The Pakistan Development Review
36 : 4 Part II (Winter 1997) pp. 613—643

The Distribution of New Wheat Varieties in the Pakistan Punjab: The Role and Functioning of Institutions

MARIE-JOSÉ SMITS and WOUTER TIMS

This case study concerns the technology choice of farmers in the Pakistan Punjab with regard to wheat varieties. It argues that profitability of new crop technologies can only partly explain their adoption, as access to inputs limits the choice of farmers. In Pakistan, access to inputs is limited due to market structures and associated institutional factors.

In applied microeconomics, technology choice is commonly estimated with the use of adoption models: the (expected) profitability of prevailing and the new technologies are compared, and it is assumed that the farmers opt for the most profitable one (taking account of risk aversion and incomplete information). A simplification often made is to assume that everyone has unlimited access to all relevant goods and services. In this paper the latter assumption is tested. More specifically, the paper is concerned with the consequences of limits due to the organisational infrastructure of markets.

A so-called "bivariate probit model with partial observability" is applied in order to estimate adoption behaviour. Such a model makes it possible to distinguish two classes of explanatory variables; in this case one with variables concerning profitability and one with variables concerning accessibility. The model assumes that both profitability (depending, among others, on production means of the farmer) and accessibility (depending, among others, on the social network of the farmer) have to reach a certain threshold before the farmer will adopt the new technology.

Econometric results confirm that the assumption that all actors have access to all goods which are sold in markets is indeed too rigid in the case described here.

1. INTRODUCTION

What motivates farmers to adopt new technology and to apply this in their fields? Pakistan has a long history of such innovations having been adopted and applied: a history in which it was in some cases a leader amongst developing countries. It has an enviable record of success and has therefore been the focus of much research activity addressed to the issue of adoption behaviour by farmers. When the present study intends to add to the knowledge in this area, one must therefore have good reasons to undertake it.

Marie-José Smits and Prof. Wouter Tims are both affiliated to the Centre for World Food Studies, Amsterdam.

Authors' Note: We wish to thank M. Ghaffar Chaudhry, Michiel Keyzer, Piet Rietveld, Wim van Veen, and Lia van Wesenbeeck for their comments on an earlier draft.

It appears to the authors that the focus of most previous studies[1] is too narrowly defined and that a somewhat broader approach is desirable. Two main issues are brought forward as possible extensions of the analysis. The first concerns the way in which technological choice is offered to farmers, involving supplying institutions which narrow down farmers' choices. The way in which markets of technology and inputs are organised is crucial, ranging from competitive markets and many suppliers vying for the farmers' interest, to monopolistic structures—particularly organised in the public sector—which limit technology choice to few options only. The second-related-issue is, that the more confined the choices these markets offer, the higher the importance will be of the social relations which farmers have, both in their own communities and with supplying institutions, to obtain access to technology and to inputs.

These two issues play an important role in the discussions concerning adoption behaviour in Pakistan and elsewhere. These are in fact at the heart of the discussions around the distributive effects of new technology: which farmers have access, and what are the reasons for the observed differences? Also, this issue plays a role in the exchanges about the organisation of markets: what is the proper role of the price mechanism and what is the appropriate role of Government intervention? Nevertheless, systematic studies of adoption behaviour which take account of these matters are few. In a modest way, the present study attempts to bring these issues within the focus of the research, both as an attempt to demonstrate their relevance and to identify suitable methods of analysis.

In the coming years the emphasis in agricultural policy will increasingly be on ways to accelerate yield growth. Major efforts are being made to identify suitable technologies and to promote their adoption. The limits to suitable land and water supplies, continued growth of the population and the need to optimise the contribution of the agricultural sector to the balance of payments all point in that direction. The policy framework will therefore also be reviewed from time to time, to design measures which can promote a dynamic sector. In this light, the present research may have some relevance.

In this article the emphasis is on adoption of new wheat varieties. Pakistan has been at the forefront of introducing innovative techniques in its crop cultivation ever since the mid 'sixties, beginning with modern seed varieties for wheat and their associated inputs and followed over time by the introduction of such approaches to rice cultivation and more recently to cotton. In Section 2 we focus on the circumstances under which this innovation took place, in terms of resource availability and policies. Section 3 presents the line of reasoning of the empirical part of the study. The empirical study analyses the choice of wheat varieties in two

[1]An overview of the theory of adoption models is given by Feder *et al.* (1985) and by Besley and Case (1993).

districts in the Punjab of Pakistan, i.e. Faisalabad and Attock. We argue that one can not assume on forehand that the input market is competitive. In Section 4, we will explain why the input market for wheat seeds in the Pakistan Punjab is not competitive. If the input market is not competitive (or not completely competitive), then non market institutions may be important. Examples of non market institutions in Pakistan which are relevant in this sense are: interlocking markets and the trickling down system. These two institutions are described in Section 5. Because the wheat seed sector is not competitive, and because of the existence of non market institutions, access to the input market for wheat seeds is limited in the Pakistan Punjab. We will illustrate this statement quantitatively in Section 6. In Section 7 we analyse the adoption behaviour of Punjab wheat farmers by a bivariate probit model with partial observability. In this model we assume that both profit and access play a significant role in the adoption process of farmers. Both profitability and accessibility have to reach a certain threshold in order for a farmer to be able to adopt a new technology. Finally, in Section 8 we will give a summary and the conclusions.

2. HISTORIC OVERVIEW OF AGRICULTURAL PRODUCTION IN PAKISTAN

The economic history of Pakistan was dominated by the performance of its agricultural sector. Since Independence in 1947 and a slow start in the early years, the growth of agricultural production accelerated. On average over the entire period till present, the rate of growth amounted to almost 4.0 percent per annum, even when some slowing down can be observed in recent years, since around 1990.

This is a remarkable performance for more reasons than one. To begin with, there are few developing countries which matched this performance. Large countries in terms of their population and at comparable levels of *per capita* income did perform less favourably at most times or on average. Indian rates of agricultural development remained on average a full percentage point per annum lower; China has experienced high rates of growth only since the mid 'seventies. Even more remarkable is the fact that general economic policies and their stance towards agriculture have provided distinct disincentives and sometimes were even hostile to agricultural development.

2.1. The Environment of Agricultural Innovation[2]

The capacity of Pakistan's agriculture to feed a large and growing population is not provided by nature itself. The country has an arid climate and what little rainfall occurs tends to be unreliable. The natural conditions by themselves make agriculture risky. Possibilities to irrigate large tracts of land where already noted

[2]This section is to a large extent based on Hamid and Tims (1990).

centuries ago, with the potential to extend cultivation of crops and the rearing of livestock beyond the areas along the rivers and into a much larger area, assuring a reliable supply of water. In the middle of the 19th century the implementation began, leading to a vast expansion of the cultivable area. At the time of Independence in 1947 Pakistan contained almost 11 million hectares of land commanded by irrigation systems diverting water from the Indus river and its tributaries. In addition, the country contained at the time some land irrigated outside the main system, usually by traditional local means (0.4 million hectares), some cultivable land in riverain areas (0.7 million hectares) and about 2.5 million hectares of so-called *barani* area, with rainfed cultivation.

