Vulnerability, risk management and agricultural development

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This paper examines the relationship between agricultural development, vulnerability to shocks and the risk management practices of small farmers in developing countries. Economic thinking on technology adoption has long been influenced by a model of a rational but risk-averse farmer. Experimental evidence suggests that aversion to downside risk is a better representation of human preferences than aversion to risk per se. The prescribed solution, no matter what kind of risk the farmer is concerned about, is to offer insurance. Recent field experiments indicate that other behavioral considerations play a role as well, such as impulse purchases and vulnerability to marketing campaigns. This may explain why adoption of agricultural innovations is often gradual and displays patterns consistent with peer effects through social networks and geographical proximity.

Keywords: agricultural development; technology adoption; risk management; downside risk; farmer behavior; sub-Saharan Africa

JEL codes: O33; Q12; Q18

Cet article examine la relation entre le développement agricole, la vulnérabilité face aux chocs, et les pratiques des petits fermiers en matière de gestion des risques, dans les pays en voie de développement. Depuis longtemps le modèle d'un fermier rationnel est opposé à la prise de risque influence le raisonnement des économistes concernant l'adoption des technologies. Les preuves expérimentales suggèrent que l'aversion pour le risque baissier relève plus des préférences humaines que de l'aversion pour le risque en soi. La solution prescrite, indépendamment du risque redouté par le fermier, consiste à offrir une assurance. De récentes expériences sur le terrain indiquent que d'autres considérations comportementales ont également leur rôle à jouer, comme les achats par impulsion et la vulnérabilité face aux campagnes commerciales. Ceci pourrait expliquer la raison pour laquelle l'adoption d'innovations agricoles se fait souvent de manière progressive et dévoile les habitudes d'une dynamique de groupe spécifiques au réseau social et à la proximité géographique.

Mots-clés : *développement agricole ; adoption des technologies ; gestion des risques ; risque baissier ; comportement des fermiers ; Afrique sub-saharienne*

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1. Introduction

Vulnerability to risk is a dominant feature of the livelihoods of the poor. This is particularly true for small farmers in developing countries. Shocks affect welfare through the changes they make to income, assets and health. For many poor farmers in developing countries, risk remains a serious cause of poverty – and even ruin. In still too many cases, risk is a matter of life or death.

Households' desire to protect themselves against shocks is thought to affect their production and savings decisions. This applies in particular to the adoption of agricultural technology. Choosing between crops and techniques of production is like choosing between lotteries, each with its own distribution of anticipated earnings. Farmers who are fearful of future loss of earnings may be reluctant to adopt technological innovations that offer a variable or unknown return.

This observation forms the basis of much thinking about technology adoption by small farmers in developing countries. Reluctance to adopt new agricultural technology for fear of risk is often seen as a key contributor to the persistence of rural poverty: poor people fear the risk associated with innovation and this keeps them poor.

While the argument is intellectually convincing, what remains unclear is how relevant it is in practice. The purpose of this paper is to revisit the literature on the risk management and technology adoption practices of rural households in the developing world. The interaction between risk and poverty has received much attention in the development literature over the last three decades. I have summarized much of it in my book on rural poverty, risk and development (Fafchamps, 2003). Here I focus on a number of issues that do not receive much coverage in the book but have emerged as active research areas in recent years.

I start by taking stock of what we know and do not know about the behavior of farmers with respect to shocks. I then examine what we know about how risk affects behavior, with a particular emphasis on the behavior of farmers in developing countries. I then turn to the recent literature on technology adoption, with a special focus on findings from field experiments.

2. Shocks

There is no doubt that shocks affect the livelihood of numerous individuals and households across the world. Our primary interest is in how the behavior and welfare of poor households is affected by risk. Although the literature sometimes uses the words 'risk' and 'shocks' interchangeably, the two concepts are quite distinct.

Shocks can affect welfare and behavior even if they were unanticipated, that is, even if people never expected the shock to happen and took no precaution against it. People often respond to a shock, trying to minimize its adverse effects or maximize its beneficial effects. But this does not imply that their behavior is affected by risk. This happens only if people understand a shock may occur in the future and somehow adjust their behavior to that possibility. For instance, people may anticipate becoming ill at some point in the future, and this may induce them to secure health insurance. Or they may anticipate rainfall variations and adapt their cropping pattern to be resilient to drought. But there are other instances in which people do not anticipate future shocks and do not prepare for them, for instance when they ignore the possibility of a flood or earthquake. When people anticipate future shocks we say that there behavior is affected by risk.

Much of the empirical literature focuses on the effect of shocks rather than risk. This is understandable. The impact of shocks on outcomes and behavior is relatively easy to demonstrate rigorously, given that most shocks are determined by events beyond the control of individual agents. Consequently, when using shocks as regressors to explain various outcome and behavioral variables, exogeneity is seldom in question and this facilitates causal inference. In contrast, it is much harder to document the effect of risk on behavior, with the possible exception of laboratory experiments.

