Institutional Barriers to Technology Di¤usion in Rural Africa

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September 6, 2002

1 Introduction

Why is Africa poor? Conversely, what has sustained the immense economic growth we have seen in the U.K., the U.S., and other developed countries over the last couple of centuries? While there is no single answer to these questions, technical change looms large among possible explanations. From Solow's seminal work on growth theory to the "new growth economics", technical change is the engine of long term growth. Whether you are looking at the phenomenal growth of Silicon Valley or the stagnant poverty of much of rural Africa, the congruence between economic growth and technical change is striking.

Joseph Schumpeter (1961) describes technical change as having three stages: invention (the …rst realization of an idea), innovation (the …rst bringing of an invention to the market place), and di¤usion (the spread of the innovation through the market place). Technical change becomes economically important through di¤usion. Looking at rural Africa's lack of robust economic growth and dearth of modern technology, it appears that technology di¤usion has failed there. I propose that this failure is partly due to institutional barriers to technology di¤usion and technical change. Ecology and history have conspired to create institutions that are hostile to new technologies. In this paper I present a model of an institutional environment in a stylized rural African village that prevents the di¤usion of a pro…table, low-risk agricultural technology.

The rest of the paper is organized as follows. In the next section, I discuss the importance of technical change. In section 3, I describe the current theories on technology di¤usion and how institutional issues are relevant. In sections 4 and 5 I give the background and motivation for the two linked games that I present in section 6. In section 7 I extract a few predictions from the model. I conclude in section 8.

2 Importance of Technical Change

The importance of technical change to economic growth has been noted for many years, although it has recently received a jolt of attention due to the endogenous growth models of Romer (1986,1990), Lucas (1988), and a host of others. Solow (1956) originally noted the importance of technical change to long run growth in GDP per Capita. In his neo-classical framework, however, technical progress was assumed exogenous and available to all equally. This implies that all countries will eventually converge and grow at a constant rate. Clearly, this has not been borne out by experience. In response to this problem the "new growth economics" emerged in the late 80's, led largely by Romer's two papers. In the …rst (1986) he presents a model where endogenous growth arises from "learning-by-doing" spillovers. In the second paper (1990), endogenous growth is a result of partially appropriable R&D, which has spillovers throughout the economy, thus assuring long-run growth. A number of papers (Stokey 1988, Young 1993, Grossman and Helpman 1991) expand on the models to consider the e¤ects on Less Developed Countries (LDCs) and conclude that poverty traps could emerge.

In contrast to the neoclassical theory, the practitioners of what Fagerberg (1994) calls the "technology-gap approach to economic growth" assume that there is a cost to transmitting knowledge. They acknowledge that technology may be partially a public good, but that it is largely a speci…c good "embedded in organizational structures (such as) …rms, networks, or institutions." Therefore these theorists (including Nelson, Winter, and Dosi for example) believe that di¤erences in technology are the key to di¤erences in economic growth. Abramovitz and David (1994) are in this tradition, when they talk about the "catch-up" and "convergence" of OECD countries after WWII. They attribute productivity catch-up to technological progress. One of the key issues in this literature is whether the existence of a technology gap provides a bene…t to the "follower" nation in terms of savings on R&D.

According to Fagerberg (1994), general empirical results are hard to come by, but one stylized fact seems to emerge. A technology gap combined with either a high level of investment or education leads to faster growth. In other words, a follower can have an advantage in certain institutional environments. At a more general level, it is apparent that technical progress a¤ects productivity growth and that productivity growth a¤ects economic growth.

Economic growth, however, is not the only reason for interest in technology di¤usion. The rising interest in environmental issues has also spurred interest in the di¤usion of new technologies. This is particularly salient in the case of developing countries and climate change. Developing countries — India and China in particular — have a much larger potential for energy growth than the developed countries. Also, they are currently using very ine¢cient and pollution-intensive forms of energy. The di¤usion of clean and e¢cient energy sources to the developing world will have a pay-o¤ not only for the recipient countries but also for the world as a whole.