Although the supply of irrigation water permitted multiple cropping, this did not, in fact, take place in the early years except in a limited area of the Northwest Frontier Province. In 1965, the average cropping intensity on irrigated lands amounted to barely 87 percent: even less than one crop was grown on average on irrigated land per annum. With each new barrage and canal development, particularly after Independence, came the extension and development of new cultivable areas but water supplies—even in the *kharif* (summer) months—remained inadequate. The problem became even more acute because of the loss of three upper reaches of rivers which delivered irrigation water to Pakistan, but were gradually diverted after Partition to India.

To replace the water from these rivers, a major investment programme was adopted in the late 'fifties, mainly building link canals to supply water from the Indus and the most North-western rivers to the beds of the Eastern ones. But the programme also, for the first time, included the construction of major water storage: Mangla Dam on the Jhelum followed by Tarbela Dam on the Indus. This not only increased the total supply of irrigation water but also enabled a better distribution of supplies over the seasons. Particularly this feature made it possible to think about a higher cropping intensity, rather than a larger cropped area.

This led to a shift of attention from horizontal agricultural development—more water and more acreage—to possibilities of increasing cropping intensities in the area already cultivated. At the same time it was realised that yields of most major crops were very low and that intensification also needed to address opportunities for increasing these yields. For example, average yields of wheat and rice for all of Pakistan ranged between 800 and 850 kg/ha, only half or even less than was obtained in other countries. The investments in additional and more reliable water supplies would only have reasonable returns when crop yields could be raised.

Investments in agriculture until the late 'seventies were large—some 25 percent of total investment outlays[3]—but were also mainly directed towards

[3]A detailed history of irrigation developments is provided in Lieftinck, Sadove and Creyke (1968).

improving the water supply in the existing agricultural area. By the end of that period the total water supply had roughly doubled, with a significant contribution by pumped groundwater. The installation of tubewells began already in the 'fifties, supplementing scarce surface water; presently groundwater contributes some 40 percent of total irrigation water and is supplied by about 300,000 wells in the private sector. On the whole, groundwater supplies roughly offset the losses from seepage in the canal system; mining of groundwater occurred in areas where in previous years the groundwater table had risen and caused waterlogging, salinity and alkalinity.

Increased water availability set the stage for Pakistan's agricultural growth, but it has also brought a number of problems in its wake. Efficiency of water use is a major issue as further supply increases can hardly be expected. Combating ecological deterioration which is both cause and consequence of an improperly maintained supply system also needs to be mentioned.

With agricultural development taking place in the period since Independence, based to a large extent on increased availability of water, complementary infrastructure and supporting provisions have become increasingly inadequate and not geared to new requirements. Rural roads are inadequate, marketing and storage are not geared to the growing and diversifying marketable surpluses, the availability and distribution of credit to farmers is low and skewed. Compared to water development and the financial outlays devoted to it, the attention paid to the supporting infrastructure serving the agricultural sector has traditionally be scant.

In comparison to the economic infrastructure, even less attention was given to the social environment, particularly to rural education, health facilities, water supply and housing. Efforts are now on their way to put more emphasis on these aspects of rural development, but it will take many years and arduous efforts to set the balance straight. At the same time, farmers have apparently been quite responsive to the opportunities offered by larger irrigation supplies, adding to those by installing large numbers of private tubewells on their land and mechanising their operations to increase cropping intensities and yields, and to avoid labour scarcities. Summing up, there is a historical background which is dominated by investments in water supply and by on-farm private investments, but with serious shortcomings on the side of supporting infrastructure, both in terms of economic as well as—even more pronounced—social facilities.

Price and subsidy policies constitute the third element of the environment. Although there have been changes over time, these policies have on the whole been detrimental to agricultural growth as these did reduce the returns that could otherwise have been obtained from innovation. This was done by keeping domestic agricultural prices below equivalent world market prices, enforced by border taxes and subsidies and, sometimes, by a state trading monopoly. This resulted in large forced savings transferred out of the agricultural sector to domestic consumers and to the

Government. This outflow was to some extent compensated by targeted subsidies, prominently on fertilisers but also on agricultural machinery, but this did not offset the outflow which in most years since 1970 and throughout the 'eighties amounted to some 20 percent of agricultural value-added.

In the early years after Independence such policies probably were justified as resources for economic development were scarce and agriculture was amongst the few sources to be tapped. In later years, when agricultural growth accelerated because of larger water availability and a proven willingness of farmers to innovate, it simply retarded economic growth and led to wasteful use of resources. There is general recognition at present that the system is to be abolished and replaced by a less interventionist environment. This will take considerable time as vested interests with a strong political influence will resist the necessary changes.

2.2. Agricultural Performance

The first 15 years after Independence into the middle 'sixties, agricultural production increased by barely 2.4 percent per annum, lagging behind the growth of population. Imports of wheat, the most important staple food, rose gradually to more than 20 percent of total availability. As particularly Punjab province had been a net-exporting area in pre-Independence days, this was considered to be avoidable. Still, policies remained geared to extensive rather than intensive agricultural growth. Increasing water supplies and putting more land under the plough featured strongly in this period up to the middle 'sixties. Consequently, acreage expansion accounted for a major part of production increases, at 1.8 percent per year. The remaining 0.6 percent reflected more a shift towards higher-valued crops and hardly any increase of yields.

Taking 1965 as the base year, agricultural production in the next three decades has shown a markedly better performance. On average there was through 1997 a rate of growth of 3.9 percent which is matched by few countries for such a long period of time. There were some periods when trend growth was substantially exceeded and others when performance was at best mediocre: these periods are not only associated with weather cycles—which do not overly affect the country as most of the land is irrigated—but more prominently with the policy environment.[4] A rough but modest estimate puts the overall loss of growth due to unfavourable pricing and exchange rate policies at about 1.0 percent per year for this period.

Since 1965 the area under crops still increased but at a decelerating rate: an average of some 1.3 percent per year with the rates remaining below 1.0 percent in the most recent period. This implies a significantly higher impact of yield growth, even when including the effects of a further shift to higher-value crops, in particular

[4]Hamid and Tims (*op. cit.*) give a more detailed account. See also Hamid, Nabi and Nasim (1989).

away from the traditional coarse grains. Yield increases have accounted on average for more that 2.5 percent growth of production *per annum* over this extended period. It is a sobering fact, however, that even at this higher growth of output, Pakistan has not been able to meet its domestic food needs as population growth was unrelentingly high. At its low average income level, income elasticities are also relatively high, causing the balance between supply and demand to face continued tension.

Yield increases of the past three decades testify to the capability of the land to bring larger returns; by all accounts, the limits are still far higher than current yield levels. Progressive farmers throughout the country demonstrate this fact vividly. The main ingredients for reaping further benefits through higher yields are the farmers themselves who adopt better methods with appropriate inputs, and who apply those efficiently, being encouraged by the prevailing policy environment.

3. ADAPTATION OF PREVAILING ADOPTION MODELS

In adoption models the adoption behaviour of farmers towards new methods and new inputs is estimated. The adoption behaviour is influenced by the appropriateness of the inputs for different types of farmers, and by the (physical, social and political) environment of the farmers.

The subject of the research described here is the adoption of high yielding varieties, and the influence of the prevailing policy environment. Especially, we are interested in the way in which technological choice is offered to farmers, involving supply institutions. Our prospected contribution to the existing literature on technology choice of farmers is the incorporation of institutions into a technology choice model. In this section we will give our point of view on existing literature on technology adoption and explain our argument for incorporation of the role of institutions into adoption models.