There is a voluminous empirical literature documenting the many ways that adverse shocks of various kinds can decrease human welfare temporarily or permanently. Rainfall data, for instance, have been extensively used to identify the effect of weather shocks on agricultural yields and incomes (Portner, 2008a, Chapter 4 for a recent example). Other detrimental weather effects have been documented, such as long-term effects on school attendance and enrollment (Jacoby & Skoufias, 1997), and the nutrition and height of children (Alderman et al., 2006) and their ultimate educational attainment (Portner, 2008b).

The effects of health shocks are well documented, too. The effect of the death of a parent on a child's future has been studied by a number of authors (e.g. Akresh, 2004; Evans, 2004; Ksoll, 2007). In a similar vein, Fafchamps and Kebede (2007) document the effects of disability on income and well-being. Other authors have similarly studied the adverse effects of political events and warfare (Miguel & Roland, 2006). Crime too has been linked to a reduction in welfare (e.g. Fafchamps & Minten, 2004, 2009).

The literature has extensively studied the beneficial effect of positive shocks, such as the introduction of a cash transfer (e.g. Progresa) or food-for-work program. Here the emphasis has been on long-term beneficial effects on children's education, nutrition and health. In a similar vein, De Mel et al. (2007) document the effect a cash grant has on micro-enterprise income and household welfare.

Although this literature clearly demonstrates that positive and negative shocks can have a dramatic impact on current and future human welfare, this does not, by itself, demonstrate that people anticipated these shocks in any way and adjusted their behavior accordingly. Put differently, the recent empirical development literature has relatively little to say about the possible effect of risk on behavior.

At first glance this is strange, because the theoretical literature on risk has focused primarily if not exclusively on how the prospect of future shocks anticipatively affects behavior. For those interested in farmers, the paper that started it all is Sandmo's seminal contribution (1971) showing that risk aversion leads to under-investment and under-production. Other theoretical contributions similarly indicate that, in the absence of insurance markets, risk-averse investors would shy away from risky assets and concentrate their portfolio in safe assets, even if their return is lower (Drèze & Modigliani, 1972).

On the basis of these theoretical observations, risk aversion combined with the absence of insurance is often mentioned as a potentially important contributing factor to poverty traps: poor households are predicted to stay away from high return investment opportunities because they fear the consequences of failure. These ideas influenced the development literature of the 1970s and 1980s, for instance leading Binswanger (1980) to measure risk aversion among ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) farmers in the late 1970s.

3. Risk management theory

Because Sandmo's argument has been so influential, it is worthwhile providing a modern treatment of it. We first illustrate what happens when a market for insurance exists. Consider an expected utility household model of the form:

$$V(Y) = \max_{W,A,N} U(Y - W - A + N) + \beta EV\left(W(1+r) + \pi(A)\theta - N\gamma\theta\right) \tag{1}$$

This model can be seen either as a two-period model (as in the original Sandmo paper) or as the Bellman equation of an inter-temporal model. *Y* is current income (cash-in-hand), *W* is saving in a liquid asset with a fixed return *r*, *A* is investment in a risky activity $\pi(A)\theta$ where θ is a random shock and *N* is the sale of a security that pays a unit return of $\gamma\theta$. We assume that the risky activity has positive but decreasing marginal returns in *A*: $\pi' > 0$ and $\pi'' < 0$. The return on security *N* is perfectly correlated with θ and hence with the return from the risky activity. Thus, by selling security *N*, the household is able to 'sell' the risk from the risky activity at a fixed price $1/\gamma$, thereby shifting as much of the risk θ onto others as it wishes. The first order conditions are:

$$-U' + \beta E[V'](1+r) = 0 \tag{2}$$

$$-U' + \beta E[V'\theta]\pi' = 0 \tag{3}$$

$$-U' + \beta E[V'\theta]\gamma = 0 \tag{4}$$

Equations (3) and (4) can easily be manipulated to yield:

$$\pi'(A) = \gamma \tag{5}$$

Equation (5) implies that the choice of *A* depends only on the price of the security *N*. Separability applies: production decisions do not depend on household preferences, including their preferences regarding risk. The model can be amended so that *N* resembles more closely an insurance contract, with an identical result.

Separability no longer holds if a market for securities or for insurance does not exist. To see this, consider the model without *N*:

$$\max_{W,A} U(Y - W - A) + \beta EV\left(W(1+r) + \pi(A)\theta\right).$$

The first order conditions are:

$$-U' + \beta E[V'](1+r) = 0 \tag{6}$$

$$-U' + \beta E[V'\theta]\pi' = 0 \tag{7}$$

which, after some straightforward manipulation, yields:

$$\pi'(A_a) = (1+r)\frac{E[V']}{E[V'\theta]} \tag{8}$$

where A_a denotes the level of investment of a risk averse household. In the case of a risk neutral household, *V* is linear and thus V' is a constant that factors out. Equation (8) then simplifies to:

$$\pi'(A_n)E[\theta] = (1+r) \tag{9}$$

where A_n denotes the level of investment of a risk neutral household. Equation (9) implies that the expected marginal return to investment equals the interest rate.