3 Technology Di¤usion

I am concentrating on technology di¤usion because 1) it is through di¤usion that technical change becomes economically and environmentally important and 2) it is through di¤usion that LDCs can take advantage of the existing technology gap. Di¤usion theory can be divided into three frameworks. The most common approach is built around information and uncertainty, and is typi…ed by Mans…eld (1966). He argues that the speed of adoption is directly related to the pro…tability of the new technology, and inversely related to the capital outlay, the initial uncertainty regarding the pro…tability, and the time required to reduce the initial uncertainty. But poor information and uncertainty don't explain the extreme inertia seen in Africa. Agricultural extension services are common. Peace Corps volunteers have been working in Africa for 30 years, with little evidence of technical change. On top of this, many of the new technologies o¤ered to rural farmers exhibit very little risk compared to the current technologies.

A second approach is based on the heterogeneity of adopters. Stoneman (1987) terms this the "rank" approach, since one can think of …rms (or consumers) as being ranked in order of the bene…ts they will get from adopting a new technology. As the price of a new technology falls, more …rms (or consumers) will gain a positive bene…t from adopting it, and therefore it will di¤use. There is evidence that such factors as …rm size, market power, ownership structure, and unionization all effect the speed of adoption (Stoneman and Karshenas 1995). Why do such factors affect the ability of a firm to adopt a new technology? Most likely it is the institutional framework: the internal organization of the firm and its external networks. All the inputs to a firm, including production factors, capital, labor, insurance, and infrastructure will have an effect on its choice of technology. Similarly, the relationships with "downstream" actors, such as the buyers of its product, will have an effect as well. This is likely to be particularly important in developing countries where market institutions are not well developed.

A third approach to diffusion is the strategic approach. When there are positive externalities to adoption of a new technology, Beath et al (1995) show that excessive inertia can occur, and communities may get stuck in a Pareto-inferior equilibrium. This is most typically thought of in terms of the characteristics of the technology itself. For example telephones, fax machines, and Internet sites all have positive externalities. But more subtle externalities can arise as well. Infrastructures that support new technologies often involve economies of scale. Paved roads and convenient gas stations will generally not arise until a number of people are driving cars. New technologies often require specialists to service and repair them, but it is not economic for a specialist to locate in an area where there are only a few firms that need his help. Further, if the cost of adoption is reduced due to information spillovers, then the adoption cost itself may be a function of the number of current users, rather than just a function of time. Hence, positive adoption externalities are not limited to specific network technologies. The question this paper looks at is what kind of institutional framework favors one equilibrium over another.

4 Technology and Informal Insurance in Africa: A Parable

After the success of the green revolution in Asia, there was great hope for similar success in Africa. That hope has largely turned to despair. While the population has grown steadily food production has not. There has been very little adoption of new agricultural technologies in Africa. In West Africa, for example, nearly 100% of the increase in food production since 1960 has come from expanded harvest area rather than improvements in technology(Eicher, 1992). This land expansion is inefficient and cannot continue indefinitely, or even much longer (Sanders et. al., 1996). Already, marginal land is being farmed, causing environmental damage (Anderson and Hazell, 1994). Why have new technologies (including high yielding varieties of seed, animal traction, and improved agronomic practices such as terracing) not been adopted in Sub-Saharan Africa? There are a number of suggested, inter-related causes for the technical stagnation in the literature ranging from lack of credit, human capital, appropriate institutions or infrastructure to excessive risk aversion.

I am interested in institutional barriers to technology diffusion, particularly informal risk-sharing institutions. Historically, Africans have faced harsh and unpredictable conditions. Various forms of informal insurance have arisen in response to this environment. One form of insurance that I am interested in is ex-post smoothing of idiosyncratic shocks through community sharing. Another is old-age insurance.

4.1 Community Risk Sharing

> Development literature is full of cases of farmers who made spectacular gains in harvests, yet deserted their improved practice a year or two later because of peer or group pressure. (Roland Bunch, 1982)

Development workers have long noticed that a new technology was unlikely to be retained in the long run if only a small number of farmers adopt it in the short run. On the other hand, if a "critical mass" of local farmers adopt an innovation, then the probability that it will still be in use five or six years later is quite high. This "critical mass" usually ranges from 25% to 45% of the community, but in some "tightly organized" communities it may encompass everyone (Bunch, 1982). Sociologists explain that traditional communities are accustomed to living in an environment of consensus. How can an economist explain this? I believe at least part of the answer lies in community risk sharing schemes.