The standard way to describe technology choice in the agricultural sector in microeconomics is by using so-called adoption models. These adoption models assume that a farmer chooses a new technology based on expected profitability under uncertainty. Therefore, the profitability of a new technology is estimated for a specific farmer, given his/her means of production and compared to that under existing technology. Special attention is paid to risks (the choice for a new technology may increase risk), information (the farmer needs to have adequate information about a new technology) and time (there are early adopters and others who adopt later on in the process).

There are different types of adoption models, but they all share the assumption that farmers pay the same price for the same input and all farmers to have access to all inputs needed. (In a detailed adoption model prices may vary due to transportation costs.) These models follow microeconomic theory: because there are many farmers, they are assumed to be price-takers on the input-markets. Farmers are price-takers in

the case of a competitive market, but also in the case of a monopolistic market, both when the monopolist is a private firm or a government agency. However, the assumption that farmers are price-takers presumes that everybody has access to the market, i.e. everybody can buy the products or services given the predetermined price. Because of the renewed interest shown by economists in the functioning of institutions, it is important to assess the assumptions mentioned here.

We argue that adoption models describe only a part of the total decision-making process. The decision-making process can be described as a decision chain, which consists of all people who make decisions relevant to the introduction of a new technology, e.g. politicians, R&D researchers, input suppliers, output traders, farmers, etc. Some of these actors determine the decision space of other actors within the chain.

Farmers are the last link in the chain, and their decision space is determined, among others, by the input suppliers. If the input market is truly competitive or the bureaucracy works perfectly, the assumption that farmers are price-takers and that everybody has access to the market can be justified. However, we can not always assume that the market, and even less the bureaucracy, will operate perfectly.

When the market structure is limited, for example due to the infrastructure or organisational aspects, an institution may "fill the gap". Institutions are a combination of formal and informal agreements, customs, traditions, etc. Institutions are, therefore, accepted by the majority but are not officially registered. When the markets structure is limited, equal access to inputs for all farmers can not be assumed on forehand. Therefore, access constraints have to be incorporated in models which estimate the adoption behaviour of farmers towards new technologies, i.e. adoption models. In this case, both profit and access are relevant to estimate the outcome of adoption behaviour.

In order to adopt a new technology, farmers need to be able to buy the inputs needed for the technology. If the input market is competitive, i.e. their are no physical or organisational limitations, we may assume that all farmers have access to the inputs, given their budget and the prices. Following microeconomic theory, we may assume that in such case farmers choose the technology which is most profitable. In the prevailing adoption models, perfect competition of the input market is assumed, and hence, it is assumed that all farmers have equal access to the inputs (given transportation costs). In econometric adoption models one often makes use of so-called probit models, because the dependent variable is discrete, i.e. in most cases dichotomous. (See Figure 1, left-hand side.)

Our statement can be described as follows (see Figure 1):

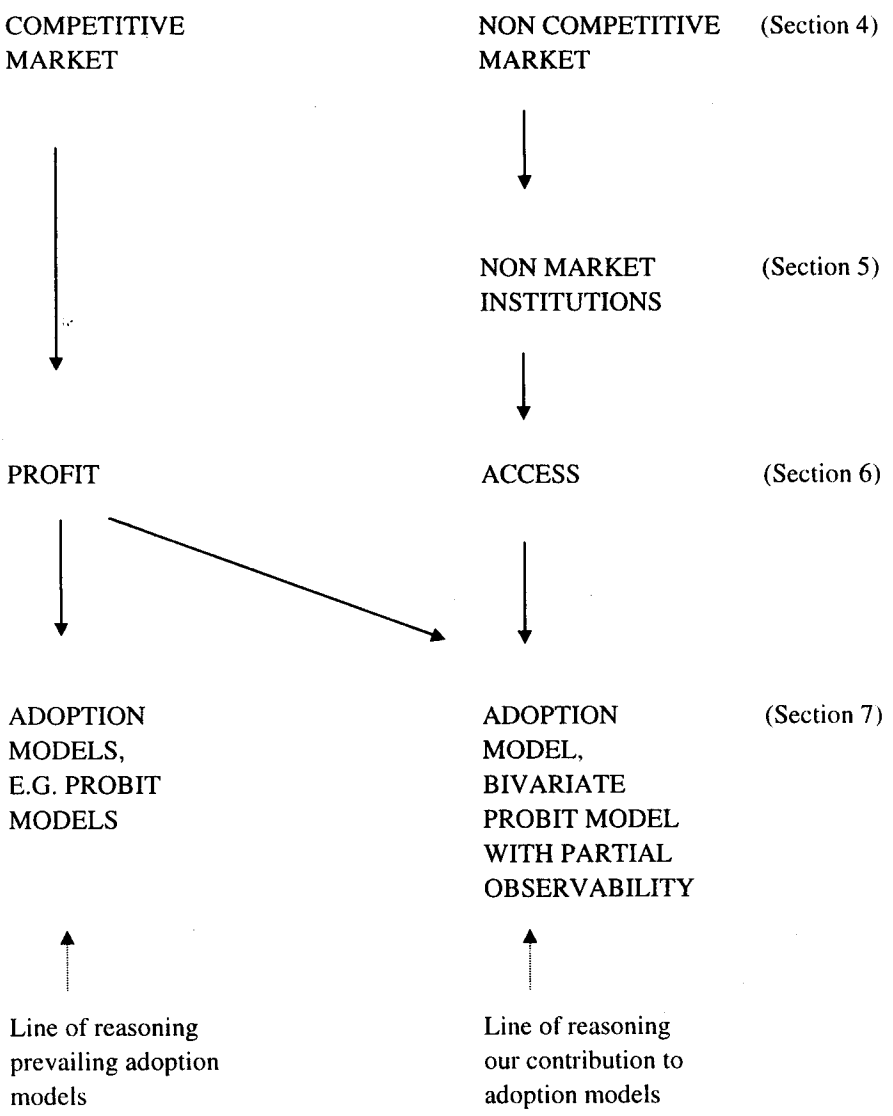


Fig. 1. Outline of the Argument for Adaptation Adoption Models.

In addition to non competitive input markets (Section 4), also non market institutions have to be considered (Section 5). We will investigate to which extent access constraints towards the input market is relevant (Section 6), and if so, incorporate access constraints besides profit expectations in our adoption model (Section 7).

4. NON COMPETITIVE MARKET FOR WHEAT SEEDS IN THE PAKISTAN PUNJAB

Wheat varieties can be divided in two groups: banned and recommended. In Pakistan the Varietal Evaluation Committee of the Ministry of Food and Agriculture decides every year which varieties will be banned in which region, based on rust susceptibility of the variety. The fight against rust in wheat is a matter of general importance, since rust is infectious and wheat is the main food crop in Pakistan. Rust cannot be tackled with pesticides. Wheat varieties become susceptible to rust over time, and ideally, a variety should be replaced every seven years. Besides resistance to rust, new varieties generally also have better yield potentials.

The most common source of wheat seeds for households is the seed retained from the previous year's crop. Because wheat is a self-pollinated crop, wheat seed can be saved by the farmer and used for sowing the next year, with little change in genetic make-up and yield potential. Therefore, the purchase of new seed is only necessary when a new variety is adopted.

