Institutional Barriers to Technology Diffusion in Rural Africa*

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Abstract

This paper analyzes the connection between informal insurance institutions in rural Africa and the adoption of new technologies. We model two linked games – a community risk-sharing game and an old-age insurance game – and analyze the multiple equilibria that arise. We provide a numerical example that indicates that informal insurance institutions may put a downward pressure on the adoption of new technologies.

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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 first realization of an idea), innovation (the first bringing of an invention to the market place), and diffusion (the spread of the innovation through the market place). Technical change becomes economically important through diffusion. Looking at rural Africa's lack of robust economic growth and dearth of modern technology, it appears that technology diffusion has failed there. I propose that this failure is partly due to institutional barriers to technology diffusion 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 diffusion of a profitable, low-risk agricultural technology.

The rest of the paper is organized as follows. In the next section, I discuss the importance of technical change and review some of the current theories on technology diffusion and institutions. In sections 3 and 4, I give the background and motivation for the two linked games that I present in section 5. In section 6, I discuss the equilibria of the linked games, and conclude with a discussion in Section 7.

2 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 neoclassical 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 first (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 1991**?**, Grossman and Helpman 1991**?**) expand on the models to consider the effects 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 specific good "embedded in organizational structures (such as) firms, networks, or institutions." Therefore these theorists (including Nelson, Winter, and Dosi for example) believe that differences in technology are the key to differences in economic growth. Abromovitz 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 benefit 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 affects productivity growth and that productivity growth affects economic growth.

Economic growth, however, is not the only reason for interest in technology diffusion. The rising interest in environmental issues has also spurred interest in the diffusion 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 inefficient and pollution-intensive forms of energy. The diffusion of clean and efficient energy sources to the developing world will have a pay-off not only for the recipient countries but also for the world as a whole.

2.1 Technology Diffusion

I concentrate on technology diffusion because 1) it is through diffusion that technical change becomes economically and environmentally important and 2) it is through diffusion that LDCs can take advantage of the existing technology gap. Diffusion theory can be divided into three frameworks. The most common approach is built around information and uncertainty, and is typified by Mansfield (1968)**?**. He argues that the speed of adoption is directly related to the profitability of the new technology, and inversely related to the capital outlay, the initial uncertainty regarding the profitability, 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 offered 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 firms (or consumers) as being ranked in order of the benefits they will get from adopting a new technology. As the price of a new technology falls, more firms (or consumers) will gain a positive benefit from adopting it, and therefore it will diffuse. There is evidence that factors such as firm 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.

3 Technology and Informal Insurance in Africa

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 investigate 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. I consider the interaction between technology adoption and two forms of insurance: ex-post smoothing of idiosyncratic shocks through community sharing and old-age insurance.

3.1 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 (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 (1998**?**) 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.

3.2 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.

4 Linked Games as an Institution

The theory of institutions is very young and still in the midst of being defined. Institutions are commonly thought of as organizations. Douglass North (1991)**?** 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 defines institutions as "the rules of the game or, more formally the humanly devised constraints that shape human interactions." Aoki (2001)**?** argues even further, that an institution is an outcome of a game - a self-enforcing Nash equilibrium. Otherwise, difficult 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, and internal firm organization. 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, define the outcome.

What qualifies the informal insurance arrangements discussed in the previous section as institutions? They involve multiple equilibria and linked games, and are firmly rooted in specific 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 first 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 first. 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 one 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, 2001)**?**. 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.

5 The Model

5.1 Old Age Insurance Game.

There are two periods in the old-age insurance game. In the first period, both the head of household (the "father") and his son work the farm. In the second period, the father 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. Given the negative real interest rates and low incomes found in many developing countries, I assume that savings for retirement is minimal. 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 father always has one period of experience more than the son does.