We want to know whether A_a is in general smaller than A_n. We first note that if $\frac{E[V']}{E[V'\theta]} > 1$, then $\pi'(A_a) > 1 + r$. Since $\pi'' < 0$, this also implies that $A_a < A_n$. In contrast, if $\pi'(A_a) < 1 + r$, then the optimal choice of A_a is above A_n. Whether A_a is greater or smaller than A_n therefore depends on whether $E[V'\theta]$ is greater or smaller than $E[V']$.

It can be shown that $E[V'\theta] < E[V']$ when the household is risk averse. To see why, note that $E[V']$ can be regarded as a straight average and $E[V'\theta]$ as a weighted average, where the θs are the weights.[1] If the household is risk averse, large values of θ – large incomes – are associated with low values of marginal utility V'. Similarly, low values of θ are associated with high values of V'. This means that in the weighted sum $E[V'\theta]$, high values of V' get a low weight while low values of V' get a high weight. It follows that $E[V'\theta] < E[V']$ and thus that $A_a < A_n$.[2]

In Sandmo's original treatment of this model, $V(.)$ is taken to represent utility and its curvature is interpreted as risk aversion. As equation (1) illustrates, however, $V(.)$ is better seen as a value function. Its curvature depends not only on the curvature of utility function $U(.)$ – i.e. intrinsic risk preferences – but also on the availability of self-insurance devices, e.g. precautionary savings in the form of liquid assets *W*. The more *W* the household holds, the better it can smooth income shocks and the flatter $V(.)$ is. Access to other forms of insurance, however imperfect, will also flatten $V(.)$, making farming decisions less sensitive to risk and under-investment less serious. These findings have subsequently been extended in various directions (Newbery & Stiglitz, 1981). Kimball (1990) in particular has shown that a monotonic relationship exists between investment decisions A_a and prudence, defined as V'''/V''.

We have thus established that $A_a < A_n$ – there is under-investment – if the decision maker is risk averse and does not have access to insurance. This result has been and still is very influential. It has been used extensively as a possible explanation of why poor households refrain from investing in (more risky) new technology. The question is whether this insight is empirically relevant.

4. Evidence on risk and risk taking

Unfortunately, we do not have a lot of hard evidence that risk is the main obstacle to the adoption of new technology by poor farmers in the developing world. As mentioned earlier, this issue attracted some attention in the 1970s and 1980s. But by the 1990s the research

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[1] This is most easily seen if θ is normalized so that $E[\theta]=1$; otherwise, divide by $E[\theta]$ and redefine θ as $\theta/E[\theta]$.

[2] This can be formalized as follows. To save on notation, write $V'(W(1+r)+\pi(A)\theta)$ more compactly as $V'(\theta)$. We have:

$$V'(\theta) > V'(E[\theta]) \text{ if } \theta < E[\theta]$$
$$V'(\theta) < V'(E[\theta]) \text{ if } \theta > E[\theta].$$

Consequently, we may write:

$$V'(\theta)(\theta - E[\theta]) \le V'(E[\theta])(\theta - E[\theta]) \text{ for all } \theta.$$

Since this is true for all θ, it is also true on average. Taking expectations, we have:

$$E\left[V'(\theta)(\theta - E[\theta])\right] \le E\left[V'(E[\theta])(\theta - E[\theta])\right]$$
$$E\left[V'(\theta)\theta\right] - E\left[V'(\theta)\right]E[\theta] \le V'(E[\theta])(E[\theta] - E[\theta]) = 0$$

which leads to

$$E\left[V'(\theta)\theta\right] \le E\left[V'(\theta)\right]E[\theta]$$

as claimed.

emphasis had shifted to risk coping strategies involving precautionary saving and mutual insurance. One possible explanation for this turn of events was that the exogeneity of many shocks (e.g. rainfall, illness) provides an easy identification strategy for drawing causal inference about the effect of shocks on transfers, asset sales or savings. Analyzing the effect of risk on risk taking by farmers in developing countries is harder to do.

4.1 Econometric evidence

It is empirically difficult to formally test theories that relate decisions made by poor households to the relative riskiness of the options available to them. There are two main reasons for this. First, it is very difficult to obtain measurable variation in risk across individuals since, by definition, risk materializes over time. Consequently, a lot of information is required to construct reasonable measures of risk. Second, even when measures of riskiness can be constructed, sufficient exogenous variation in risk must be available to distinguish what can reasonably be attributed to risk as opposed to other features typically correlated with risk. For instance, different agro-climatic regions have different crop-specific risk levels. But since they also differ in many other respects, not least the profitability of different crops or activities, it is difficult to ascribe a causal interpretation to empirical regularities, even if they can be shown to be present.