About one fourth to one fifth of the households uses wheat seeds they got from other farmers, less than one tenth of the households buys wheat seeds at a depot.[5] Hence, a banned variety can remain in the fields for a long time.

The Federal Seed Certification Department (FSCD) of the Ministry of Food and Agriculture takes care of the certification of recommended varieties to protect seed quality and avoid fraud. Both the public sector and registered private companies can obtain a certification for their seeds. Below, when referring to the private sector, we mean registered private companies which sell certified seeds.

Both the public and the private sector are active on the wheat seeds markets in Pakistan. However, the private sector has a relatively small market share. The public sector (the Punjab Seed Corporation, PSC) presumably sold close to 60 thousand tons in 95-96, while private national seed companies sold 14 thousand tons in the same year, and Cargill (a multinational) sold slightly over 2 thousand tons. Therefore, the private market constitutes barely one fifth of the Punjab market.

Different prices are used by the public and private sector. Table 1 gives an overview of prevailing prices for wheat seeds. The first row of prices concerns certified seeds distributed by the public sector. The second and third rows inform about prices in the private sector.

The two figures in each cell of the table is due to the fact that the seeds are sold in two qualities: the lowest figure concerns untreated seeds, i.e. not treated against fungil, whereas the second concerns treated seeds. It should be noted that both the public and the private sector in principle sell the same product, e.g. the variety Inqlab 91.

[5]Heisey (1990), pp. 53.

Table 1

Prices for Wheat Seeds in the Pakistan Punjab 1993–1997 (in Rupees per Kilogram)

1993-94	1994-95	1995-96	1996-97
Price of Certified Seeds for Wheat from PSC (Public Sector)			
5.60-6.80	6.35-7.35	6.60-7.65	7.45-8.50
Cargill Wheat Seed Prices (Multinational)			
8.00-9.00	9.00	9.00-10.00	
Private National Seed Companies' Wheat Seed Prices			
6.00-8.75	6.90-9.00	6.50-10.62	

Source: Federal Seed Certification Department, Ministry of Food and Agriculture, except 1996-97, information from Punjab Seed Corporation.

The only time when public sector seeds were slightly more expensive than those from the private sector was in 1995-96, when untreated seeds were Rs 6.60/kg from public sector sources against Rs 6.50/kg from national private companies. At all other times, prices from private sector sources were higher. Seeds from public sector sources are uniformly priced at the farm level all over the Punjab. Prices from private sector sources may differ at the farm level due to transport costs.

Why does the public sector sell wheat seeds cheaper than the private sector? This situation may arise because either: (1) there is a subsidy involved in the distribution of seeds by the public sector, because public sector seeds are destined to a specific part of the agricultural population, or (2) there is a price differentiation versus the private seed companies because this is part of public sector marketing policy.

However, according to the Federal Seed Certification Department (FSCD, Dr Syed Irfan Ahmad[6]) the Punjab Seed Corporation (PSC) is the only profitable public institute in Pakistan, notwithstanding the absence of any subsidy. Furthermore, and again according to FSCD, PSC produced 69.087 tons of certified seeds in 1995-96, and sold 59.921 tons of certified seeds. Thus, more than 9.000 tons were left over in spite of the lower price range. Also, price differentiation is stated not to be an element of public sector marketing policy. The issue remains therefore why PSC is

[6]Private consultation with Dr Syed Irfan Ahmad.

not able to sell its supplies at the lower price, when the private sector apparently is able to do so at a notably higher price in most years.

Some possible answers suggest themselves. First, there may be different premiums permitted to public versus private dealers. According to a PSC staff member the premium for public dealers in 1995 was Rs 20 per 100 kg, amounting to a premium of less than 3 percent. In 1996 the premium was increased to Rs 30 per 100 kg. According to a private dealer, Jamil Qureshi,[7] the commission for dealers in the private sector is 10 percent. Thus, the dealers in the private sector have stronger incentives to sell their product. A second factor may be the limited storage facilities of PSC. The public sector corporation is not always able to store the seeds at convenient places for the farmers.[8] Third, the public and private sectors may, in the perception of farmers, not sell the same product. Differences in quality may occur due to malpractice and to the absence of effective quality control.

Above we showed that within the wheat seed market in the Pakistan Punjab different prices are put to use for the same product. The public sector (PSC) is almost always cheaper than the private sector. On the other hand, the public sector has left-overs while the private sector is able to sell the same product for a higher price. The public sector takes care of more than 80 percent of the market for certified seeds. All together, these are indications that the input market for wheat seeds is not competitive in the Pakistan Punjab.

5. NON-MARKET INSTITUTIONS: INTERLOCKING MARKETS AND THE TRICKLING DOWN SYSTEM

When the market is restrained, non market institutions may take over part of the action. We pay attention to institutions, because we expect that informal arrangements, informal contacts, informal networks etc., are important besides the formal contacts with institutes in order to have access to new technologies.

We emphasise the meaning of the concept of 'institutions', because our aim is to broaden the views regarding adoption behaviour by including the role of institutions in this process. The meaning of the word 'institutions' in the economic literature has become richer over the years, but there is still confusion on its definition. An overview of the theory of agrarian institutions, based on economics and extended with empirical studies, can be found in Bardhan (1989), and in Hoff, Braverman and Stiglitz (1993).

Institutions are about how people organise social life in order to survive as a community. The production and distribution of goods are important aspects of survival, and therefore give rise to the creation of institutions.

[7]Private consultation with Jamil Qureshi.
[8]Ahmad and Chaudhri (1994), pp. 321–354.

A possible definition of an institution is "a set of rules, compliance procedures, and moral and ethical behavioural norms that help individuals to achieve efficiency which is beneficial for society in general." Such a definition fits within microeconomic theory. The market mechanism is an institution which, according to microeconomic theory, is beneficial for society in general (given certain conditions, see Welfare Theory). The definition of institutions by Douglass North is somewhat different. He states that institutions are "a set of rules, compliance procedures, and moral and ethical behavioural norms designed to constrain the behaviour of individuals in the interest of maximising wealth or utility of principals."[9] The definition used by North is not 'neutral'; he states that institutions are in the interest of a specific group of people at the cost of others. The definitions are complementary, given that institutions are sometimes beneficial for society in general and sometimes beneficial only to some principal actors, depending on the situation. It is important to study whether a certain institution is beneficial for society in general or for the principal actors only. The market structure in this regard is crucial, since the maximising of wealth or utility is associated with competitive markets which comply to strict conditions and criteria.

Institutions are informal arrangements for interaction between people. Part of the interaction is directed towards transactions. In Pakistan, institutions based on packages of transactions, instead of singular (separate, isolated) transactions, are popular. Packages of transactions can be described as interlocking markets. In Pakistan interlocking markets are very important and often the let out of land and/or the provision of credit are part of the package. Land lease and credit are transactions which take time, i.e. the price for the service/good is paid after some time. Transactions such as the distribution of seeds are often linked to transactions as credit supply, land rent, etc. Interlocking markets enable to diminish risks (because the supplier and demander will meet each other again in the future and are somehow dependent on each other) and increase the exchange of personal contacts (because one meets each other more than once). Big differences in wealth, e.g. in landownership, increase the chance that the relationship has a hierarchic character.

