United Nations University

WIDER

World Institute for Development Economics Research

Research Paper No. 2005/41

The Role of Information in Technology Adoption under Poverty

Jinhua Zhao*

June 2005

Abstract

An important channel through which globalization affects poverty is introducing new technologies to developing countries. Adoption of new technologies can be hindered by uncertainties about their efficiency. This paper studies the role of information exchange between adopters and others about a new technology and about each other's likelihood of adoption. We show that information about the technology can reduce adoption at the beginning of the diffusion process and increase adoption later. Information about each other increases adoption at the beginning and reduces adoption later on. We also discuss ways to promote adoption, including initial information provision, timing communication about the technology and about each farmer, and compensating early adopters for their information services.

Keywords: ICT, diffusion, globalization, econometric methods

JEL classification: O33, C11, I32

* Department of Economics, Iowa State University, Ames, IA; email: jzhao@iastate.edu

This is a revised version of the paper originally prepared for the UNU-WIDER project meeting on The Impact of Globalization on the World's Poor, directed by Professors Machiko Nissanke and Erik Thorbecke, and held in Helsinki, 29-30 October 2004.

UNU-WIDER acknowledges the financial contributions to its research programme by the governments of Denmark (Royal Ministry of Foreign Affairs), Finland (Ministry for Foreign Affairs), Norway (Royal Ministry of Foreign Affairs), Sweden (Swedish International Development Cooperation Agency—Sida) and the United Kingdom (Department for International Development).

ISSN 1810-2611 ISBN 92-9190-722-7 (internet version)

Acknowledgement

I thank participants of the UNU-WIDER project meeting on 'The Impact of Globalization on the World's Poor', 29-30 October 2004, Helsinki.

UNU World Institute for Development Economics Research (UNU-WIDER)
Katajanokanlaituri 6 B, 00160 Helsinki, Finland

1 Introduction

One of the major approaches to reducing the world's poverty is to promote the adoption and diffusion of new technologies in less developed regions. Green Revolution, by introducing new seeds and intensive agriculture, helped millions of people out of poverty. Efficient irrigation systems such as sprinkler and drip irrigation not only improve productivity but also help preserve scarce water resource. Biotechnologies and genetically modified foods could potentially significantly increase food production in developing countries. Globalization has the potential of making new technologies available to developing countries. However, it is the adoption and diffusion that eventually determine whether developing countries can truly benefit from the new technologies brought to them through the globalization process.

Technology adoption and diffusion face two main obstacles in developing regions: the lack of capital, credit and risk-sharing, and the lack of information. A new technology may require sizable sunk investment, and adopting it could be a risky business. Facing limited financial resource and risk sharing, agents would be reluctant to adopt "profitable" technologies if there is a chance that the technologies fail since the sunk adoption costs cannot be recouped. Compounding the problem is the limited access to information about new technologies: regions under poverty often do not have well-functioning extension services by universities or the government. As a result, farmers may at first be extremely uncertain about the profitability of the new technologies.

Without rich external information sources, farmers in developing countries rely heavily on their neighbors who have already adopted the technologies to obtain such information. The diffusion of new technologies in this case is rather typical: one or few of "leaders" adopt a new technology. As the advantage of the new technology is demonstrated by the success of the early adopters, other local villagers start to follow the suit. The resulting diffusion path is typically logistic, and full adoption occurs gradually.

In a sense, early adopters provide an information service, a positive externality, to their neighbors. They are the ones who face the initial adoption risk when information is extremely limited. If they fail, they will bear the sunk cost. If they succeed, others will benefit. In many cases, a new technology does not get adopted or diffused either because there are no or too few such early adopters, or because these adopters hit a string of bad luck and fail to demonstrate the advantage of the new technology.