This probably explains why there has been very little research on the effect of risk on behavior among rural households in developing countries. Using survey data from Pakistani dairy farmers, Kurosaki and Fafchamps (2002) show that observed cropping patterns are consistent with farmers' desire to cover their fodder production needs to reduce exposure to input price risk. In this paper, risk measures are constructed by combining longitudinal price data with cross-sectional yield variation. The effect of risk on decisions is estimated using a structural model that allows for risk-averse preferences.

Using panel household data on rural Ethiopia, Rogg (2005) shows that the asset holdings and portfolio mix of rural households is correlated with relative riskiness in a way that is consistent with theory. Hill (2005) shows that the more risk-averse Ugandan farmers were less likely to replant coffee trees, given the risk represented by the coffee wilt disease. In a different vein, Portner (2008b) uses historical data on hurricane incidence in Honduras to construct a measure of location-specific hurricane risk. The author then uses this risk measure to estimate the effect of risk on education decisions. He shows that locations with a higher risk of hurricanes invest more in education, even though hurricane events themselves have a negative effect on education. Portner interprets these results as suggesting that households invest in education so as to be better able to escape the worst consequences of future hurricanes.

Though valiant, all these studies suffer from the need to make some assumptions to achieve identification. In particular, they have to make assumptions about the absence of omitted variable bias (e.g. that the risk measure is not capturing something else) and about possible endogenous placement (e.g. that risk-averse individuals may have left areas more affected by risk).

Other authors have sought to simulate the anticipated gain from risk reduction. If risk aversion explains farmers' reluctance to adopt new technologies, then reducing risk should bring large advantages. Using detailed data on ICRISAT farmers in India, Walker and Ryan (1990) estimate the welfare gain that would be induced by a complete elimination of millet yield risk. They find that the equivalent variation of the complete elimination of such risk is only a small proportion of total income. One may argue that the explanation for these findings is that millet is a drought-resistant crop with low variance, so perhaps they may not be representative of the risk reduction achieved by avoiding drought-vulnerable crops. What the Walker and Ryan simulation illustrates, however, is that farmers grow different crops and in general have diversified sources of income, so that risk associated with a single crop need not make a large contribution to total income risk.

Health shocks, in contrast, may be of more importance because they affect the household's ability to produce and generate income. Fafchamps and Lund (2003) and De Weerdt and Fafchamps (2007) indeed find that transfers and informal loans respond to health shocks.

4.2 Circumstantial evidence

While rigorous empirical evidence on the relationship between risk and risk taking is hard to find for rural households in developing countries, there is ample circumstantial evidence that the Sandmo model is not consistent with farmers' behavior. First of all, farmers by definition engage in activities that carry a lot of risk. So they do not appear to shy away from risk.

Existing theory suggests that farmers are more likely to engage in risky activities if they are well insured. Is this the case? Not really. Government-sponsored safety nets for rural dwellers remain conspicuous by their absence. Although many examples have been found of informal and semi-formal insurance mechanisms operating in poor rural communities, the evidence also shows that these mechanisms almost never provide adequate protection against shocks (e.g. Rosenzweig, 1988; Townsend, 1994; Fafchamps & Lund, 2003). It is therefore very unlikely that the reason why small farmers engage in risk activities is because they are well insured.

Could it then be that they have sufficient liquid assets to self-insure? There is indeed ample evidence that rural households across the developing world accumulate savings or liquid assets as a form of precautionary savings (e.g. Deaton, 1991, 1992). But these assets are seldom sufficient to smooth consumption. Fafchamps et al. (1998) and Kazianga and Udry (2004), for instance, show that Burkina Faso rural households affected by the 1984 drought refrained from selling cattle and opted to reduce consumption instead and may have incurred excess mortality as a result. The reason offered for this result is that farmers fear losing productive assets. Distress sale of land or cattle appears to be considered with great reluctance by many rural households: it may solve an immediate scarcity problem, but it will lead to more severe poverty in the future, a point formalized for instance by Carter and Zimmerman (2000). Lybbert et al. (2000) revisit this issue in the context of East African pastoralists, showing that herders who have too few animals to sustain themselves during transhumance cannot maintain a pastoralist lifestyle – and face a much higher probability of losing all their livestock.

What these two examples suggest is that poor farmers deal with risk in ways that appear different from those suggested by Sandmo's model. In Burkina Faso, farmers prefer to reduce consumption rather than sell cattle. In East Africa, pastoralists prefer to hold onto their animals to preserve their lifestyle. In both cases, households appear remarkably willing to 'toughen it up', that is, to face up to the consequences of risk. Of course, their choices are severely limited, but the evidence does not seem to indicate that poor farmers shy away from risky activities.