Udry(1994) presents evidence of ex-post risk sharing in Northern Nigeria in the form of contingent loans. Interest-free "loans" are extended to those in need with no specified payment schedule. The understanding is that the loan will be paid back when the lender himself falls into need. The sharing of grain or meals with farmers who are temporarily in need is common in Africa (see e.g. Fafchamps, 1992). Platteau and Hayami (1998) describe how accusations of witchcraft are used to persuade the "lucky" to share their bounty with the community. These practices work against the adoption of new technologies in a couple of different ways. There are free-rider problems: since extra gains are shared with the community, incentives to increase production are severely curtailed. Even worse, if the community does not have full information on the costs or yields of a new technology it may overestimate the returns and demand more sharing. In my experience in Ghana it was a common fear that relatives and neighbors would overestimate an individual's wealth and therefore insist upon "gifts" more than the individual could comfortably afford. Ligon (forthcoming) presents evidence that, indeed, there is not full information sharing in many small villages and that the amount of risk successfully smoothed reflects this. If the community underestimates the cost of a new technology (such as fertilizer), it would reduce the expected return of adopting that technology. If the community is expected to make mistakes regarding the actual value of the harvest, it would increase the variance of the income stream under the new technology.

The above analysis would apply primarily to technologies that are entirely new to a region. Given generations of experience with traditional technologies, yields (and work effort) can be well estimated by glancing at a field, and costs are well-known. Introducing different crops or seed varieties or new agronomic practices may cause the community to be less sure of how much was actually harvested. If, alternatively, the entire community (or at least a critical mass) were to become familiar with a new technology, then this risk could be alleviated. This may explain the "critical mass" phenomenon. This tendency to avoid new technology in the presence of community risk sharing will be reinforced by the informal old-age insurance that I describe below.

4.2 Old Age Insurance

How can a rural African farmer assure adequate support in his old age? There is little formal old age insurance available to self-employed farmers in Africa, so this is a pressing question. If a farmer owns cattle or land, he can use that to secure his old age, either directly by selling it off as needed, or indirectly by using it as a strategic bequest (see Bernheim, Shleifer and Summers, 1985). In the latter case, the farmer can promise his property to those who support him in his old age. As long as the value of the property is greater than the expected value of the support, someone should comply. Throughout much of West Africa, however, land is not owned by an individual, but rather by the local chieftaincy, who divides it among the local people to be farmed. When a friend of mine in northern Ghana decided he wanted to farm, he simply rode his bike around until he saw a fallow field, then requested its use from the chief. A strategic bequest of land under this arrangement would be ineffective at best. Additionally, many poor farmers do not have cattle or any durable property that could serve as a strategic bequest. Their situation is difficult. Altruism from son to father is a possible motivation for old-age care, but may not be relied upon. An alternative model is suggested by Bergstrom and Stark (1993) where some people are pure imitators, and will care for their aging parents as they saw their parents care for their own aging parents. Other people in this model are rational maximizers. They show that the optimal choice for the maximizers is often to care for their aging parents. Nevertheless, if mistakes were made in such a society, the aging farmers may not feel secure. Simmons (1960) points out that in poor, traditional cultures most old people perform some kind of work or service for as long as they are able. It is not uncommon for those who can no longer be of service to be supported at a minimal level, or not at all.