In this paper, we study the role of information and communication in the adoption and diffusion of a new technology in a community of farmers under poverty. The community has a fixed number of farmers, currently all using a traditional technology. A new technology is introduced, the profitability of which is uncertain. Farmers have different adoption costs due possibly to their different degrees of risk aversion, and a farmer's adoption cost is his private information. All farmers in the village share the same initial beliefs about the profitability of the new technology. When a farmer adopts the technology, others imperfectly observe the performance of the new technology, and thus obtain more (but possibly imperfect) information about the profitability. Depending on how closely farmers communicate and the nature of the new technology, adopters may release different degrees of information about the performance of the new technology.

We study the adoption game in the village where each farmer decides when to adopt the new technology. Since farmers can learn about the new technology from early adopters, each farmer has incentive to wait for others to adopt first. That is, each has the incentive to strategically delay his adoption. Of course, early adoption has the advantage of reaping the benefits of a successful new technology at an early time. In the (unique) perfect Bayesian equilibrium, farmers expect that those with lower adoption costs will adopt first. However, since the adoption costs are private information, the adoption process may temporarily stop when farmers gradually work up their knowledge about who should be the next to adopt.

We use this model to study three approaches to helping promote the adoption and diffusion of new technologies: extension service, communication among villagers, and institutions that compensate early adopters for their information service. Extension service, by providing initial information about the new technology, clearly helps promote early adoption and faster diffusion. Further, it also helps reduce the incentives of farmers to strategically delay their adoption decisions.

In our model, there are two kinds of communication among villagers: communication about each other's adoption costs, and communication about the profitability of the new technology. We show that both types of communications may or may not enhance adoption and diffusion, depending on when they occur. For example, although communication about technology helps disseminate information about the new technology, it also causes farmers to delay adoption in anticipation of such information in the future. If few farmers have adopted, the delay effect dominates and better communication can slow down the adoption. If, on the other hand, a lot of farmers have already adopted the technology, the effect of information about the technology dominates, and better communication promotes adoption.

Our paper is related to the literature on the role of information exchange among agents in technology adoption and diffusion. The empirical literature started with agricultural technologies (Case (1992), Foster and Rosenzweig (1995), and Besley and Case (1993, 1997)) and has expanded to medical drugs (Berndt, Pindyck and Azoulay (1999)) and computers (Goolsbee and Klenow (1999)). Relying mostly on micro-level data, these studies consistently find significant neighbor influences. That is, rational profit-maximizing agents do respond to information released by other adopters. Further, using a structural estimation model, Besley and Case (1997) found that agents also anticipate and actively respond to future information from other adopters: They tend to strategically delay adoption to wait for other adopters' information. They found that a model with the forward-looking behavior performs better than one with the agents passively responding to existing information.

Our paper is also related to the information cascade literature (Banerjee (1992), Bikhchandani, Hirshleifer and Welch (1992) Choi (1997), Zhang (1997), Caplin and Leahy (1998) and Chamley and Gale (1994)). However, different from that literature, in our model the agent does not have private signals about the technology. Thus his adoption (or nonadoption) decision in itself does not reveal any information about the technology.

The paper is organized as follows. Following Zhao (2005), we describe the adoption game and possible diffusion patterns in Section 2. Section 3 shows the approaches that could promote adoption and diffusion of new technologies in developing countries. We discuss the impacts of new technologies on poverty in Section 4, and conclude the paper in Section 5.

2 The Adoption Model

We sketch the adoption model in this section; the details are in Zhao (2005). Consider a village of N farmers, which each farmer being a single decision maker. The farmers are similar in several aspects: they are under poverty with limited access to credit markets, and they are currently using the same farming technology, termed traditional technology. As the economy opens up, a new technology is introduced that has the potential of directly increasing farm income. However, the new technology also introduces uncertainty and the possibility of a loss. Specifically, adopting the new technology requires a sunk cost that could be a significant financial liability for a farmer under poverty. The profitability of the new technology is uncertain, with a strictly positive probability that the added income from the new technology cannot fully compensate the adoption cost.