There is another reason why Sandmo's model is a poor candidate to explain resistance to innovation. Much agricultural technology is divisible. This is particularly true for much Green Revolution-type technology, such as improved seeds, chemical fertilizer and pesticides. This dramatically reduces the risk associated with farmer experimentation, since it is fairly easy to try out a new technology on a small scale before adopting it on the whole farm. Yet agricultural surveys provide little evidence of small-scale experimentation by farmers in developing countries. Partial adoption of a new crop or technology would also make sense from a diversification point of view: even though a new crop or technology may be more risky than an existing one, combining both may nevertheless reduce risk relative to the old technology alone. For this reason, one would expect risk-averse farmers to be keen to adopt new divisible technologies, but only partially. Yet farmers often seem to switch entirely to a new technique of production, even though they may subsequently revert to the old technology if the outcome was unsatisfactory. This kind of behavior is difficult to reconcile with the idea that farmers seek to minimize risk.

Sub-Saharan Africa is often mentioned as a place where farmers have been very reluctant to introduce new agricultural practices. This is often taken as a reason for the poor agricultural performance of the continent. Yet such claims fail to acknowledge that African agriculture has changed dramatically over the last century or so. Perhaps the most obvious and far-reaching change has been the introduction of new crops – maize, rice, sweet potatoes, cassava, tomato, potato, to name but a few. These crops have spread massively over the last two decades, with some government support.

New cash crops have also emerged that are grown by small farmers, either for export or for local urban markets. This is true for Africa, such as pineapple, green beans, onion (e.g. Jaffee & Morton, 1995; Conley & Udry, 2001). It is even more true for India, where an agriculture traditionally centered on staple foods is rapidly moving towards horticulture and the production of high risk/high return crops. External intervention has often been instrumental in fostering these changes, primarily in terms of marketing and input distribution (e.g. Conning, 2001; Bandiera & Rasul, 2006; Ashraf et al., 2009). But adoption has been widespread locally even though these crops are often quite risky, with volatile prices and variable yields. On the basis of these experiences, risk aversion does not appear to have been the impediment to agricultural innovation that it was once thought to be. There seems to be little value in the idea that it is risk aversion that stops poor agricultural households making decisions that would, in time, make them more prosperous. Risk aversion appears a poor candidate to explain persistent rural poverty.

5. Adoption and input delivery mechanisms

There nevertheless remain a number of puzzles that continue to defy explanation. If farmers are not risk averse in the Sandmo sense, how can we explain the fact that decentralized market forces seem to have a difficult time delivering agricultural inputs to poor farmers in developing countries? Successful input distribution schemes appear to combine two key features: they provide inputs on credit and they eliminate 'out-of-pocket risk' without eliminating upside risk, that is, they are designed in such a way that the farmer pays for inputs only if the crop is successful.

The first and most enduring example of an input delivery scheme that shares these features is sharecropping. In a sharecropping contract, a farmer pays for land with a portion of the harvest produced by that land. While upfront payment can be requested for fixed rental contracts, this is not possible for sharecropping contracts since payment can only be assessed after harvest. This means that land is de facto given on credit. It is also common for the landlord to provide other inputs on credit (e.g. Braverman & Stiglitz, 1986; Shaban, 1987; Dubois, 2000; Jacoby et al., 2002). Sharecropping therefore provides farmers with agricultural inputs on credit. Furthermore, it eliminates bankruptcy risk: if the crop fails, nothing is paid.[3] In spite of initial fears regarding landlords' willingness to invest in new technology (Bhaduri, 1973), the bulk of the evidence now indicates that sharecropping is an effective way of delivering input credit to producers (e.g. Braverman & Stiglitz, 1986; Gavian & Teklu, 1996; Jacoby et al., 2002).

The second example is taken from the input delivery practices of agricultural marketing boards during and after the colonial period in sub-Saharan Africa.[4] It was common practice for these boards to provide farmers with agricultural inputs at the beginning of the season and to recoup the cost of these inputs at harvest time. Since many of these boards had a monopsony on the cash crop they were responsible for, producers could not abscond from the credit they had received by selling to someone else.[5] This method of recouping input credit through monopsony means that farmers are responsible for input costs only up to the value of their cash crop output. The method by which this is accomplished varies (sometimes input costs are simply deducted from a pan-territorial output price, sometimes villagers as a group are held collectively responsible for the payment of inputs used in their village). But the end result is the same: where crops fail, producers pay nothing.

The third example comes from contract farming. In many ways, contract farming resembles what agricultural marketing boards do: they provide affiliated growers with seeds and inputs and promise to purchase all or part of their output, at which time input costs are deducted from the output price. The crop itself serves as collateral for the inputs and the contractor often has the right to harvest the crop to recoup the cost of the inputs.[6] Although in theory contractors could seek to recover all input costs on growers' assets in case of crop failure, they hesitate to do so, so as not to antagonize their growers. So, de facto, growers pay nothing in case of crop failure.