The father will always prefer to hire the son in the second period 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 father 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 father and son) will be the profit earned by farming with two laborers and medium experience. The father 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 father 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 father's residual is $\pi(1, 2; t) - \pi(0, 1; t)$. Similarly, in the second period the father's residual is $\pi(2, 1; t) - \pi(1, 1; t)$. I assume constant returns to labor for both the old and new technologies: given that land is free and abundant, a second laborer simply adds a second plot of land. Thus, the father prefers to hire the son: $\pi(1, 1; t) < \pi(1, 2; t) - \pi(0, 1; t)$. Let the father's discount factor be δ, and u be the time-additive utility function. t_i $i = 0, 1$ represents the "old" or "new" technology respectively. The father's total payoff under technology i is

$$P_{Fi} = u\left[\pi\left(1,2;t_i\right) - \pi\left(0,1;t_i\right)\right] + \delta u\left[\pi\left(2,1;t_i\right) - \pi\left(1,1;t_i\right)\right] \tag{1}$$

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

$$\pi\left(e,L;t_1\right) > \pi\left(e,L;t_0\right) \tag{2}$$

but that it erodes the father's experience advantage:

$$\pi\left(e+1,L;t_1\right) - \pi\left(e,L;t_1\right) < \pi\left(e+1,L;t_0\right) - \pi\left(e,L;t_0\right) \tag{3}$$

The idea is that this experience is gained over time: it is valuable precisely because the technology does not change. 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 $\pi\left(0,1;t_1\right)$ and $\pi\left(1,1;t_1\right)$. The father, on the other hand, may be worse off. In particular, if there is little or no savings and the intertemporal elasticity of substitution is low, then the father will categorically prefer the old technology to the new.

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 much of the benefit of a new technology.

5.2 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 one farm were growing a new hybrid or a new crop, the other 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 risk sharing with n players. Each player's profits are independent random variables P_i, with mean $\bar{P}_i$ and standard deviation σ. After risk-sharing Player i receives a total profit of

$$\frac{1}{n}\sum_{j}\left(P_j - \bar{P}_j\right) + \bar{P}_i \tag{4}$$

Risk sharing is fair and efficient: it does not impact each player's expected value; and each players variance is reduced to $\frac{\sigma^2}{n}$. This is equivalent to the optimal transfer in Coate and Ravallion (1993).

For expository purposes, I assume that profits under the new technology have the same distribution as under the old technology, only shifted to the right. This assumption strongly favors the adoption of the new technology. In the numerical example below, I use a more realistic assumption that the coefficient of variation (CV) stays constant across technologies.

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 technologies are mutually exclusive.

What happens if there is an information problem? What if the community cannot accurately determine the profits of an adopter? Assume that there is some "noise" on the community's assessment of the adopter's profit. Specifically, assume that z is a random variable distributed with mean and variance $(0, \sigma_a)$, where σ_a is the amount of uncertainty around the assessment. If one person adopts and the community continues with the same sharing rule, then each members variance after sharing is

$$\operatorname{var}\left[\frac{1}{n}\left[\sum_{j\neq a}\left(P_j-\bar{P}_j\right)+\left(P_a+z-\bar{P}_a\right)\right]+\bar{P}_i\right] \tag{5}$$

$$=\frac{1}{n^2}\left[(n-1)\,\sigma^2+\sigma^2+\sigma_a^2\right]=\frac{\sigma^2}{n}+\frac{\sigma_a^2}{n^2} \tag{6}$$

In order to consider the case of m adopters, I must make an assumption about how the amount of noise experienced by the community changes as the number of adopters changes. I assume that the noise increases linearly until half the community adopts, and then decreases linearly. Thus, given $m \leq \frac{n}{2}$ adopters, each player's variance is

$$\frac{\sigma^2}{n}+m\frac{\sigma_a^2}{n^2} \tag{7}$$

The variance in (7) above is greater than the variance under the old technology, $\frac{\sigma^2}{n}$. Thus, adoption of a new technology increases risk, even when the technologies themselves have identical variances when they stand alone. An extension agent that did not recognize this would underestimate the amount of risk presented by a new technology. The adopter is getting more expected value in return for the greater variance, but the community is strictly worse off.

I assume that the adoption of a new technology by a subset of the community leads to one of two outcomes: the community continues to share as before, accepting the added risk; or the community chooses not to share with the adopters. The community will compare the variance with and without sharing. If the community chooses not to share with the m adopters then each non-adopter's total variance will be $\frac{\sigma^2}{n-m}$.

6 Equilibria of combined games

To explicitly link the games I assume that each father and his son share risk in the same way as the community in general, and that when they work together, they farm twice as much land, thus their risk is reduced.