The sunk adoption cost could be different for different farmers, depending on their degrees of risk aversion, financial resources, abilities and familiarity with operating new technologies, and the technology's fit to their needs. For example, farmers with off-farm income may have higher abilities to bear the uncertainty, and those with higher education levels or more experiences with similar technologies will incur lower adoption costs. We call the idiosyncratic part of the adoption cost each farmer's type, which is his private information. Others only have imperfect information about this type.

Formally, without loss of generality, we normalize the profit of the traditional technology to zero. Farmers have the same imperfect initial information about the new technology's constant per period profit e, knowing that it is distributed non-atomically according to $F_0(\cdot)$ on $[e_l, e_h]$ with $e_l > 0$. The sunk adoption cost of farmer n is $c_n = \theta_n c$, where θ_n is the farmer's type and $c > 0$. Other farmers in the village do not know θ_n for sure, knowing only that it is non-atomatically distributed according to $G_0(\cdot)$ on $\Theta \equiv [\underline{\theta}, 1]$ with $\underline{\theta} > 0$. Such beliefs are i.i.d. across the farmers.

Since $e_l > 0$ and the adoption cost is sunk, the adoption is irreversible. That is, new technology users will never abandon it in favor of the traditional technology, even if the new technology performs less than expected and results in a net adoption loss. The likelihood of a loss from the new technology clearly depends on a farmer's type: it is more likely for higher type/cost farmers. To rule out trivial cases, we assume values of parameters e_l, e_h, and $\underline{\theta}$ such that *every* farmer type faces strictly positive probabilities of adoption losses as well as of net gains. In other words, given prior information about e, every farmer could potentially gain from adopting the new technology, even for those whose types are high (close to 1), and every farmer could also lose from adoption, even for the low cost types (close to $\underline{\theta}$).

Since adoption is irreversible and incurs sunk costs, real option theory implies that farmers have incentive to obtain more information before adoption. We assume that the only information source to supplement the prior information about e is farmers who have already adopted the new technology. Suppose farmer n adopts in period t. At the end of this period, others who have not adopted, called remaining farmers or farmers, will observe the performance of the new technology, e.g., the crop yield or hte adopter's realized profit. The performance depends on both the technology's efficiency e and a range of random factors such as weather, farmer n's effort, etc. We let p_n denote the signal, which is a function of e and a random variable ε_n. Observing p_n, the remaining farmers update their belief about e according to Bayes rule. The updated belief becomes the starting belief about e in period

$t+1$. Clearly, the updated belief about e is more accurate when more farmers adopt and thus more signals about e are released. Under certain regularity conditions, the Bayes rule also means that when a higher p_n is observed, the remaining farmers believe that e is higher. For simplicity, we also assume that p_n is constant through time, i.e., each adopter releases information about e only once. Thus, after a farmer adopts, it releases a signal about e and is out of the adoption game.

The adoption game is then a dynamic Bayesian game, where a history consists of the adoption decisions of the farmers as well as their realized profit signals, and the players at each history consist of the remaining farmers at that point. Their actions are simply to adopt or to wait until future periods, and a farmer's strategy is a function describing his action as a function of the history and his type. The (common) starting belief about player types is given by $G_0(\cdot)$, which is subsequently updated after observing the actions of the players.

At each point in time, information about e is described entirely by the prior $F_0(\cdot)$ and the collection of signals that have been observed so far. Let I_t be a realized history in period t, which includes the collection of the observed signals up to time t. If farmer n decides to adopt in this period, his expected payoff is

$$\pi(I_t, \theta_n) = E_{e|I_t}\left(\frac{e}{r}\right) - \theta_n c, \tag{1}$$

where r is the discount rate, and the expectation of e is taken conditional on the signals in I_t.