One of the services that an aging farmer can provide to the household is sharing the benefit of his experience. Often he has farmed the same fields, using the same technology, for a lifetime. He has witnessed many different weather patterns, shortages, infestations, etc. He is in an excellent position to advise. Rosenzweig and Wolpin (1985) presented evidence that households with at least one elderly farmer had above average yields in years of bad weather. But the value of an elder's experience is based largely on the existence of stagnant technology. If a new technology is adopted, the differential benefit of the elderly's experience will almost surely be reduced. Using a modern analogy, think of all the adults with years of experience operating TVs who were quickly outpaced by their children after buying a VCR. In fact, sometimes years of experience with an old technology can be a detriment to using a new technology (Perez and Soete, 1988). For example, some of the modern high-yielding varieties of rice grow at a predetermined pace, regardless of the weather or the season. In contrast, the traditional varieties go through different stages according to the season, regardless of when they were planted. All the signs that signalled that a certain stage was being reached for a traditional variety may be misleading for the new variety. In this case, the old farmer would have no service to perform for the farm, and chance being left without adequate support. Therefore, older farmers who will have to rely on their children for support may resist new technology.

5 Linked Games as an Institution

The theory of institutions is very young and still in the midst of being de…ned. Institutions are commonly thought of as organizations. Douglass North (1990) points out, however, that the interesting issues are the formation and structure of the rules that organizations follow when making decisions and acting. Hence, he de…nes institutions as "the rules of the game or, more formally the humanly devised constraints that shape human interactions." Aoki (1998) argues even further, that an institution is an outcome of a game - a self-enforcing Nash equilibrium. Otherwise, di¢cult questions arise, such as: where did the rules come from; and who is enforcing them? Some examples of institutions are social norms, a formal legal system (where the state is considered a player of the game), corporate governance arrangements, internal …rm organization, etc. Finally, Sugden (1986) points out that to be considered an institution there must be more than one equilibrium. Otherwise, technical constraints, rather than humanly constructed constraints, de…ne the outcome.

What quali…es the informal insurance arrangements discussed in the previous section as institutions? They involve multiple equilibria and linked games, and are …rmly rooted in speci…c institutional environments. For example, assume that the parameters of the new technology and the community risk sharing arrangement are such that adoption of the new technology by any individual is blocked. This leaves the possibility of two distinct equilibria. The …rst is that no one in the community adopts the new technology. The second is that the entire community adopts the technology together, thus learning enough about it to prevent information problems. The second equilibrium is clearly Pareto-superior to the …rst. What would cause the inferior equilibrium to be chosen? The explanation lies in other institutional arrangements that interlink with the community risk sharing game. One example of such a link is the old age insurance game. Because of retirement needs, the older generation prefers not to adopt a new technology, even if it is superior. If the bargaining power lies with this older generation, it may be uneconomic for individuals from the younger generation to adopt on their own, given the community risk sharing. Thus the two games reinforce the lack of technical change. The risk-sharing game keeps the sons from adopting the new technology unilaterally. The old-age insurance game keeps the risk-sharing game in a lower equilibrium.

But we can step back even further and analyze the impact of other institutions on the insurance arrangements as well. Land rights have a major impact. Due to the historical abundance of land, institutions reinforcing strong private property rights to land have not arisen in Africa; nor has an ethic to conserve land or use it wisely. Since land is not privately owned, it cannot be used for retirement. This leaves the aged to rely on altruism, their experience, and what little work they can do for support. This in turn may lead them to reject new technologies. Land rights also impact the equilibrium in the community risk sharing game. If a farmer wants to increase his production, he can trade off the benefits of a new technology with the benefits of farming more land. Historically, farmers have chosen to farm more land. Recently, however, the quality of available land has been much poorer than in the past. Nevertheless, the benefits of keeping the same risk structure (by using the same technology on new land) may outweigh the benefits of the new technology. Thus, even if adopting the new technology would be marginally better than continuing with the old technology, it may not be as good as keeping the old technology and expanding the land farmed.

Ex-post community risk sharing is itself only one possible form of reducing risk and increasing utility. One example of an alternative is ex-ante community cooperation. For example, in Japan during the Tokugawa period, it was common for villagers to work together to build and maintain irrigation systems (Aoki, 1998). This reduced risk by providing a regular water supply. Additionally, it increased the expected return and left the villagers as residual claimants of their own profits. Platteau and Hayami (1998) suggest that the rise of these two contrasting institutions is related to the relative abundance and scarcity of land. Aoki counters that the American west, for example, had a similar abundance of land, and yet very different institutions developed there. Either way, the specific form of risk sharing found in much of Africa is a barrier to technology diffusion.