The equilibria depend on how the game is structured. I consider three alternate structures. In Structure I, I formulate a three-stage game as follows: first, each son decides simultaneously whether to adopt or not; second, each father decides; third, the community decides whether to risk share or not. In Structure II, I reverse the order of the first two stages: each father decides simultaneously, then the sons decide. Again, the community decides whether to risk share in the third stage. Finally, in Structure III, all members of the community decide simultaneously whether to adopt or not in the first stage, followed by the community risk-sharing decision. Figure 1

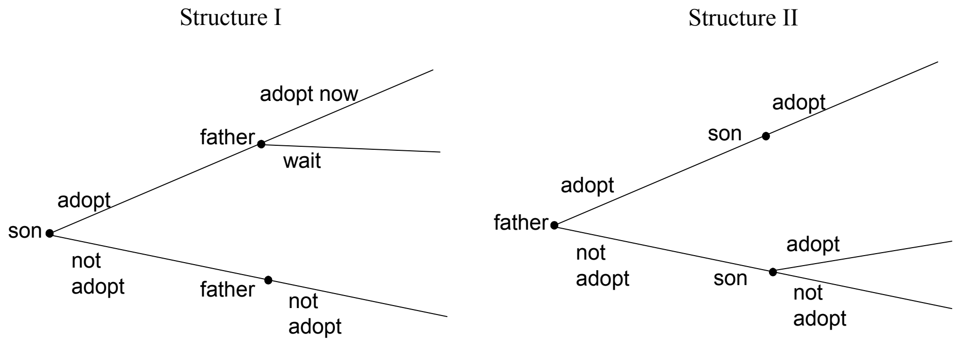

Figure 1: The father-son subgame, under two different assumptions about the structure of the game.

illustrates the extensive form representation of the subgame played by a particular father-son pair under Structures I and II. Note that I am assuming that the father will never adopt unless the son does; and the son will adopt if the father does.

I analyze three possible equilibria – a no-adoption equilibrium; a full-adoption equilibrium; and a blocking equilibrium. In order to check the no-adoption equilibrium in each of the three game structures I need to determine under what conditions a) the father will refuse to adopt, given that the son has adopted; and under what conditions b) the son adopts, given that the father has not adopted. These two conditions define the equilibrium in all three structures.

In the third stage, given m adopters, the community will share if $\frac{\sigma^2}{n-m} > \frac{\sigma^2}{n} + m\frac{\sigma_a^2}{n^2}$. The community will choose not to share if $\sigma_a^2 \geq \frac{n}{n-m}\sigma^2$. I assume this condition is satisfied for $m \leq \frac{n}{2}$.

To make the discussion concrete, I assume that each farmer has an exponential utility function, $u(x) = 1 - e^{-\zeta x}$ that satisfies the expected utility property, and that all profits are distributed normally. I can then use the simplification that the certain equivalent (CE) of a normal random variable with mean μ and variance σ^2 is equal to $\mu - \frac{\zeta\sigma^2}{2}$. The expected utility of x is greater than the expected utility of y if and only if the CE of x is greater than the CE of y. Thus I will work in certain equivalents. Additionally, I will assume that consumption in the two periods are perfect substitutes[1]. In the numerical example, I consider the impact of the elasticity of substitution across time.

6.1 No-adoption equilibrium

6.1.1 Father's Decision

Consider the father's decision, assuming that the son adopts. The father must work with the son in the second period in order to have any income. So, the father must adopt in the second period. His decision is whether to adopt now or wait until the second period. The father may choose not to adopt if the gains from risk sharing with the community outweigh the gains from the new technology. If the father adopts now his CE is

$$\bar{P}_{F1} - (1+\delta)\frac{\zeta\sigma^2}{4} \tag{8}$$

where the bar over the random variable indicates the expected value. If he waits and adopts next period

$$\text{CE} = \bar{\pi}(1,1;t_0) + \delta\left[\bar{\pi}(2,1;t_1) - \bar{\pi}(1,1;t_1)\right] - \frac{\zeta\sigma^2}{2(n-1)} - \delta\frac{\zeta\sigma^2}{4} \tag{9}$$

[1] That is that the time-additive utility function $u(c) = c$. This has no impact on the father's decision, since his utility is the same in the second period whether he waits or adopts now. This assumptions makes the son more likely to choose adoption.