If farmer n decides to wait, his expected payoff depends not only on his belief about e but also on his belief about the number of additional signals he expects to observe in future periods. The latter belief in turn depends on his belief about the number of adopters in future periods, or the types of the remaining farmers. If he believes that the remaining farmers are of low cost types, he would expect to receive more signals in the future than if his belief is that the remaining farmers are of high types. Let $\boldsymbol{g}_{-n}(t)$ be the density of n's belief about the types of other remaining farmers, and $\boldsymbol{s}_{-n}$ be their strategies in future periods. Then his payoff of waiting in period t is

$$
\begin{aligned}
&v(I_t, \boldsymbol{g}_{-n}(t), \boldsymbol{s}_{-n}, \theta_n) = \\
&\qquad \frac{1}{1+r} E_{I_{t+1}|I_t, \boldsymbol{g}_{-n}(t), \boldsymbol{s}_{-n}(I_t)} \max\left\{\pi(I_{t+1}, \theta_n), v(I_{t+1}, \boldsymbol{g}_{-n}(t+1), \boldsymbol{s}_{-n}, \theta_n)\right\}.
\end{aligned} \tag{2}
$$

That is, if farmer n waits in period t, he will again decide whether or not to adopt in period $t+1$, when his belief about e will be updated based on the new signals released by the new adopters in periods t, and his belief about the types will be updated based on the actions of the remaining farmers in period t.

Zhao (2005) shows that this game has a unique symmetric perfect Bayesian equilibrium (PBE). Along an equilibrium path, low cost farmers adopt first: if at any time a farmer of type θ_1 adopts, then all farmers of type $\theta \leq \theta_1$ either have already adopted or will also adopt in this period. The intuition is that waiting is beneficial only when new information about e helps avoid bad investment. Otherwise, if all possible future information suggests that the new technology should be adopted, the farmer should adopt now due to discounting. Since higher cost types face higher likelihoods of bad investment, future information is more useful to them. They are more willing to wait and less willing to adopt now.

The equilibrium strategy at time t is thus represented by a critical type, η_t^*, so that farmer types with $\theta_n \leq \eta_t^*$ will adopt and those with $\theta_n > \eta_t^*$ will wait. Of course, η_t^* is a function of history I_t, which contains information about e. Since all farmers whose types are below η_t^* have adopted at the end of period t, this equilibrium strategy becomes the starting belief in the next period: in period $t+1$, the remaining farmers all have types distributed according to $G_0(\cdot)$ conditional on $\theta > \eta_t^*$. In other words, the belief at $t+1$ is represented by a number, denoted by $\hat{\eta}_{t+1}$, which equals the equilibrium strategy in the previous period η_t^*.

At time t, given history I_t and belief about types of remaining farmers $\hat{\eta}_t$, the equilibrium strategy is $\eta_t^*(I_t, \hat{\eta}_t)$. Clearly, as the realized profit signals in I_t increase, η_t^* also rises. When remaining farmers observe higher profit signals, they are more willing to adopt (or more types will adopt). Further, when belief $\hat{\eta}_t$ rises, η_t^* also increases. When a remaining farmer believes that the other remaining farmers are of higher cost types (since $\hat{\eta}_t$ is higher), he expects that the other farmers will be less likely to adopt in this period. Consequently, fewer new profit signals about e will be generated by waiting, resulting in lower incentive for this farmer to wait, or higher incentive for him to adopt now.

The realization of a specific equilibrium path depends on the realizations of the profit signals of adopters. The distribution of the possible paths covers a range of diffusion patterns observed in the real world. For example, the adoption process may take some time to start even after the new technology is made available, and the diffusion process may temporarily stop for several periods before it resumes. The late start and temporary stops usually do not arise in other game theoretic adoption models, and is a unique feature of our approach.