The institutional environment effects the games in other ways as well. State-provided pensions or even community-provided pensions would change the nature of the old-age insurance game. Agricultural extension efforts that focus on transferring technology to only a subset of local farmers may inadvertently add to the inertia.

6 The Model

6.1 Old Age Insurance Game.

There are two periods in the old-age insurance game. In the first period, both the head of household (the “head”) and his son work the farm. In the second period, the head is elderly and only the son works. I assume that land is free and abundant (see Platteau and Hayami 1998), and so the son can leave at any time to start his own farm and avoid having to share the output with his father. There is no saving from one period to the next. This is a severe assumption, which I may try to relax in later research. At low income levels, however, it is not unrealistic, particularly given the negative real interest rates found in many developing countries. I assume no altruism between family members, and therefore a commitment problem exists: how can the father assure himself consumption in the second period? The answer is in the experience he has gained through working the same fields year after year. I assume that each of the players gains experience for each period he works. The head always has one period of experience more than the son does.

The head will always prefer to hire the son if the son’s reservation price is below the total farm profit (wages are not deducted). This is because he must have some consumption in the second period, or he will die. In the first period the son has “low” experience and the head has “medium”. The son’s reservation price in the first period will be the profit he can earn farming alone with low experience. The total farm profit (with head and son) will be the profit earned by farming with two laborers and medium experience. The head will be the residual claimant after paying the son’s reservation price. In the second period the son’s reservation price will increase to reflect his medium experience. Since the elderly head is not working, he will only be able to capture the difference between the profit under medium experience and under high experience.

Specifically, let profit π be a function of experience level ($e = 0, 1, 2$), number of laborers ($L = 1, 2$), and technology ($t = t_0, t_1$). First period total profits are $\pi(e, L; t) = \pi(1, 2; t)$ and the son’s reservation price is $\pi(0, 1; t)$; thus the head’s residual is $\pi(1, 2; t) - \pi(0, 1; t)$. Similarly, in the second period the head’s residual is $\pi(2, 1; t) - \pi(1, 1; t)$. Without invoking utility explicitly, I assume that the head prefers to receive the above residuals to receiving $\pi(1, 1; t)$ in the first period and nothing in the second. If the head’s discount factor is δ, then his total payoff under the "old" technology is

$$P_0 = \pi(1,2;t_0) - \pi(0,1;t_0) + \delta[\pi(2,1;t_0) - \pi(1,1;t_0)] \quad (1)$$

I assume that the new technology, t_1, is superior:

$$\pi(e,L;t_1) > \pi(e,L;t_0) \quad (2)$$

but that it erodes the head's experience advantage:

$$\pi(e+1,L;t_1) - \pi(e,L;t_1) < \pi(e+1,L;t_0) - \pi(e,L;t_0) \quad (3)$$

The idea is that this experience is gained over time: it is valuable precisely because the technology does not change. The payoff to the head under the new technology is similar to (1) above:

$$P_1 = \pi(1,2;t_1) - \pi(0,1;t_1) + \delta[\pi(2,1;t_1) - \pi(1,1;t_1)] \quad (4)$$

The son is unambiguously better off under the new technology. If he were able to adopt the new technology unilaterally and employ it on his own farm then his reservation price in the two periods would be $\pi(0,1;t_1)$ and $\pi(1,1;t_1)$. In this case the head would also be better off adopting the new technology. But what if the son cannot adopt unilaterally? This is where this game is linked with the community risk sharing game. Assume that the son can only adopt if the head does.