The father will refuse to adopt if and only if (8) $\leq$ (9). Rearranging the terms, the condition for non-adoption can be written as follows:

$$\frac{\zeta(n-3)}{4(n-1)}\sigma^2 \geq [\bar{\pi}(1,2;t_1) - \bar{\pi}(0,1;t_1)] - \bar{\pi}(1,1;t_0) \tag{10}$$

On the right-hand side is the father's gain from adopting in the first period, *given* that his son has adopted. This is always positive since

$$\bar{\pi}(1,2;t_1) - \bar{\pi}(0,1;t_1) = 2\bar{\pi}(1,1;t_1) - \bar{\pi}(0,1;t_1) \geq \bar{\pi}(1,1;t_1) > \bar{\pi}(1,1;t_0) \tag{11}$$

On the left hand side of (10) are the risk-sharing gains from *not adopting*. Thus the father will refuse to adopt when the value of risk sharing is high (high riskiness, large community, high risk aversion) compared to the benefit from the new technology.

6.1.2 Son's Decision

Define the expected payoff for sons in a similar manner to (1):

$$P_{Si} \equiv \pi(0,1;t_i) + \delta\pi(1,1;t_i) \tag{12}$$

Assume that the father waits to adopt and consider the son's decision. The son's CE if he adopts is

$$\bar{P}_{S1} - \frac{\zeta\sigma^2}{2} - \delta\frac{\zeta\sigma^2}{4} \tag{13}$$

So the son adopts if and only if

$$\bar{P}_{S1} - \frac{\zeta\sigma^2}{2} - \delta\frac{\zeta\sigma^2}{4} \geq \bar{P}_{S0} - (1+\delta)\frac{\zeta}{2n}\sigma^2 \tag{14}$$

The son chooses not to adopt if

$$\sigma^2 \geq \frac{4n}{\zeta\left(n\left[2+\delta\right] - 2\left[1+\delta\right]\right)}\left\{\bar{P}_{S1} - \bar{P}_{S0}\right\} \tag{15}$$

Again, it is more likely that the son will choose not to adopt when the value of risk sharing is high compared to the benefit from the new technology.

6.1.3 Equilibrium Conditions for No-Adoption

To analyze when no-adoption is an equilibrium, assume that all other families have chosen not to adopt, and focus on the sub-game between one son and one father. Under Structure I, where the son makes the adoption decision in the first stage, *no adoption* is a unique sub-game perfect equilibrium (of the father-son subgame) only if both conditions (10) and (15) are satisfied. This is because the father's threat to not adopt must be credible. Under Structure II, on the other hand, where the father makes the adoption decision in the first stage, only the son's condition (15) must be satisfied for *no adoption* to be a unique sub-game perfect equilibrium. Finally, under Structure III, where the decisions are simultaneous, *no adoption* is a unique equilibrium if (10) and (15) are both satisfied; and *adoption* is a unique equilibrium if neither (10) nor (15) are satisfied. If the son's condition (15) is satisfied, but the fathers condition (10) is not satisfied, then both *adoption* and *no-adoption* are equilibria in the father-son subgame.

Thus, I have shown that it may be an equilibrium for a clearly superior, stochastically dominant technology to be not adopted. The non-adoption equilibrium becomes more likely as the noise σ_a, increases, as risk aversion increases, when the community is large, and when the benefit from the new technology is small. In Section 7 I provide an empirical example.

6.2 Full adoption equilibrium

Assume all families but one are adopting. In this case, the single non-adopting family will choose to risk share with the adopters. Thus the son is always better off adopting, regardless of the father's action. And given that the son will adopt, the father is better off adopting too. Full adoption is always an equilibrium.