To see how this can happen, consider the first period when the only available information about e is $F_0(\cdot)$. Given this information, and belief about the farmer types, an equilibrium strategy η_1^* exists, implying an agreement and expectation that farmers with types $\theta \leq \eta_1^*$ will adopt. However, given the non-atomatic belief $F_0(\cdot)$ and finite number of farmers, there is a strictly positive probability that all types of the farmers are above η_1^*. If this is indeed the case, nobody adopts and no new signal is generated about e. Then the period two game is different from the period one game in only one aspect: the belief about the types of the farmers is updated to be $G_0(\cdot)$ conditional on $\theta > \theta_1^*$. That is, $\hat{\eta}_2 = \eta_1^*$. Since the farmers are believed to be of higher costs, the incentive to wait decreases or the incentive to adopt rises. Thus the equilibrium strategy η_2^* is higher than η_1^*. If still every farmer's type is above η_2^*, the game enters period three with the belief that $\theta > \eta_2^*$, resulting yet in an even higher η_3^*. This process continues until low cost farmers start to adopt. By the same argument, the diffusion process may stop temporarily when there is no farmer type below the equilibrium strategy in a period, until the belief $\hat{\eta}_t$ works itself up so that new adopters materialize.

In our model, the diffusion process stops either when all farmers have adopted or when the last adopters release sufficiently strong negative profit signals so that in hindsight, they should not have adopted. Suppose several farmers adopt in period t, and at the end of t, extremely low profit signals are released by these adopters. In fact, these signals are so low that, based on the new information about e in I_{t+1}, some of these adopters should not have adopted: $\eta_{t+1}^*(I_{t+1}, \hat{\eta}_{t+1}) < \eta_t^*(I_t, \hat{\eta}_t)$. Since η^* is increasing in profit signals in I and $\hat{\eta}$, this inequality is possible when the new profit signals in I_{t+1} are sufficiently low. Then in period $t+1$, no farmer will adopt since everyone's type is above $\hat{\eta}_{t+1} = \eta_t^*$, which is higher than the equilibrium strategy η_{t+1}^*. Further, the belief about farmer types will not be updated in period $t+2$ since it is expected that nobody will adopt in period $t+1$. In other words, the fact that nobody adopted in $t+1$ does not bring any new information about the farmer types.

Therefore, there are two possibilities in which zero adoption can occur in a period. The farmers may have expected some low cost types but it turns out that everyone is of relatively high costs, or the new adopters hit bad luck and release strongly negative signals. The first scenario only leads to temporary stop of the diffusion process as belief about types can work itself up. The second scenario causes complete stop of the process.

The equilibrium diffusion path is also likely to demonstrate a logistic pattern, which has been documented for a range of technologies. The intuition is quite simple. In early periods, there are few profit signals due to the small number of adopters. The farmers thus have strong incentive to wait for more information, resulting in a slow adoption rate. As more farmers adopt and more signals are observed, the incentive to wait goes down and the adoption rate goes up. Eventually the adoption rate will fall again because only high cost farmers are left.

3 Promoting the Diffusion of New Technologies

The adoption model provides a useful tool to study informational approaches to promoting the adoption and diffusion of new technologies and to study the effects of globalization and poverty on the diffusion process. We discuss the implications of our model in the following three aspects.

3.1 Initial Information Provision

The adoption model shows that more starting information about a new technology will promote its adoption in two ways. First, since farmers under poverty are typically risk averse, more information reduces the risk premium part of the adoption cost. Second, over and above the risk premium effect, even when farmers are risk neutral, more starting information reduces the farmers' incentive to delay adoption in anticipation of more future information. That is, it promotes adoption by reducing farmers' strategic delay incentives.

Initial information about new technologies, especially agricultural technologies, could come from a range of sources, including extension services of universities and government agencies, marketing specialists, and private technology consultants (Sunding and Zilberman (2001)). There is well documented evidence of the importance of extension services in improving agricultural productivity (Rosegrant and Evenson (1992), Jin et al. (forthcoming)). Some developing countries such as China have widely utilized demonstration projects in providing information about new technologies.