The question now is when will the head refuse to adopt the new technology? When is $P_1 < P_0$? Notice that the second period payoff is lower under t_1 than t_0, by assumption (3). The first period payoffs can be written as

$$P_t^1 = \pi(1,2;t) - \pi(0,1;t) = \pi(1,2;t) - \pi(0,2;t) + \pi(0,2;t) - \pi(0,1;t)$$

Again, from (3) we have that

$$\pi(1,2;t_1) - \pi(0,2;t_1) < \pi(1,2;t_0) - \pi(0,2;t_0)$$

Thus, whether the technology is adopted or not depends only on the marginal product of labor under each technology. If

$$\pi(0,2;t_1) - \pi(0,1;t_1) \leq \pi(0,2;t_0) - \pi(0,1;t_0)$$

then the head will not adopt the new technology. In order for the farmer to adopt, the marginal product of labor of the new technology must be high enough to offset the farmer's losses due to experience erosion. Interestingly, the decision does not depend on the absolute gain from the new technology. Note that a subsidy paid will have no effect at all. It will simply raise the son's reservation price by the subsidy amount.

This is a principal-agent game, with a twist. The principal (the farmer) relies on the agent for two different arrangements: for labor, and for old-age insurance. This allows the agent to capture all of the benefits of a new technology. In general, the more transactions that are done with one partner, the higher the switching costs will be to find another partner even for just one of the transactions. The higher the switching costs, the more benefits the partner will be able to capture. Some examples of this are below:

1. A state that provides third party enforcement and that also provides inputs or consumes output of the firm.

2. The "market women" in Ghana who provide seeds and loans to farmers as well as buy their produce.

3. Family firms, where family members provide labor, informal insurance for old age, health, or unemployment, as well as offspring, and social enjoyment.

This game can be expanded and further analyzed by using utility explicitly, allowing savings, allowing the elderly to work a small amount, and introducing altruism from the father to the son. For example, if savings were allowed, then the absolute gain from the new technology would come into play. If the new technology were profitable enough, then the head would adopt it and save what he needed for retirement.

6.2 Community Risk Sharing Game.

Communities can self-insure against idiosyncratic risk. Udry (1994) presents evidence that ex-post sharing is used to smooth risk in northern Nigeria. Coate and Ravallion (1993) present a model of ex-post risk sharing without commitment. They show that a lack of commitment will cause risk sharing to be less than optimal if both parties are very poor or if the spread between realized incomes is too large. They, however, assume that there are no information problems. This is reasonable in a small rural community where all the farmers are using similar technology. If a new technology is introduced, however, and only a small subset of farmers adopts it, then information problems may arise. The community's assessment of a farmer's harvest under a new technology would contain some "noise". For example, if he were growing a new hybrid or a new crop, the farmers may not be able to accurately judge his harvest or the cost of his inputs and therefore misjudge the amount he has to share.

I model the game with two players. Player Y represents the "community" and uses old technology to achieve a random profit y. Player X faces a decision about whether or not to adopt a new technology. He has a random profit x, with superscript o or n to signify whether it is the old or the new technology. Profits under the new technology are assumed to have the same distribution as under the old technology, only shifted to the right. As a result the new technology has a higher expected value than the old technology and the same variance.

$$
\begin{aligned}
E(y) &= E(x^o) < E(x^n) \\
\sigma_y &= \sigma_o = \sigma_n \\
Var(y) &= \sigma_y^2; Var(x^o) = \sigma_o^2; Var(x^n) = \sigma_n^2
\end{aligned}
$$

I am only interested in the community's response to idiosyncratic risk, rather than to community–wide risk, so I assume that the players' profits are independent of each other. I further assume that the old and new technologies are perfectly correlated when used by the same player. This means that the farmer gets no benefit from diversification. This is a reasonable assumption for many of the risks a farmer faces, such as personal illness and many kinds of pests. Nevertheless, there are many ways one would expect the old and new technologies not to be perfectly correlated on the same farm. To the degree that this is true, it would reduce the farmers risk in a way I am not considering here. Finally, I make a simplifying assumption that the objective of the risk sharing is to minimize the variance of the profits, while keeping the expected value constant. This rules out the possibility of player X insuring player Y for some positive risk premium. This is a reasonable assumption if the new technology will not significantly increase the wealth of player X.

