in bad years. Good year yield gains are equal to 40% of avoided yield losses in bad years. The estimated benefit/cost ratio of adoption is 2.7. Lessons learned from the Sub1 case study are the following: (1) Technologies should be simple to adopt and use for success with smallholder farmers in developing country contexts. In this case, Sub1 is identical to already widely used Swarna in all aspects else than flood tolerance. The adoption decision is thus particularly simple. That there is benefit from simplifying the decision making process to facilitate adoption by farmers had been noted for fertilizer doses by Schilbach et al. (2015). They recommend using color spoons to simplify memorization of fertilizer doses. Casaburi et al. (2014) show that text messages sent by sugar plantation owners to contracted farmers about when and how much fertilizer to apply helps the latter make correct decisions. (2) Gains from technological improvements should be large. In the case of Sub1, the benefit-cost ratio from adopting and adapting is 2.7, with no yield penalty in normal years. (3) Technologies should be transformative in inducing change in behavior. Here, adoption induces other adoptions and changes in practices such as fertilizer use and labor intensive methods. We observe that when such technologies are available, demand follows supply with the existing mediating factors. Sub1 farmers for example find access to the necessary liquidity without the need for new credit schemes. But there is a deficit of existence of such technologies for rainfed areas. For instance, the value in farmers' fields of new seeds for drought and heat tolerance is still uncertain, in spite of the potential large gains in reducing downside risk from these climatic events. Without offering new technologies that reduce downside risks in good potential but risky rainfed areas, it is unlikely that a Green Revolution will come about.

Information: Case of extension service for Sub1 in Odisha

Using a field survey, we observed that, in spite of its proven value in farmers fields, the Sub1 technology was not widely known by farmers through the extension service, agro-dealers, or the media. Why do current information systems often do not work? RCT methodology was used to experiment with alternative choices of contact farmers to diffuse information in social networks, and with alternative designs for extension services.

Prior research on extension services has shown the flaws of commonly used approaches. In the Training and Visit System, the widely popular approach championed by the World Bank starting in the 1970s, contact farmers trained by extension officers as intermediaries in social networks generally failed to convince others due to lack of incentives in performing these roles (Anderson et al., 2006). In the Farmer Field School system, student farmers were extensively trained to understand technology, but they were not equipped to convey to others what they had learned at the school. In India's Agricultural Technology Management Agency, clustered Head-to-Head demonstrations (i.e., with treatment and control plots over large areas) and farmer field days both run by extension agents do not demonstrate technology the way farmers use them, and thus have limited impact on what farmers can do once they are on their own (Glendenning et al., 2010). That lack of adoption may be due to the fact that extension agents make recommendations according to their own objective functions and own assessed resource costs, as opposed to those of farmers, had been noted by Duflo et al. (2008) as a potential source of erroneous recommendations. The Agricultural Knowledge Information