Globalization plays a vital role in disseminating information about new technologies. As summarized in Keller (2004), over 90% of the technological explanations for an average country's productivity growth is from foreign sources. Through international trade, foreign direct investment, and interaction among persons with scientific and technological expertise, globalization helps bring new technologies from their inventors to eventual users. Our model indicates that to fully utilize the potential brought about by globalization, developing country governments should strive to enhance extension services, and establish marketing channels in order to increase information flow to the rural population.

Information service is even more important for farmers under poverty, because they are the ones who are more risk averse and who are more willing to delay adoption for more information. In other words, information services will be more efficient in promoting adoption when potential adopters have limited financial resources. A viable poverty alleviation tool, therefore, is information provision, in addition to the traditional tools such as income transfer.

3.2 Communication about New Technology and about Each Other

Since early adopters provide information service to other potential adopters, it has been argued that increased communication about new technologies helps promote adoption and diffusion. However, our game theoretic model shows that if this kind of communication becomes more effective, farmers may expect that future signals from early adopters will carry more information about the new technology. They may have more incentive to delay adoption and wait for such signals, so that increased communication about technologies could delay rather than expedite the adoption process.

Thus communication about new technologies leads to two opposing forces in the adoption process. If there are already sufficiently many adopters, more efficient communication increases the information content of their signals. Increased information helps remaining farmers make more informed decisions and will speed up adoption. Otherwise, if there are no or few adopters, the prospect of more communication will only serve to delay the adoption process. It is then important to *time* the communication about technologies to balance the two factors. For example, a mechanism may be set up in which information exchange about the new technology will be conducted only after a sufficiently high proportion of the farmers have adopted the technology.

Our model indicates that the adoption process is also affected by imperfect information about other farmers' types or their likelihood of adopting the technology. Consequently, communication about the types will also affect the adoption process. Again, timing of this kind of communication is important. Consider a technology that is gradually diffused. In early periods, only extremely low cost farmers will adopt without waiting for more profit signals. To the extent that increased communication reduces the variance of the belief about types, the probability of expecting truly low types will go down as the variance decreases. That is, more communication reduces farmers' expectation of the number of early adopters. Since waiting leads to fewer expected signals, the incentive to wait goes down and the adoption speeds up. Thus, exchanging information about each other's likelihood of adoption at the beginning of the diffusion process will speed up adoption.

However, increased communication about types may slow down adoption in the middle of the diffusion process for gradually diffused technologies. Suppose, without loss of generality, the belief is such that the types are normally distributed. As the communication reduces the variance of beliefs, the believed probability of farmers in the middle of the distribution goes up. That is, the expected number of new signals will also go up, increasing the incentive to wait and reducing the incentive to adopt now.

Therefore, it is important to distinguish between the two kinds of communication, about the technology and about each other. They may have opposite impacts on adoption, and each may have different impacts depending on the phase of the diffusion process. Simply increasing information exchange may not always speed up adoption.

3.3 Subsidizing Early Adopters

Our model shows that early adopters provide a positive information externality to other potential adopters. Lack of mechanisms for early adopters to internalize the externality leads to lower than efficient adoption rate. Thus, one approach to speed up adoption is to compensate early adopters for their information service. The efficient compensation level equals the expected gain of others from the new profit signals, which includes both the direct information value and the value from reduced strategic delay due to increased information. There are several ways in which early adopters can be compensated.

A simple mechanism is for the government to directly subsidize early adopters. For example, the government may offer cost sharing, rebates or price discounts for new technologies that are not widely adopted. The subsidy rate can be gradually reduced as the adoption rate increases, and eventually phased out. The subsidy enhances incentives of farmers to adopt now, and the fact that the subsidy rate gradually decreases reduces the incentives to wait. Such a program essentially maintains efficient information transmission from early adopters to others while overcoming the strategic delay that would be a result of the anticipation of the information exchange.