I assume that the risk sharing is achieved through an ex-post transfer that is a function of the difference between the realized profits. Coate and Ravallion (1993) show that if the expected values of the two profits are the same, then the optimal risk sharing is equal to $\theta(x, y) = \frac{y - x}{2}$ where player Y transfers an amount of θ (which may be positive or negative) to player X. If the players' profits have different expected values, however, this arrangement would be a bad deal for the player with the higher expected value. I assume that the players find a better solution. In the Appendix A, I show that if the transfer is linear in the difference of the realized profits, i.e. θ takes the form

$$\theta(x, y) = \frac{y - x}{\alpha} + k$$

for some α and k, then the optimal sharing rule is

$$\theta(x, y) = \frac{y - x}{2} - \frac{E(y) - E(x)}{2}.$$

If player X's profits can be perfectly observed by player Y then

$$E(y - \theta(x, y)) = E\left(\frac{y + x}{2} + \frac{E(y) - E(x)}{2}\right) = \frac{E(y) + E(x)}{2} + \frac{E(y) - E(x)}{2} = E(y)$$

and

$$Var(y - \theta(x, y)) = Var\left(\frac{y + x}{2}\right) = \frac{1}{4}\left(\sigma_y^2 + \sigma_x^2\right) = \frac{1}{2}Var(y). \qquad (5)$$

Similarly for player X. Specifically comparing the old and the new technologies,

$$\begin{aligned} E(y - \theta(x^o, y)) &= E(y - \theta(x^n, y)) \\ Var(y - \theta(x^o, y)) &= Var(y - \theta(x^n, y)) \end{aligned}$$

So player Y is indifferent between the two technologies, while

$$\begin{aligned} E(x^n + \theta(x^n, y)) &> E(x^o + \theta(x^o, y)) \\ Var(x^n + \theta(x^n, y)) &= Var(x^o + \theta(x^o, y)) \end{aligned}$$

so player X strictly prefers to adopt the new technology and continue risk sharing.

Now, what happens if there is an information problem? What if the community cannot accurately determine the profits of player X? Assume that there is some "noise" on player Y's assessment of player X's profit, if and only if X adopts the new technology. Specifically, assume that x^a is a random variable distributed with parameters (x^n, σ_a), where $\sigma_a^2 = Var(x^a | x^n)$ is the amount of uncertainty around the assessment. I assume that $\sigma_a^2 \le \sigma_n^2$. Note that

$$E(x^a) = E[E(x^a | x^n)] = E(x^n)$$

and

$$Var(x^a) = E[Var(x^a | x^n)] + Var[E(x^a | x^n)] = \sigma_a^2 + \sigma_n^2.$$

The sharing rule θ will now have to be a function of y and x^a. If the players continue to use the same sharing rule $\theta(x^a, y) = \frac{y - x^a}{2} - \frac{E(y) - E(x)}{2}$ then player Y's expected value and variance will be

$$\begin{aligned} E(y - \theta(x^a, y)) &= E(y) \\ Var(y - \theta(x^a, y)) &= \frac{1}{4}\left(\sigma_y^2 + \sigma_n^2 + \sigma_a^2\right) \end{aligned} \quad (6)$$

Note that the variance in (6) above is less than the variance without the risk sharing, but is greater than the variance under the old technology in equation (5). Player X's values are

$$\begin{aligned} E(x^n + \theta(x^a, y)) &= E(x^n) > E(x^o) \\ Var(x^n + \theta(x^a, y)) &= \frac{1}{4}\left(\sigma_y^2 + \sigma_n^2 + \sigma_a^2\right) > Var(x^o + \theta(x^o, y)) \end{aligned} \quad (7)$$

So, while the expected value for player X is higher under the new technology, so is the variance. It is interesting to note that the variance in player X's profit is higher under the new technology, even though the technologies themselves have identical variances when they stand alone. The presence of community risk sharing and information problems increase the risk to the farmer above the purely technical risk presented by the technology. An extension agent that did not consider the above would underestimate the amount of risk presented by the new technology.