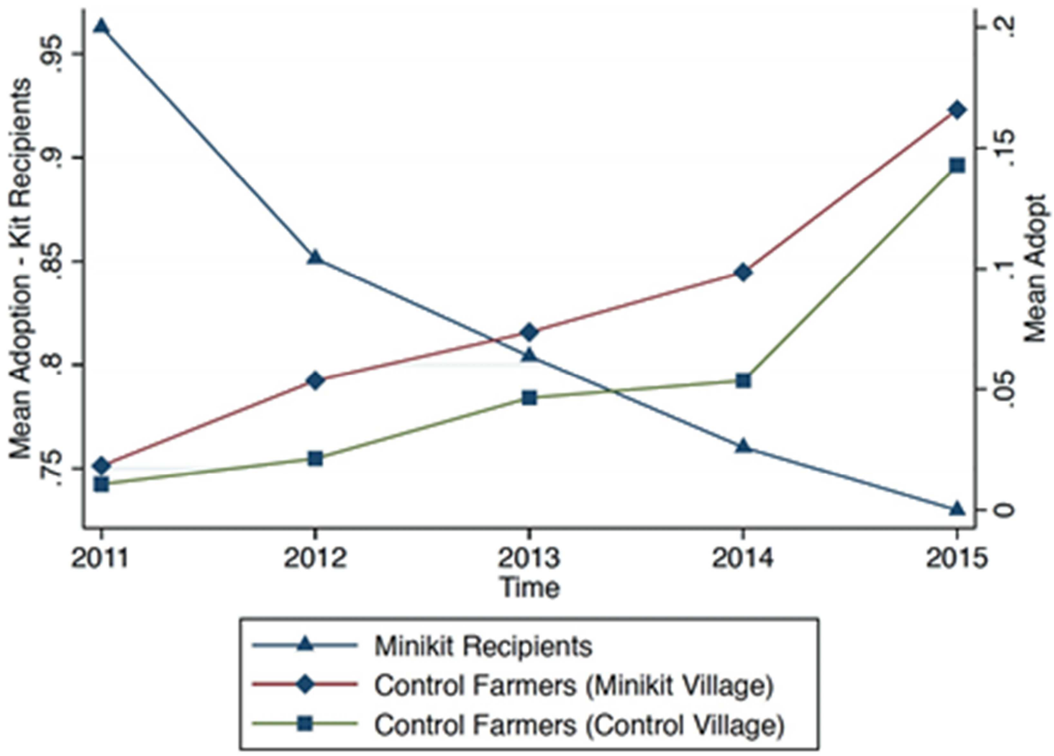
Systems approach advocated by the Neuchatel Initiative (Swanson and Davis, 2014) relies on private agents in value chains such as agro-dealers and commercial partners to serve as sources of information on new technologies. However, in many developing countries, such value chains are hardly in place and cannot yet fulfill these information-providing functions.

Results obtained from field experiments suggest the following conclusions to increase information on new technologies: (1) Strategically selecting early adopters can make a difference for social learning (Beaman et al., 2014). Best entry points may be peer farmers, lead farmers, or multiple other farmers according to circumstances. Impact of choice of entry points on subsequent diffusion is however relatively modest, and reduced by heterogeneity of conditions across farmers (Tjernstrom, 2015). (2) It is important to give results-based incentives to demonstration farmers for them to actively diffuse information in social networks (BenYishay and Mobarak, 2015). (3) Information about technology should be given to farmers the way they learn: Head-to-Head demonstration plots should be managed by farmers under their own circumstances, not by extension agents pursuing their own objective functions; choice of the counterfactual plot by demonstration farmers in farmer field days helps reveal their types to others; farmer field days should be run by the demonstrating farmer rather than the extension agent as farmers learn best from other famers. (4) As value chains develop, extension advice should be increasingly focused on agro-dealers and commercial partners who can convey information to farmers as part of sales relations and interlinked transactions in commercial contracts.

Availability: Case of seed supply for Sub1 in Odisha

The diffusion of Sub1 seeds in the flood prone areas of Odisha has been disappointingly slow. In a follow-up survey four years after the randomized introduction of minikits in treatment villages, the initial 30% coverage had not expanded (Figure 4). One quarter of the minikit recipients had lost access to seeds due to weather events or mismanagement of seeds and could not find replacement. Control farmers in the same villages had increased use of Sub1 to 16%, just enough to replace the existing minikit recipients and to maintain the 30% initial coverage. In control villages, adoption had only reached 14%. In spite of high demand for Sub1 when seeds were experimentally made available through door-to-door sales (Emerick, 2016), diffusion was hampered by lack of availability of seeds. We thus conclude that there is much need to improve the local availability of new seeds to allow adoption of Green Revolution technology. Farmer-to-farmer diffusion is not effective because social networks are segmented, farmers who have the new seeds have no incentives to pass them along broadly to others, and there is a lack of quality certification and trust to support farmer-to-farmer diffusion. The Odisha State Seed Corporation (OSSC), a parastatal, is blocking the entry of private dealers by subsidizing sales and at the same time is inefficient in making seeds available to willing buyers, resulting in local shortages. Clearly, private seed companies and agro-dealers need to be put into place to make the new seeds locally available.