An example of a package of deals, which is relevant for Pakistan, can be found in the share-cropping arrangements. A share-cropping arrangement in Pakistan uses to have the following characteristics: the output is shared between the share-cropper and the landlord, for example on a fifty-fifty basis; often the landlord supplies inputs like fertiliser and seeds. In a share-cropping arrangement land lease is an essential part of the deal.

Another institution which is relevant in Pakistan for the informal organisation of transactions is the trickling down system. The trickling down system is often described in the literature on technology adoption. It can refer to the diffusion of

[9]North (1981), pp. 201-202.

information: some "innovative" farmers receive information on a new technology first, and they spread the information to other farmers. It may, however, also refer to the spread of the technology itself. For example, when a new wheat variety is introduced, the farmers with the most land and the best contacts will buy/get the new variety first. In subsequent years the variety is multiplied, and the innovative farmers will give/sell the variety to other farmers. This process continues over the years with more and more farmers being able to buy/get the new variety. In this way, in a couple of years, a new variety can be distributed without the need for a large "official" distribution network.

Interlocking markets and the trickling down system have in common that they are institutions which organise transactions, essentially in a hierarchic way, and often based on personal contacts. Furthermore, both interlocking markets and the trickling down system are used to diffuse improved wheat seeds.

The trickling down system seems to be reasonable since (1) the larger farmers are best able to bear the risks that are involved in the use of a new technology like a new variety, (2) the farmers with less land get the new varieties in this way not as quickly as possible but probably cheaper than in any other way. However, a disadvantage of the trickling down system is that not everybody has access to the new varieties immediately. It takes some time before the farmers at the bottom of the social pyramid get access to the new varieties.

6. ACCESS CONSTRAINTS TOWARDS THE INPUT MARKET FOR WHEAT SEEDS

In this section we investigate to which extent access problems concerning new wheat varieties exist for farmers in the Pakistan Punjab. In order to tackle this question, we make use of data collected for this purpose in 1997. We start with a description of the data collection, and next, in Section 6.2, make use of the data to answer the question concerning access limitations.

6.1. Data Collection

Data were collected in February-April 1997 with the help of PIDE staff members.[10] Two districts of the Pakistan Punjab, Faisalabad and Attock, were visited. In Faisalabad 88 persons were interviewed in 6 villages (chaks) and in Attock 115 persons in 8 villages were interviewed.

The choice of the districts and persons is based on a data set collected by IFPRI.[11] In the period 1986–1991 IFPRI collected data in 53 villages located in 4

[10]The data collection was possible thanks to the great help of Dr Sohail J. Malik, Dr. Sarfraz K. Qureshi, and Dr. M. Ghaffar Chaudhry. and the enumerators, Annis H. Hamadani, Ali Muhammad, Azkar Ahmad, and Muhammad Azhar.

[11]A more detailed description of the IFPRI data set can be found in Alderman and Garcia (1993).

districts in rural Pakistan. IFPRI kindly allowed us to use their data set. For the research described here, additional data was needed on social networks. Therefore, the 1997-survey was organised. The IFPRI-data set contains four districts in three provinces; the 1997-data collection concentrates on two districts only, namely Faisalabad and Attock, which are both part of the province of Punjab. The Punjab is the main wheat producing province in Pakistan, and given constraints of time and available finance, this seemed an appropriate concentration. In Faisalabad, wheat is produced on irrigated land, whereas in Attock wheat production is rain fed. The households interviewed for the 1997-data set were engaged in the "technology adoption by wheat farmers"—survey by IFPRI in 1989. All, except one, of the households of the "technology adoption by wheat farmers"—survey were traced back and were interviewed. For the research described in this article, we used only the 1997-data set. In future research we plan to apply both the IFPRI and the 1997-data set.

6.2. Access Constraints

One of the questions in the questionnaire concerns the main perceived constraint for not buying new wheat varieties. We asked all wheat producers who used banned wheat varieties, why they did not adopt new varieties. It has to be emphasised that we did not give the farmers a list of possible answers on forehand. Table 2 gives an overview of the answers.

Table 2

Reasons for Non-adoption of Recommended Wheat Varieties, in Percentages

	Price	Access	Information	Not Applicable
Faisalabad	40	30	21	9
Attock	69	14	4	13

For most wheat producers, the price of new wheat seeds is the main reason for not adopting new varieties. In both districts, Faisalabad and Attock, access is the second most mentioned reason for non adoption. Accordingly, we conclude that access constraints are important enough to be taken into account.

In both districts, Faisalabad and Attock, price is most often mentioned as a reason for non adoption, and access is the second most mentioned reason. However, we see remarkable differences between Faisalabad and Attock in the percentages. In Faisalabad, access is relatively more of a problem than in Attock, i.e. in 30 percent versus 14 percent of the cases. An explanation for this difference can be that Attock

is close to Rawalpindi, i.e. in one day one can travel from Attock to Rawalpindi and back. Rawalpindi is a big city from where many private dealers operate. Hence, it is to be expected that farmers from Attock have more easily access to private dealers than farmers in Faisalabad. This access to private dealers may decrease the access problem to the input market.

The farmers who did adopt a new wheat variety, were asked from which type of input supplier they obtained the seeds. An outline of the answers is given in Table 3.

Table 3

Input Suppliers of Wheat Seeds, in Percentages

	Private Sector	Public Sector	Other
Faisalabad	9	35	56
Attock	33	30	37

In Attock, relatively more households buy from private input suppliers than in Faisalabad, i.e. in 33 percent versus 9 percent of the cases.

These figures confirm our expectation that in Attock access to inputs is less of a problem than in Faisalabad, because in Attock more households buy from private input suppliers compared with Faisalabad. This explains the differences in results between Faisalabad and Attock.

For Attock we saw a high percentage of farmers who mentioned that price is the main constraint for not using recommended varieties. The price of wheat seeds from the private sector is generally higher than in the public sector. Since in Attock on average more households buy from private input suppliers than in Faisalabad, this may explain the high percentage for price as the main reason in Attock (Table 2).

As mentioned in the previous section, the trickling down system may refer to the diffusion of information or to the diffusion of seeds. It is interesting to see in Table 2 that access to seeds is in both districts more of a constraint than access to information, i.e. 30 percent versus 21 percent for Faisalabad and 14 percent versus 4 percent for Attock.

7. BIVARIATE PROBIT MODELS FOR ESTIMATING ADOPTION OF WHEAT VARIETIES[12]

Statistical Methods Used

The models proposed for the data analysis are so-called "bivariate probit

[12] Heisey, Tetlay, Ahmed and Ahmad (1990).

models with partial observability". Applied Bivariate probit models with partial observability are rare.[13] A mathematical description of a bivariate probit model with partial observability is given in Appendix 1.[14] Below, we state why this bivariate type of model can be useful for the research described here.

We assume that both profitability and accessibility are important for a farmer in order to be able to adopt a new technology, as is represented in Figure 2.

		Profit	
		+	–
Access	+	adoption	no adoption
	–	no adoption	no adoption

Fig. 2. Adoption Behaviour given Profitability and Accessibility.

We expect that when a new technology is both profitable and accessible, a farmer will adopt the new technology; otherwise not.

A bivariate probit model with partial observability has three basic characteristics, as implied by its name. It is a probit model and therefore the dependent variable is discrete. In this case the dependent variable is adoption/no adoption. It is a bivariate model because the variables are divided in two groups. In this case one group of variables represents profitability and another group stands for accessibility. It is a model with partial observability because not everything we might be interested in is observed. In this case we observe only whether a farmer adopts or not. When a farmer does not adopt, we do not observe whether the constraint is profitability, access, or both.