These three input delivery schemes have two features in common: payment at harvest and no payment in case of crop failure. Otherwise, the details of input repayment vary considerably from one example to the next – in the sharecropping example, costs are paid as a share of harvest; in the agricultural marketing board example, costs are deducted from the output price or paid jointly by villagers; in contract farming, costs are deducted from the value of the harvested crop. This much variation suggests that these contractual details are less important than the two principles listed above. Similar principles can be successfully applied to other technology delivery schemes, such as animal traction equipment.[7]

In my book on risk and rural development (Fafchamps, 2003), I offer a simple extension of the Sandmo model that can account for these observations. Farmers are assumed to worry

[3] In fact, there is evidence that even when harvest is poor although not zero, tenants are also excused from sharing output with the landlord (e.g. Singh, 1989; Dutta et al., 1989).
[4] Cotton marketing boards in West Africa are a good illustration of these practices (Roberts, 1996).
[5] Although some invariably tried to do so, especially those living near porous borders such as that between Senegal and Gambia.
[6] In fact, certain contracts stipulate that harvesting is done by the contractor itself.
[7] In this case, repayment of the equipment is spread over several years and producers get a repayment holiday if they can show that they were hit by an adverse shock (ILO, 1984).

about out-of-pocket risk: they do not like to finish the year in the red. The addition of this simple assumption is sufficient to account for the success of the above-mentioned schemes even if farmers are otherwise risk neutral (or even risk loving). This is important because we have argued earlier in this paper that the expected utility framework – which assumes aversion to upside as well as downside risk – may not be very convincing.

The question then is: why is assuming aversion to out-of-pocket risk any more reasonable than assuming risk aversion in an expected utility framework? Here behavioral economics comes to the rescue.

6. Evidence from experimental and behavioral economics

In this section we first examine the extent to which issues related to loss aversion, poor understanding of low probability events and biased views on downside and upside risks can account for the observed low adoption of agricultural innovation – and the success of certain delivery schemes. The general conclusion is that the observed behavior of poor farmers in developing countries is difficult to reconcile with the standard expected utility model.

As a result, the more recent literature on innovation adoption has begun to incorporate more and more elements borrowed from laboratory experiments and behavioral economics. We summarize some of the new explanations that have been proposed and the way they are being explored through field experiments. Risk and vulnerability to risk loom large in these new explanations, provided one is willing to expand the definition of risk to include vulnerability to one's own failings. People seem to have developed behaviors and devices which are perhaps best understood as protection against oneself.

We begin by discussing experiments on the provision of insurance to small farmers and their unexpected results. We then turn to the role of savings commitment as protection against the risk of temptation to spend. Here the source of risk is something very much internal to the person, and vulnerability is that of the future self relative to the self-indulging present self. Recent field experiments on credit and social networks in a developing context throw a useful light on these sources of risk and how some households respond to them.

Seen from the perspective of this new literature, farmer behavior in terms of technology adoption raises complex risk avoidance issues: the risk inherent to the technology itself, which is the focus of the standard model; but also the risk of not resisting the impulse to buy something new, and the risk of not being sufficiently organized to follow through with the new technology, especially if it requires future financial outlays.

6.1 Risk and risk aversion

Ever since Binswanger's (1980) early work on risk aversion among ICRISAT farmers, researchers working on agricultural technology issues have been aware of experimental economics. But they may not have taken advantage of all its lessons.

Results from laboratory experiments have long suggested that what humans fear is not risk but the prospect of loss (Tversky, 1991). This is most easily demonstrated by experiments in which participants are asked to choose between lotteries with identical final payoffs, but a different sequence of events. While participants are often willing to gamble for future gain, they are less willing to put earlier winnings at risk, even if final payoffs are identically distributed. This could explain why farmers are not willing to put assets at risk by buying agricultural inputs they are not guaranteed to recoup. By eliminating downside risk, the input delivery contracts discussed earlier do not remove upside risk but they deal with loss aversion.

Laboratory experiments have also shown that humans have a poor intuitive understanding of low probability events. For instance, it is common for participants in experiments to be willing to pay the same for a risk reduction of one in a thousand or one in a million even though the former should be worth one thousand times more than the latter. People are sensitive to whether they have recently been affected by similar events and can recall similar incidents. Indeed, recent exposure to low probability events tends to dramatically raise people's willingness to pay to protect themselves against the future recurrence of similar events. It follows that people respond to how the risk of future events is framed and whether they can recognize past experiences in experimental situations. Finally, people may be quite averse to small probability events that are beyond their control (e.g. a plane crash) but not overly worried by high(er) probability events they perceive to be under their control (e.g. a motorbike accident). Taken together, this evidence suggests that people are actually not very rational when it comes to small risks, but also that they are weary of downside risk beyond their control.

Experiments further suggest that people may be overly optimistic when it comes to upside risk. People often overestimate their chances in risky ventures. As a result, they often want to over invest, provided they are sheltered from downside risk. This may explain why many entrepreneurs whose honesty is not in question seem keen to invest uncollateralized borrowed funds in risky projects. Such findings are in line with our earlier observation about the relative success of agricultural input delivery schemes that protect farmers from downside risk but expose them to considerable upside risk.