Figure 4. Lack of seed availability holds back diffusion



Note : In Minikit (Treatment) Villages, loss of access to seeds among minikit recipients (from 97% to 73%, left axis) has been compensated by access to seeds by non-minikit recipients (control farmers) rising from 0 to 16% right axis), resulting over the years in a constant 33% adopters, the initial distribution rate of minikits in the village. Loss of access to seeds among minikit recipients was due to harvest losses and seed management failures, with no access to replacement. In control villages, the adoption rate rose from 0 to 14% (right axis), showing lack of seed availability to support rapid diffusion.

Conclusion: Resetting the focus on effective supply

We have posed the technology adoption puzzle as the lack of occurrence of a Green Revolution for smallholder farmers in extensive areas of good potential but risky rainfed agriculture that characterizes most of Sub-Saharan Africa and Eastern India. It is symptomized by low fertilizer use due to low productivity technology. By reviewing the literature, we have shown that pragmatically used field experiments can be useful to address the adoption puzzle (Jack, 2011; ATAI, 2016). Randomized control trials have principally emphasized the lack of demand and mediating factor constraints in addressing the adoption puzzle. Experiments have thus been conducted on the roles of behavior, credit, insurance, markets, and policy in constraining adoption. These results have been useful in explaining low adoption and suggesting options for improvement, but the puzzle still remains in large areas of the world, suggesting that more experimentation on how to remove these constraints is still needed. Experimental results also show that lack of effective supply of technology for smallholder farmers in rainfed areas remains a major limiting factor to technology adoption. It requires existence, information, and local availability of technology to make a Green Revolution possible.

Policy implications that derive from these results are to: (1) Invest more in the existence of technological innovations for smallholder farmers under rainfed conditions. Needed are new technologies with large benefits (i.e., with high benefit/cost ratio from risk reduction) and fit for adoption (i.e., simple to adopt and inductive of transformative behavior). (2) Give more information about existing technology to farmers the way they learn. This requires redesigning the extension system to correspond to the way farmers learn, increasing the effectiveness of social learning mechanisms, and promoting the emergence of informative agents in value chains.[1] (3) Increase the local availability of technological innovations by fixing the seed supply system and promoting the role of marketing and contractual agents in value chains.

Recommendations to international donors are correspondingly to reset priorities toward increasing the effective supply of innovations. Regarding existence, this implies increased support to discovery-type agricultural research as an international public good. In spite of CGIAR successes and bold reforms (with the formulation of six consolidated CGIAR Research Projects, or CRPs), only 20% of a nearly US$1 billion annual budget goes to discovery research, as opposed to the 50% that was expected to follow the reforms. Increasing the budget share that goes to research requires resolving a collective action problem among donors in the provision of an international public good, which the CRP reforms have not been sufficient to address. Donors remain more motivated to fund interventions that address their own development concerns, typically dealing with specific aspects of poverty and the environment, rather than investing in core research. Recent calculations of returns to investing in agricultural research show that under- investment remains a pervasive problem, especially for Sub-Saharan Africa (Pardey et al., 2016) but also for the world at large (Hurley et al., 2014). Regarding information, it requires revalorizing investment in extension to help farmers learn to decide in adopting new technologies. Instead, extension services have been the chronic poor child of foreign aid, including closure of ISNAR (the International Service for National Agricultural Research), the CGIAR center dedicated to extension. The results we present here show that this has been a costly decision that may now be a constraint on effectiveness of the CGIAR technology adoption mandate. Finally, regarding availability, there is a need to invest in supporting the emergence of private agents in value chains as a source of information and availability of new technologies. This implies giving more attention to the emergence of a private sector in agricultural value chains, and to the ability of smallholder farmers to link to these agents as sources of technology.

[1] This topic was recently explored in a workshop organized by FERDI and SPIA, held at the FERDI in Clermont-Ferrand in May 2016. See de Janvry, Macours, and Sadoulet (2016)

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