A bivariate probit model with partial observability allows us to use two groups of independent variables, both with the same dependent variable; the two groups may in turn partially include the same independent variables. To use the same independent

[13]Praag (1996), unpublished, Ph.D. thesis.

[14]A mathematical description is also given by Maddala (1983), pp. 278–289.

variable in both groups has the advantage that we can estimate *for what reason* the independent variable is important for the dependent variable, i.e. technology adoption. The bivariate probit model with partial observability allows us to estimate to which extent profitability and to which extent accessibility is important as an explanation for the weight of a certain variable. We use the model as developed by Abowd and Farber.[15]

Bivariate Probit Model with Partial Observability

The dependent variable is:

TECH = use of recommended wheat varieties (=1) or banned wheat varieties (=0).

The independent variables are:

ACRES = on how many acres did you produce wheat last year (*rabi* season 1995-1996, continuous variable).

COUNCIL = do you have a relative or do you have a friend who is member of a union council (=1) or not (=0). (The union council is the lowest administrative level.)

DISTRICT = either Attock (=1) or Faisalabad (=0).

FERT = did you use DAP in *rabi* season 1995-1996 on the plot where you grew wheat (=1) or not (=0). (DAP was the most advanced fertiliser mentioned in the survey and by IFPRI.)

LAND = land property of household (continuous variable).

OWNS = do you have a relative who owns more than 20 acres of land (=1) or not (=0).

ROTA = for Attock: production of wheat in rotation with *jowar* (local grain), or left fallow (=1), else (=0); for Faisalabad: production of wheat in rotation with cotton (American), vegetables, or pulses (=1), else (=0).

We distinguish accessibility and profitability as possible constraints for non adoption of recommended wheat seeds. Profitability depends on production and prices. However, prices are difficult to obtain at farm level. Officially it is maintained that the price for wheat seeds, i.e. the PSC price, and the output price for wheat, i.e. the procurement price, are the same for all farmers. Therefore, we will restrict the concept of profitability to its production component.

Production variables are:

ACRES, the amount of acres used for wheat production is important as a

[15]Abowd and Farber (1982), pp. 354–367.

production variable, if economies of scale play a role in the adoption of wheat varieties;
ROTA, the rotation pattern is relevant because double cropping has become the standard in Pakistan. New varieties may differ concerning the length of the growing season, since nowadays one tries to develop early maturing varieties. For a farmer it is important what he earns in a whole year, and not only what he earns with wheat production. Therefore the wheat variety has to fit within his rotation pattern.

Accessibility depends on both physical and social infrastructure. In this study, we want to emphasise the importance of the social infrastructure, i.e. the role of institutions. Therefore, we concentrate on social network variables.

Social network variables are:

COUNCIL, contacts with members of a village level administrative unit, may say something about the social status of a person within a village;
OWNS, contacts with a person who owns much land may say something about contacts with people with a high social status.

Besides variables which are classified exclusively as production or social network variables, also variables are included which may either be important as production or social network variable.

Variables which may either be a social network or a production variable are:

FERT, the use of fertiliser is meaningful because new wheat varieties in general react more strongly on nitrogen than old varieties. Therefore, a high quality fertiliser may be important for production. However, access to a high quality fertiliser like DAP may also say something about one's social network. If someone has access to DAP, he may also have access to new wheat varieties;
LAND stands for landownership, and land is an important asset. Therefore, wheat producers who own a lot of land are wealthy and it can be expected that wealth has an influence on one's risk behaviour. Furthermore, landownership is important for one's social status, and may in that sense influence one's social network.

The variables COUNCIL and OWNS are significant, which means that social network variables are relevant in this model. ROTA is also significant, but ACRES is not. FERT is not significant as a production variable, but it is as social network variable. The variable FERT is defined as: did the household use the fertiliser DAP on the piece of land on which wheat was produced. DAP is a modern, advanced type of fertiliser. As with seeds, access to DAP may need well developed social networks.

production variable, if economies of scale play a role in the adoption of wheat varieties;

ROTA, the rotation pattern is relevant because double cropping has become the standard in Pakistan. New varieties may differ concerning the length of the growing season, since nowadays one tries to develop early maturing varieties. For a farmer it is important what he earns in a whole year, and not only what he earns with wheat production. Therefore the wheat variety has to fit within his rotation pattern.

Accessibility depends on both physical and social infrastructure. In this study, we want to emphasise the importance of the social infrastructure, i.e. the role of institutions. Therefore, we concentrate on social network variables.

Social network variables are:

COUNCIL, contacts with members of a village level administrative unit, may say something about the social status of a person within a village;

OWNS, contacts with a person who owns much land may say something about contacts with people with a high social status.

Besides variables which are classified exclusively as production or social network variables, also variables are included which may either be important as production or social network variable.

Variables which may either be a social network or a production variable are:

FERT, the use of fertiliser is meaningful because new wheat varieties in general react more strongly on nitrogen than old varieties. Therefore, a high quality fertiliser may be important for production. However, access to a high quality fertiliser like DAP may also say something about one's social network. If someone has access to DAP, he may also have access to new wheat varieties;

LAND stands for landownership, and land is an important asset. Therefore, wheat producers who own a lot of land are wealthy and it can be expected that wealth has an influence on one's risk behaviour. Furthermore, landownership is important for one's social status, and may in that sense influence one's social network.

The variables COUNCIL and OWNS are significant, which means that social network variables are relevant in this model. ROTA is also significant, but ACRES is not. FERT is not significant as a production variable, but it is as social network variable. The variable FERT is defined as: did the household use the fertiliser DAP on the piece of land on which wheat was produced. DAP is a modern, advanced type of fertiliser. As with seeds, access to DAP may need well developed social networks.

LAND is neither significant as a production variable, nor as a social network variable. Most unforeseen about the results given above, are the low *t*-values for ACRES and LAND. In Section 7.3 we will give an explanation for the low values of LAND and ACRES. The variable DISTRICT is significant, which means that there are significant differences between Faisalabad and Attock. Since Faisalabad is irrigated, and Attock is rainfed, this is not unexpected. We conclude that the social network variables appear to play a more important role in the adoption process than the production variables.

Table 4

Bivariate Probit Model with Partial Observability; the Dependent Variable is TECH, i.e. the Use of either Recommended or Banned Wheat Varieties; the Independent Variables are Distinguished into Production Variables and Social Network Variables

	Production Variables		Social Network Variables	
Variable	Coefficient	*t*-value	Coefficient	*t*-value
COUNCIL			0.854	1.837*
OWNS			1.485	2.115*
ACRES	0.048	0.773		
ROTA	0.632	1.877*		
LAND	0.007	0.642	–0.004	–0.382
FERT	–0.695	–0.855	1.219	2.230*
DISTRICT	–0.150	–0.330	1.521	2.885*
Intercept	0.639	0.693	–1.380	–3.423*
Loglikelihood	–99.011			
Number of Observations	182			

* Absolute *t*-values of 1.65 and above indicate that the effect differs significantly at a 10 percent level.