6.2 Oneself as a source of risk

Taken together, empirical regularities documented in laboratory experiments may help explain observed patterns of agricultural technology adoption. Recent field experiments add new insights to this body of knowledge. Of particular interest for our purpose is a recent paper by Duflo et al. (2009) on fertilizer adoption in Kenya. The authors document a series of field experiments investigating the effect of fertilizer vouchers on input usage. They find much higher fertilizer usage among farmers who were offered a voucher for future fertilizer delivery at the time of selling their crop. This finding is broadly in line with experimental findings about quasi-hyperbolic preferences, forced savings contracts and people's desire to commit future expenditures (Ashraf et al., 2006). Not all farmers are induced to purchase fertilizer by the voucher, however, possibly because of farmer heterogeneity with respect to the nature of their self-commitment problem. Furthermore, Duflo et al. (2009) observe a low fertilizer uptake even among those farmers who are offered the voucher.

These authors investigate possible explanations for their finding. Of interest is the observation that fertilizer usage drops significantly if the voucher is sold to farmers only a day or two after they sell their crop. Why this is the case is not entirely clear, however. One possibility is that the money has already found other uses, e.g. paying for debts and social obligations. Another possibility is reciprocity: when the voucher is sold by the buyer of the crop, the seller may feel some sense of obligation to reciprocate by purchasing a voucher. More work is under way to disentangle these possible explanations. What they do suggest, however, is that input usage by small farmers in developing countries may be quite sensitive to the method of delivery and sale. Rational models of input purchases are not vindicated as there are strange behavioral responses to commitment devices offered to input purchasers.

Peer effects may also matter. Ashraf et al. (2009) document an outgrower scheme run by an NGO in Kenya called DrumNet. The authors evaluate a program in Kenya that encourages the production of export-oriented crops by providing smallholder farmers with credit linked to agricultural extension and marketing services. They use an experimental design in which farmer self-help groups are randomly assigned to either a control group, a group receiving all DrumNet services or a group receiving all services except credit. Among the services offered by DrumNet, credit is the most important, a finding that is consistent with the significant investment in capital and inputs required to produce the export crop. This result is also consistent with our earlier observation about downside risk.

These results are to be compared to field experiments that offer crop insurance to small farmers. If Sandmo's model is a fair representation of small farmers' decision processes, offering insurance corrects a market failure and is the preferred way of achieving first best. Two separate teams of researchers have experimented with crop insurance in two Indian states. Their results are summarized in a jointly authored paper (Cole et al., 2009). Both field experiments have in common the offer of a voluntary insurance contract that compensates farmers in case of deficient rainfall. Payment is based on objectively collected rainfall data. Farmers purchase insurance in discrete units, with each unit equivalent to set payments conditional on rainfall. They can obtain more insurance by buying more units.

The modeling framework presented in Section 2 predicts that risk-averse farmers should purchase more insurance than risk-neutral ones. We also argued that the curvature of the value function $V(.)$ depends on the household's capacity to self-insure through the accumulation of liquid assets. This implies that households with more assets need less insurance and should therefore purchase less. Since small Indian farmers are often poor, we would therefore expect widespread adoption, with many farmers purchasing enough insurance to protect themselves against much of the rainfall risk.

This is not what the authors find. Take-up is limited – in the Gujarat experiment, only 20% of targeted farmers purchased the insurance – but sensitive to price and additional marketing. Although results from the two experiments differ somewhat, risk-averse households appear *less*, not more, likely to purchase insurance. Households do not purchase full coverage; on the contrary, they tend to purchase only one unit of insurance, no matter how large their risk exposure. Furthermore, insurance take-up is higher among wealthy households. None of these results are consistent with the standard Sandmo model. The authors also report that take-up is lower among households that are credit constrained. They argue that these results match the predictions of an extended Sandmo model with borrowing constraints. Alternative explanations exist as well, such as lack of familiarity with the insurance product.

Other patterns are more difficult to reconcile with the benchmark model. Participation in village networks and measures of familiarity with the insurance vendor are strongly correlated with insurance take-up decisions. While education does not seem to matter, endorsement by a trusted third party does. These results may reflect uncertainty about the product itself, given households' limited experience with it. They are to be compared with results reported by Ashraf et al. (2009) on the role of farmer groups, and with those of Duflo et al. (2009) regarding the possible 'reciprocity' between farmers and crop buyers/input providers.

Giné and Yang (2009) report on another similar field experiment in Malawi. They carried out a randomized field experiment to ask whether the provision of insurance against a major source of production risk induces farmers to take out loans to invest in a new crop variety. The study sample was composed of roughly 800 maize and groundnut farmers. The dominant source of production risk was the level of rainfall. The authors randomly selected half of the farmers to be offered credit to purchase high-yielding hybrid maize and improved groundnut seeds. The other half were offered a similar credit package but required to purchase (at actuarially fair rates) a weather insurance policy that partially or fully forgives the loan in the event of poor rainfall. If, as we have argued earlier, farmers are primarily concerned about the downside risk associated with credit, offering the insurance should boost take-up. Surprisingly, the authors found that take-up is lower by 13% among farmers offered insurance with the loan. At face value, this seems to reject downside risk concerns as the primary motive for low take-up of agricultural innovations. The authors, however, found suggestive evidence that the reduced take-up of the insured loan was due to the high cognitive cost of evaluating the insurance: the take-up of insured loans is positively correlated with farmer education levels, but not so for uninsured loan.