6.3 Blocking Equilibrium.

Consider a game where the factions in the community attempt to coordinate. A blocking equilibrium is where the fathers, by coordinating against adoption, can block the sons from coordinating for adoption. In game structure I, where sons adopt first, blocking is never an equilibrium. The fathers cannot credibly threaten to not-adopt, given that all the sons have. This is because a father's variance in the first period if he doesn't adopt is $\frac{\sigma^2}{n/2}$; if he does adopt it is $\frac{\sigma^2}{n/2+1}$. Thus, each individual father has an incentive to adopt immediately. The fathers cannot credibly block adoption under the assumptions of this game. If the sons coordinate they can successfully adopt the new technology.

In game structure II, I need to check when it is optimal for the sons not to adopt as a group, given that the fathers have not adopted. If the sons do not adopt then their first period variance is

$\frac{\sigma^2}{n}$; if they adopt their first period variance is $\frac{\sigma^2}{n/2}$. Thus the sons may be blocked from adopting if

$$\bar{P}_{S1} - \bar{P}_{S0} \leq \frac{\zeta}{2n}\sigma^2 \tag{16}$$

Thus, blocking is an equilibrium in this game, but requires a rather large underlying risk, σ.

In game structure III, all the fathers are one player, and all the sons are the other player. When they decide simultaneously then *adoption* is the unique equilibrium if (16) is not satisfied; both *adoption* and *no-adoption* are equilibria if (16) is satisfied.

7 Numerical Example

In Section 6, I show that non-adoption is an equilibrium under certain conditions. In this section I consider a numerical example based on evidence from the development literature. In the above analytical work I assumed that the variance was the same for the new and old technology. A more realistic assumption is that the coefficient of variation, ν, (the standard deviation divided by the mean) is the same across all technologies (See Anderson and Hazell 1989, 1994**??**). Thus, I assume that each player's standard deviation $\sigma_i = \nu \bar{P}_i$. For risk sharing to be fair and efficient we need to change the formula. Let each player i receive

$$\frac{\bar{P}_i}{\sum_{j=1}^{n} \bar{P}_j} \sum_{j=1}^{n} P_j \tag{17}$$

Then each player's expected value is the same with and without risk sharing, and each player's variance after sharing is fraction of his variance before sharing:

$$\sigma_i^2 \frac{\sum_{j=1}^n \bar{P}_j^2}{\left(\sum_{j=1}^n \bar{P}_j\right)^2} \tag{18}$$

If there are $m \leq \frac{n}{2}$ adopters, noise increases linearly, and the sharing rule stays the same, then each players variance is increased by

$$\frac{m^2 \bar{P}_i^2}{\left(\sum_{j=1}^n \bar{P}_j\right)^2} \sigma_a^2 \tag{19}$$

Assume that the base technology has a profit of \$500 given one unit of experience and \$400 given zero units. I consider a *small* innovation, that leads to profits of \$550 and \$480, respectively, and a *large* innovation that leads to profits of \$800 and \$750 respectively. The first question is how large the "noise" needs to be for the community to refuse to share with the adopters. For a small innovation, the noise would have to be between 20% and 30% larger than the underlying risk, that is $\sigma_a \approx 1.2\sigma$. For a large innovation, the noise only need be about equal to the underlying risk. These numbers imply that the community must perceive a rather large risk when one member of the community adopts a new technology. As I have modeled the game, the noise σ_a is purely technical – it results from not understanding the new technology. But the introduction of such noise poses a new risk to the community: the adopter may shirk, knowing that the community doesn't understand the costs and requirements of the new technology. This fear may be enough for the community to refuse to share risk with the adopter of a new technology.

The parameters that impact the father's decision to adopt are the riskiness of the technology (as represented by ν), the level of risk aversion, and the size of the community. Evidence from Turkey (Binici et al., 2003**?**) implies that the risk aversion coefficient for small-holder farmers, assuming an exponential utility, is around .1 over a range from \$0 to \$30,000. The range of incomes in this paper are between \$0 to \$800, so for the central case I use a risk aversion coefficient, ζ, approximately equal to $.1 * \frac{400}{15{,}000} \approx .0025$. This level of risk aversion implies that a farmer is indifferent between Normal distributions with the following means and standard deviations: $N(500, 300) \sim N(550, 360) \sim N(800, 574)$. I also consider $\zeta = .01, .005$, and $.001$. The discount factor has a very small impact – the results are very similar when $\delta = 0$ and $\delta = 1$. These two values also represent the extreme assumptions of no substitution across periods and perfect substitution across periods.