In the bivariate probit model with partial observability described above, we combined the data from Attock and Faisalabad, because we have a too limited number of observations otherwise. To investigate whether there are crucial differences between Attock and Faisalabad which are relevant for this model, we introduce interaction variables. Interaction variables were constructed for all combinations of the variable DISTRICT with each of the other independent variables.[16] Of all interaction variables constructed, we found one which does not get

[16]The interaction variable is a multiplication of the value of the variable DISTRICT with the value of one of the other variables. If the district is Faisalabad, then the interaction variable is 0 (because for Faisalabad the value of the variable DISTRICT is zero). If the district is Attock, then the interaction variable is equal to the other variable (because for Attock the value of the variable DISTRICT is one).

a minor *t*-value in the bivariate probit model. The interaction variable constructed of the variables DISTRICT and LAND is called DLAND. This variable is significant at a 90 percent level of significance (p=0.01) as a production variable in the bivariate probit model described in Table 5.

Table 5

Bivariate Probit Model with Partial Observability; the Dependent Variable is Tech, i.e. the Use of either Recommended or Banned Wheat Varieties; the Independent Variables are Distinguished into Production Variables and Social Network Variables

	Production Variables		Social Network Variables	
Variable	Coefficient	*t*-value	Coefficient	*t*-value
COUNCIL			0.180	0.619
OWNS			0.706	2.442*
ACRES	0.192	1.204		
ROTA	0.882	1.862*		
LAND	–0.010	–0.183	0.031	0.663
DLAND	0.500	1.599	–0.029	–0.632
FERT	1.160	2.311*	–0.517	–1.473
Intercept	–1.601	–3.744*	0.542	1.497
Loglikelihood	–96.898			
Number of Observations	182			

* Absolute *t*-values of 1.65 and above indicate that the effect differs significantly at a 10 percent level.

The variables OWNS and ROTA keep their significance. The variable COUNCIL is not significant anymore, whereas FERT is in Table 4 significant as a social network variable, and in Table 5 FERT is significant as a production variable. We do not have an explanation for this switch.

ACRES and LAND are still not significant, but DLAND is significant at 90 percent. This means that there is a difference between Faisalabad and Attock concerning the link between landownership and adoption of recommended wheat seeds. The sign is positive, which means that in Attock there is a positive relation between landownership and adoption of recommended wheat seeds, whereas in Faisalabad there is a negative relation. This difference between Faisalabad and Attock can also be shown graphically. (See Appendix 2). The interpretation of the differences between the two districts is given in the following section.

Extension on Results Bivariate Probit Model with Partial Observability

This section concentrates on the variables ACRES and LAND, and tries to find an explanation for the low values of these variables which are often considered to be of large importance.[17]

Concerning Table 4:

In order to confirm that it is not an accident that ACRES and LAND are not significant, we estimated an univariate probit model. In Table 6 the independent variables all have somehow to do with land, i.e. land property (LAND), use of land for wheat production (ACRES) and relatives of large landowners (OWNS). The dependent variable is: use of banned versus use of recommended wheat varieties.

Table 6

Univariate Probit Models; the Dependent Variable is Tech, i.e., the Use of either Recommended or Banned Wheat Varieties; the Independent Variables are Linked with Land

	Faisalabad		Attock		Both Districts	
Variable	Coefficient	*t*-value	Coefficient	*t*-value	Coefficient	*t*-value
LAND	−1.013	−.651	0.004	0.645	0.001	0.151
ACRES	0.157	2.709*	0.025	0.711	0.077	2.544*
OWNS	1.259	3.423*	0.471	1.673*	0.753	3.444*
DISTRICT	–	–	–	–	0.605	2.868*
Intercept	−1.244	−4.285*	0.064	0.307	−0.809	−3.869*
Loglikelihood	−37.776		−62.137		−103.599	
No. of Observations	78		104		182	

* Absolute *t*-values of 1.65 and above indicate that the effect differs significantly at a 10 percent level.

The variables ACRES and OWNS are significant for Faisalabad, and the *t*-value of LAND is again low. For Attock OWNS is significant. This table indicates that for adoption of recommended wheat varieties it is more important to know someone with much land than to have much land yourself.

The low *t*-value for LAND is again unexpected. Two reasons for this can be pointed out. First, land property does not say anything about the quality of the land. When the land is used for wheat production, it needs to have some minimum quality. ACRES may be an alternative for productive land. Secondly, the data set we use is

[17]See, for example Husain (1992). In his model on wheat varietal choice in Gilgit he uses a variable for farm size.

limited and does not include many big landlords. There are more households in the data set which use recommended wheat varieties, than there are households which can be defined as landlords. Probably, the number of landlords is too limited to give LAND a significant value. The variable ACRES is on the use of land and includes also tenants. This could be the same reason why the variable OWNS is significant and LAND is not. There are more people who know a landlord, than there are landlords themselves.

Concerning Table 5:

In Table 5 the interaction variable DLAND is significant at a 90 percent level. The pictures in Appendix 2 show that in Faisalabad the more land one owns (conditional on some other variables), the less one is willing to adopt new wheat varieties. This is opposite to what is often described in the literature. In Attock the situation is as expected.

We are not sure about the explanation for the situation in Faisalabad. Two possible explanations are given below. These explanations are compatible, i.e. it is possible that both explanations clarify part of the situation.

The first explanation is that in Faisalabad agricultural production is of relatively low risk, thanks to the irrigation network. Therefore, producers with small plots of land are able to adopt new wheat varieties without taking too much risk. Furthermore, wheat producers with large plots of land often work more extensive on their land than those with small plots, for example because they are involved in other activities besides farming. Because they work extensive, they may put less emphasis on adopting new technologies. Farmers with little land are known to work labour intensive, and therefore, they may put more effort on adopting improved methods. By contrast, production is riskful in the rainfed areas, like Attock. Only well-to-do farmers are capable of taking the risk and adopt new varieties.

The second explanation is that in Faisalabad much land is rented out or sharecropped out. In Attock most people work on their own land. In Faisalabad large landowners share out/rent out land, but they keep one piece of land for themselves. On this piece of land they produce wheat for own consumption. Often they select the wheat variety for taste reasons, and not for yield. The richer they are (the more land), the more precise they can be concerning the taste. Often old varieties are preferred above new varieties, because of the taste. On average Attock is poorer than Faisalabad, and therefore in Attock the farmers can not be so precise concerning taste.

We have to emphasise that the explanations given above are merely suggestions, and not certainties. Besides, the models described above were estimated with use of a data set with a moderate capacity, for example with a limited number of landlords and a limited number of production variables. Nevertheless, our aim was to

show the potential of a bivariate probit model with partial observability, and especially the possibility to estimate why certain independent variables are important for technology adoption.

8. SUMMARY AND CONCLUSIONS

Attention was paid to the definition of institutions. We argued that the intention of institutions is not always clear. Two possible purposes of institutions can be defined: (1) to achieve efficiency for society in general, and (2) to maximise wealth of its principals. The question we want to raise is: which of the two purposes is true in the case of wheat seed distribution in the Punjab?

In the Pakistan Punjab both public and private institutes are active in the wheat seed market, but the public sector constitutes more than 80 percent of the Punjab market. In general, the public sector is cheaper than the private sector. Furthermore, it is remarkable that the public sector has leftover stocks, i.e. is not able to sell all the wheat seeds within a year.