This brings up another consideration, namely that people have a complicated relationship with new products. Curiosity may tempt them into trying new products, but such impulse purchases may ultimately prove disappointing. People may therefore steel themselves against large impulse purchases, especially if they are poor. This would be consistent with richer Indian farmers purchasing rainfall insurance, but only one unit, while poorer farmers do not purchase any. People's ability to resist impulse purchases may be susceptible to manipulation by marketing efforts. This may explain why fertilizer vouchers in Kenya found more buyers when the purchase of the voucher was combined with the sale of the crop.

Given these considerations, adoption of new products may require reinforcement from peers: if others around them are adopting a new product, people may find it harder to resist buying it. This naturally generates threshold effects in adoption, an observation made a long time ago by Griliches (1988). In their study of US farmers, Young and Burke (2001) similarly noted the importance of peer effects and conformity in the adoption of certain types of behavior. The emerging economic literature on social network effects has revived interest in diffusion and reinforcement effects. There is extensive circumstantial evidence that social networks matter for the adoption of agricultural, technological and institutional innovations in developing countries (e.g. Foster & Rosenzweig, 1995; Conley & Udry, 2001; Bandiera & Rasul, 2006). In a recent unpublished paper, Caria (2009) argues that Ghanaian farmers who are more risk averse are less likely to experiment with new technology. This may explain why risk-averse farmers in Caria's study look to risk-neutral neighbors for advice on new technology.

Taken together, these field experiments suggest that input usage and the purchase of crop insurance are not well accounted for by the standard model presented in Section 2. While an extended model that includes credit constraints and downside risk considerations can explain some of the empirical regularities, other results indicate that subtle psychological manipulations affect take-up. Economic models of rational self-interested but risk-averse agents seem unable to predict the adoption of technological (e.g. inputs) and institutional (e.g. insurance) innovations by small farmers in developing countries. The study of agricultural innovation in such communities may benefit from drawing more intensively from the psychological and experimental literature – and even perhaps from the marketing literature.

7. Conclusion

This paper has examined the relationship between agricultural development, vulnerability to shocks and the risk management practices of small farmers in developing countries. A correct understanding of this relationship is essential to policy makers interested in fostering the introduction of technological and institutional innovations.

For many years, economic thinking on technology adoption has been influenced by a model of a rational but risk-averse farmer. This model predicts that risk aversion is a major impediment to the adoption of any innovation that increases risk, either directly (through increased yield risk or through increased variance of revenues net of input costs) or indirectly (through uncertainty about the true return from the innovation).

A first best solution to this problem is the provision of insurance, a solution that until recently was thought impractical for small farmers in developing countries. An alternative solution is the provision of safe savings vehicles to facilitate precautionary savings and self-insurance – thereby reducing the curvature of value function $V(.)$. Agricultural extension may also be required to reduce uncertainty about the true return from the proposed innovation.

A version of this model extended to include credit constraints is capable of explaining some of the empirical findings. But successful input delivery systems provide circumstantial evidence that downside risk concerns may explain farmer behavior better. This finding is consistent with experimental evidence emphasizing that loss aversion is a better representation of human preferences than risk aversion.

Recent field experiments indicate that other behavioral considerations play a role as well, such as impulse purchases and vulnerability to marketing efforts. Some field evidence suggests that small farmers may resist adopting new products not so much because they are resistant to change, but because they do not trust themselves not to succumb to impulse purchases. This may explain why adoption of agricultural innovations is often gradual and displays patterns consistent with peer effects through social networks and geographical proximity.

The literature on technology adoption in developing countries started with the view that farmers were irrational and subject to fads and fashions. This patronizing view was then abandoned entirely, to be replaced by a model of rational but constrained decision makers. The literature appears to have come full circle, with a growing interest in behavioral considerations such as loss aversion, quasi-hyperbolic preferences, impulse purchases and peer effects. This does not mean that rational behavior has been set aside entirely, but rather that the adoption of new agricultural inputs and practices is now viewed as a combination of rational and behavioral motives. Peer effects also appear more important as improved theoretical and econometric tools for studying social networks have breathed new life into the study of reinforcement and diffusion effects in the adoption of agricultural innovations.

After a long period of limited interest in research on the adoption of agricultural innovation, the literature seems to have rediscovered the topic, bringing new tools and renewed energy to the endeavor. Field experiments have brought to light the fact that standard models have a limited predictive power, opening the door to the testing of many alternative and competing explanations. Much work is needed before we reach a new consensus on what motivates technology adoption in poor rural areas.

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