Another mechanism, especially useful for risk averse farmers, is for the government to offer and/or to subsidize technology insurance for early adopters. That is, if e turns out to be below expected and the early adopters suffer losses, the government will step in and compensate (partially or completely) for the losses. Depending on the significance of the information externality, the insurance premium could be subsidized. When there is no privately provided insurance for new technologies, which is typically the case in areas under poverty, such a government program is advantageous over a direct subsidy because it offers risk sharing service for the farmers concerned. The insurance should be offered for all adopters, although the subsidy could be gradually reduced as the rate of adoption rises.

This kind of subsidized insurance could also be offered by a village itself, where farmers pool resources together to insure early adopters. In this mechanism, potential adopters "pay" for the information service of early adopters by insuring their adoption. In essence, a community or village could be organized to pay, one way or another, for "demonstration projects" offered by early adopters. It is especially useful when governments lack fiscal resources to offer direct subsidies or subsidized insurance.

4 Impacts of Technology Adoption on Poverty

Our model shows the intuitive result that more efficient technologies (those with higher e) are adopted by more farmers and are diffused more quickly. To the extent that the new technology raises farmers' income, it also alleviates poverty, particularly in the long run and on average.

However, new technologies may not alleviate poverty for every adopter. Consider the intuitive scenario where the signals about the new technology are the realized profits of the adopters. We showed that unless the technology is adopted by every farmer, the diffusion process stops only when the last adopters regret their adoption decision: their net payoffs from adoption are negative. In other words, *unless the technology is for everybody*, which is uncommon if there is such a technology at all, *some farmers, i.e., the last adopters, will inevitably be made worse off by the new technology.* If farmers under more severe poverty are more reluctant to adopt, the order of adoption starts with wealthier farmers, followed by those with less wealth. Then the last adopters who are made worse off by the new technology could well be those who needed help the most! The new technology in fact will aggravate their poverty problem.

Our model assumes that there is no network effect: if a farmer chooses not to adopt, his payoff is not directly affected by the fact that other farmers have adopted the new technology. However, new technologies typically involve network effects, either positive or negative. For example, if the new technology increases the yield, and sufficiently large number of farmers adopt, the price of the agricultural output is likely to be pushed down as the adopters' supplies increase, thereby reducing the profit of the non-adopters. Again, if the latter adopters and non-adopters are those under more severe poverty, this kind of negative network effect will aggravate the poverty problem. Of course, some technologies have positive network effects. For example, as the number of adopters increases and the market share of the new technology rises, the price of the technology may go down. If there is learning by doing and learning from others, latter adopters may learn from the experiences of using the new technology by early adopters, increasing the profit of latter adopters. The positive network effects thus help alleviate poverty for every farmer.

Thus whether a new technology alleviates poverty depends to a large extent on the nature of the new technology. Technologies that are suitable for even the lowest income farmers help reduce poverty. Those with positive network effects also alleviate poverty even if they are adopted only by relatively wealthier farmers. However, technologies with negative network effects that are suitable only for wealthy farmers could hurt farmers under poverty.

The above discussion indicates that poverty alleviation requires much more than simply introducing new technologies. Other poverty alleviation programs are needed to compensate for the possible negative effects of new technologies, and, where new technologies do help reduce poverty, to help reduce incentives against adoption and diffusion (such as to compensate for the information externalities of early adopters).

5 Conclusion

An important channel through which globalization affects poverty is the introduction of new technologies to developing countries. Even if a new technology can improve the income of rural farmers, it may not be adopted by all and its diffusion may be slow due to sunk adoption costs and uncertainties in net payoffs of the technology. This paper studies one important factor in the adoption process: information exchange between adopters and others. In particular, early adopters release information about the technology, which other potential adopters can utilize to make a more informed decision.

We show that the information service by early adopters may either speed up or slow down the diffusion process. When there are no or few early adopters, anticipation of such information increases farmers' incentive to delay adoption to wait for more information, reducing the adoption rate. The information service helps speed up diffusion only when a sufficiently large number of farmers have already adopted the technology.