Player X may or may not prefer the new technology given the above, depending on his actual utility function. Player Y, however, is clearly worse off. If the bargaining power lies with player Y, he could demand a transfer payment to make him as well off as he was before. In this case player X's expected value would be eroded, perhaps enough for him to decide not to adopt. Specifically, player Y's reservation price would be equal to his benefit under the old technology. Player X would have to make a transfer payment to player Y equal to

$$Eu\left(\frac{x^o + y}{2}\right) - Eu\left(\frac{x^a + y}{2} - \frac{E(x^n) - E(y)}{2}\right)$$

and X will adopt if and only if

$$Eu\left(x^n + \frac{y - x^a}{2} + \frac{E(x^n) - E(y)}{2}\right) + Eu\left(\frac{x^a + y}{2} - \frac{E(x^n) - E(y)}{2}\right) \geq 2Eu\left(\frac{x^o + y}{2}\right).$$

The higher σ_a, the more likely that player X will not adopt the new technology. Similarly, the smaller the increase in the expected value of the profit of the new technology or the more risk averse the players are, the more likely that player X will not adopt. Hence, a technology that to outsiders is clearly superior — having the same risk structure but a higher expected value — could quite rationally be rejected by an individual.

Finally, the above problem would be exacerbated if the community has a more optimistic prior for the new technology than the adopter does. If x^a is distributed around a mean greater than x^n, then entering into risk sharing will reduce the adopters expected value.

7 Testable hypotheses

What predictions can be gleaned by examining this institutional arrangement? We would expect to see inertia in technology diffusion in regions where there is no old age insurance. We would further expect that new technologies would be more likely to be adopted by younger families, and less likely by multigenerational families. We would expect technologies to diffuse better if they were offered to the community as a whole rather than to a model farmer or a small select group. We would expect technologies that differed very little from the old technologies to diffuse faster, since there would be less of an information problem associated with them. We would expect the level of risk aversion to matter, even if the new technology had a similar level of risk as the old technology.

8 Conclusions

Different institutional environments help to explain different rates and levels of technology diffusion. Informal insurance schemes in Africa that arose during a time of stagnant technology inadvertently undermine modern technology diffusion. Many failed attempts have been made to transfer new technology to Africa. The failure of those attempts can be largely attributed to a lack of understanding of the particular institutional environment into which the technology was to be transferred. A better understanding of indiginous institutions - both formal and informal - will allow new institutions to be developed that can aid the diffusion of technology and therefore spur economic growth. In Africa, institutions that can smooth consumption without reducing production incentives are crucial to developing the economy.

A Optimal Risk Sharing

Assume that the objective of the risk sharing is to minimize the variance of the profits while holding the expected value constant. Assume that the transfer payment from player Y to player X is a linear function of the difference between profit y and profit x. Namely

$$\theta(x,y) = \frac{y-x}{\alpha} - k$$

Where α and k are constants. Since the problem is essentially symmetric it simplifies to

$$\min_{\alpha,k} Var\left(y - \frac{y-x}{\alpha} + k\right)$$

$$s.t.\ E\left(y - \frac{y-x}{\alpha} + k\right) = E(y)$$

Note that

$$E\left(y - \frac{y-x}{\alpha} + k\right) = \frac{\alpha-1}{\alpha}E(y) + \frac{1}{\alpha}E(x) + k$$

Set this equal to the expected value of y and solve for k.

$$k = \frac{1}{\alpha}\left[E(y) - E(x)\right]$$

Now,

$$Var\left(y - \frac{y-x}{\alpha} + \frac{E(y)-E(x)}{\alpha}\right) = Var\left(\frac{\alpha-1}{\alpha}y + \frac{1}{\alpha}x\right) =$$

$$\left(\frac{\alpha-1}{\alpha}\right)^2 Var(y) + \frac{1}{\alpha^2}Var(x) = \left[\frac{(\alpha-1)^2}{\alpha^2} + \frac{1}{\alpha^2}\right] Var(y)$$

since the variance of y is assumed to equal the variance of x, and x and y are independent. So the problem reduces to

$$\min_{\alpha} \frac{\alpha^2 - 2\alpha + 2}{\alpha^2}$$

which is solved at $\alpha = 2$. Therefore the optimal risk sharing rule is

$$\theta(x, y) = \frac{y - x}{2} - \frac{E(y) - E(x)}{2}$$

where Y pays the amount θ to X, if $\theta > 0$, and X pays the amount $-\theta$ to Y otherwise.