Table 1 shows the smallest coefficient of variation (CV) that satisfies conditions analogous to (10) and (15). For example, if the father is medium risk averse ($\zeta = .0025$) and in a risk-sharing community with 30 farmers, then he will refuse to adopt a small innovation if the coefficient of variation for idiosyncratic risk is greater than .72. The same farmer will refuse to adopt a large innovation if the CV is greater than .89. By contrast, a son with $\zeta = .0025$ and in a risk sharing group of 30 will refuse to adopt the small innovation if the CV is greater than .53, and will refuse to adopt the large innovation if the CV is greater than .71. From our numerical examples it appears that the father's condition is more stringent than the sons – if the father can credibly threaten to refuse adoption, then the son will also refuse adoption.

To put these numbers in perspective, Walker (1989**?**) finds that the mean CV for grain yields for individual households in three villages in India range from .44 for cotton, to .69 for sorghum. I have not found any evidence on individual-level risk in sub-saharan Africa. Elamin and Rogers

	$\zeta = .01$		$\zeta = .005$		$\zeta = .0025$		$\zeta = .001$	
Father	$n = 6$	$n = 30$	$n = 6$	$n = 30$	$n = 6$	$n = 30$	$n = 6$	$n = 30$
small innovation	.41	.36	.58	.51	.82	.72	1.3	1.1
large innovation	.47	.44	.67	.63	.95	.89	1.5	1.4
Son								
small innovation	.28	.27	.39	.38	.56	.53	.88	.84
large innovation	.36	.35	.5	.5	.71	.71	1.1	1.1

Table 1: The smallest CV that induces no-adoption

(1992)**?** report that the country-wide sorghum yields in the Sudan have a CV of about .3. In Hazell (1989)**?**, the country-wide CV for sorghum in South Africa and Nigeria ranged between .04 to .27, compared to India with a country-wide CV for sorghum of about .09. Thus, it seems reasonable that individual farmers in many parts of rural Africa may face a CV in the range between .5 and .7. Our conclusions are that if farmers are very risk averse ($\zeta \geq .005$), then no-adoption is a likely equilibrium regardless of the structure of the game. If risk-aversion is more moderate ($\zeta \approx .0025$), then no adoption is a possible equilibrium, as long as the sons are not committing to the adoption in the first stage. If risk aversion is very low, ($\zeta \leq .001$), it is unlikely that risk sharing will have an impact on technology adoption. While the level of risk aversion and the amount of idiosyncratic risk is an open empirical question, it appears that community risk sharing may put downward pressure on the adoption of new technology.

8 Discussion

In Section 6, I show that there are at least two equilibria of the technology adoption game – no adoption and full adoption. I show additionally, that depending on the structure of the game, the older generation may credibly block adoption, even if the younger generation coordinates.

Moreover, I only specifically model two inter-related games. It is likely that the institutional structure of rural communities in Africa consist of a number of interrelated games. Some examples are the relationship between farmers and the "Market women" who sell their produce, relationships based on non-farm employment, and relationships that underpin community conflict resolution. A strong preference by the elder generation against adopting a new technology may be enough to choose the non-adoption equilibria over the adoption equilibria. Extension efforts may not help the situation, by focussing on model farmers, rather than community acceptance and understanding of a new technology.

I can make some initial predictions from examining this institutional arrangement. I would expect to see inertia in technology diffusion in regions where there is no old age insurance and where land is abundant, or individual property rights are not strong; that new technologies would be more likely to be adopted by younger families, and less likely by multigenerational families; that technologies would diffuse better if they were offered to the community as a whole rather than to a model farmer or a small select group; that technologies that differed very little from the old technologies would diffuse faster, since there would be less of an information problem associated with them; and that the level of risk aversion would matter, even if the new technology had a similar level of risk as the old technology.

Different institutional environments may help to explain different rates and levels of technology diffusion. Informal insurance schemes in Africa that arose during a time of stagnant technology may inadvertently undermine modern technology diffusion. Many failed attempts have been made to transfer new technology to Africa. The failure of these attempts may be attributed to a lack of understanding of the particular institutional environment into which the technology was to be transferred. A better understanding of indigenous 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.