Information exchange can also be about each farmer's likelihood of adoption in the current and future periods. We showed that this kind of exchange helps improve adoption in early phases of the diffusion process, but may reduce adoption in the middle part of the diffusion process.

Our model has important implications for ways to help speed up adoption and diffusion, including providing more initial information about new technologies, timing communication about the technology and about each farmer, and compensating early adopters for their information services. Our results also indicate that unless a new technology is for everybody, it will inevitably hurt some farmers, i.e., the last adopters before the diffusion stops. Even if a new technology improves farmers' income on average, it may aggravate the poverty problem for a subset of farmers.

References

Banerjee, Abhijit V., "A Simple Model of Herd Behavior," *Quarterly Journal of Economics*, 1992, *107(3)*, 797–817.

Berndt, Ernst R., Robert S. Pindyck, and Pierre Azoulay, "Network Effects and Diffusion in Pharmaceutical Markets: Antiulcer Drugs," NBER Working Paper 7024 1999.

Besley, Timothy and Anne Case, "Modeling Technology Adoption in Developing Countries," *American Economic Review*, 1993, *83*, 396–402.

___ and ___ , "Diffusion as a Learning Process: Evidence From HYV Cotton," Working Paper, Princeton University 1997.

Bikhchandani, Sushil, David Hirshleifer, and Ivo Welch, "A Theory of Fads, Fashion, Custom, and Cultural Change as Information Cascades," *Journal of Political Economy*, 1992, *100(5)*, 992–1026.

Caplin, Andrew and John Leahy, "Miracle on Sixth Avenue: Information Externalities and Search," *Economic Journal*, 1998, *108*, 60–74.

Case, Anne, "Neighborhood Influence and Technology Change," *Regional Science and Urban Economcis*, 1992, *22*, 491–508.

Chamley, Christophe and Douglas Gale, "Information Revelation and Strategic Delay in a Model of Investment," *Econometrica*, 1994, *62(5)*, 1065–1085.

Choi, Jay Pil, "Herd Behavior, the "Penguin Effect," and the Suppression of Informational Diffusion: an Analysis of Informational Externalities and Payoff Interdependency," *RAND Journal of Economics*, 1997, *28(3)*, 407–425.

Foster, Andrew and Mark Rosenzweig, "Learning by Doing and Learning from Others: Human Capital and Technological Change in Agriculture," *Journal of Political Economy*, 1995, *103*, 1176–1209.

Goolsbee, Austan and Peter J. Klenow, "Evidence on Learning nad Network Externalities in the Diffusion of Home Computers," NBER Working Paper 7329 1999.

Jin, Songqing, Jikun Huang, Ruifa Hu, and Scott Rozelle, "The Creation and Spread of Technology and Total Factor Productivity in China's Agriculture," *American Journal of Agricultural Economics*, 2005(forthcoming).

Keller, Wolfgang, "International Technology Diffusion," *Journal of Economic Literature*, 2004, *XLII*, 752–782.

Rosegrant, M. W. and R. E. Evenson, "Agricultural Productivity and Sources of Growth in South Asia," *American Journal of Agricultural Economics*, 1992, *74*, 757–761.

Shampine, Allan, "Compensating for Information Externalities in Technology Diffusion Models," *American Journal of Agricultural Economics*, 1998, *80*, 337–346.

Sunding, David and David Zilberman, "The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector," in Bruce L. Gardner and

Gordon C. Rausser, eds., *Handbook of Agricultural Economics, Vol 1A: Agricultural Production*, Amsterdam: Elsevier, 2001.

Zhang, Jianbo, "Strategic Delay and the Onset of Investment Cascades," *RAND Journal of Economics*, 1997, *28(1)*, 188–205.

Zhao, Jinhua, "Information Externalities and Strategic Delay in Technology Adoption and Diffusion," Working Paper, Iowa State University 2005.