Empirical research was done in the districts Faisalabad (irrigated) and Attock (rainfed). The aim of the empirical case study was to analyse adoption behaviour towards recommended wheat varieties with emphasis on institutional factors.

The main differences between Faisalabad and Attock, based on the empirical research, are:

- Both in Faisalabad and Attock the price of seeds is most often mentioned as main constraint.
- In Faisalabad access and information are more often mentioned as a main constraint than in Attock; in Attock the price of seeds is more often mentioned as a main constraint compared to Faisalabad.
- In Attock more households buy from private sellers compared to Faisalabad.

Since private sellers are in general more expensive, the observations above are consistent. An explanation for the differences between Attock and Faisalabad is, that Attock is located close to Islamabad and Rawalpindi. It is possible to drive within one day from Attock to these two cities and back.

Another difference found between Faisalabad and Attock is the relation between landownership and adoption of recommended wheat varieties. In Faisalabad we found a negative relation and in Attock a positive one. Possible explanations for this difference have been discussed in Section 7.3.

The main results for both districts together are:

- Access to improved wheat seeds is often a problem.
- Social networks are important for the adoption of recommended wheat seeds.

- To adopt recommended wheat seeds it is important to know a large landowner, i.e. to know someone with more than 20 acres of land. In the literature on adoption of new technologies this is often called the trickling down principle, i.e. large landowners often are the first ones to get an improved wheat variety, and after the harvest they give (sell) it to others.

We argued that interlocking markets and the trickling down system are examples of institutions. An institution exists of both formal and informal rules, agreements, customs, etc.

If mainly large landowners have access to the public sector for wheat seeds, then the low prices of improved wheat seeds are in favour of the principals, i.e. the large landowners. Because of the trickling down principle, after some time also other farmers get access to improved seeds. This makes the favouring of principals less prominent. Is the trickling down principle efficient for society in general? Because varieties become rust susceptible after some years, it is important that the distribution of new seeds goes quickly. The trickling down of new technologies in fact takes some time. Since the public sector, i.e. PSC, has left-over stocks and at the same time farmers complain that access is a problem, it should be possible to improve the efficiency.

The case study presented in this paper focused on access to recommended wheat seeds. However, the adoption of new seeds may well be linked to the adoption of other inputs, e.g. fertiliser, irrigation water, etc. Furthermore, we did no research on the price policy of wheat, i.e. the procurement price. These issues are outside the scope of this research. However, we do not deny the importance of these topics.

Concerning the statistical methods used, in this article we gave a demonstration of a bivariate probit model with partial observability. The advantage of a bivariate probit model above univariate probit models is that it gives the possibility to analyse why a certain independent variable is important for adoption behaviour. This improves the interpretation possibilities of the model. In our case study we concentrated on the importance of an independent variable for production reasons versus social network (linked with access) factors.

Appendices

APPENDIX 1

BIVARIATE PROBIT MODEL WITH PARTIAL OBSERVABILITY

In this appendix we give a mathematical description of a bivariate probit model with partial observability as developed by J. Abowd and H. Farber (1982). Abowd and Farber adapted the bivariate probit model with partial observability in such a way that it has become a sequential-decision model. In the research described here it means that for a wheat farmer in order to decide on the adoption of a new wheat variety, it is assumed that he has to decide on two thresholds in a sequential manner. For example, first the new variety has to be profitable and then, secondly, it has to be accessible. The description given below, is based on Maddala (1983) and van Praag (1996).

In order to develop a model as described Figure 2, we need to formulate a switching regression model, where the switch depends on two criteria. As is shown in Table 2, the switch in the research described here is adoption, and the two criteria are profit and access.

Two individual specific latent variables are defined, $\tilde{I}_{1i}$ representing profitability and $\tilde{I}_{2i}$ representing accessibility, where i indexes wheat producers. These constructs can be related to observed regressor variables W by a linear relation in a so-called indication function:

$$\begin{aligned} \tilde{I}_{1i} &= W_{1i}\gamma_1 - \varepsilon_{1i} \\ \tilde{I}_{2i} &= W_{2i}\gamma_2 - \varepsilon_{2i} \end{aligned} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (A.1)$$

where W_{ji} (j=1,2) is the vector of regressors, γ_j is a vector of unknown parameters and ε_{ji} is an error term with mean 0 and (normalised) variance 1. We assume that the error terms have a bivariate standard normal distribution and are independent from one another and among observations. Define two (still unobserved) dummy variables:

$$\begin{aligned} \hat{I}_{1i} &= 1 \text{ iff } \tilde{I}_{1i} > 0;\ \hat{I}_{1i} = 0 \text{ otherwise} \\ \hat{I}_{2i} &= 1 \text{ iff } \tilde{I}_{2i} > 0;\ \hat{I}_{2i} = 0 \text{ otherwise} \end{aligned} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (A.2)$$

Hence, $\hat{I}_{1i}$ equals one for a household with (sufficient) profit possibilities to use the new technology and zero for a household without (sufficient) profit possibilities. $\hat{I}_{2i}$ equals one if and only if a household has (sufficiently) access possibilities to use the new technology and is zero otherwise. For wheat producers to adopt a new technology, it has to be both profitable and accessible. Thus we obtain the model:

$$\begin{aligned} \bar{I}_i &= 1 \text{ if } \hat{I}_{1i}=1 \text{ and } \hat{I}_{2i}=1 \\ \bar{I}_i &= 0 \text{ if } \hat{I}_{1i}=0 \text{ or } \hat{I}_{2i}=0 \end{aligned} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \text{(A.3)}$$

where $\bar{I}_i$ is the observed variable which equals one for a household who adopts the new technology and equals zero otherwise.

The probability of switching to the new technology equals:

$$\begin{aligned} Pr(\bar{I}_i = 1) &= Pr(\hat{I}_{1i} = 1 \text{ and } \hat{I}_{2i} = 1) = Pr(\varepsilon_{1i} < W_{1i}\gamma_1 \text{ and } \varepsilon_{2i} < W_{2i}\gamma_2) \\ &= F(W_{1i}\gamma_1) \cdot F(W_{2i}\gamma_2) \end{aligned} \quad \ldots \text{(A.4)}$$

where $F(.,.)$ is the standard normal cumulative distribution function. Maximum likelihood estimates of γ_1 and γ_2 can be obtained by maximising the Loglikelihood function:

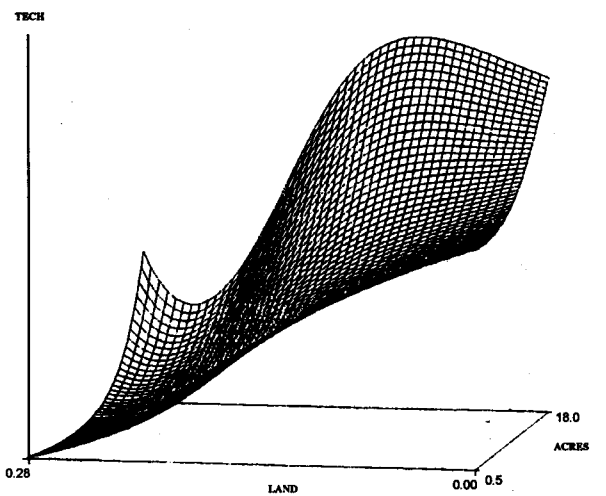
$$\log L = \sum_{i=1}^{N} \left[\bar{I}_i \log\left(F(W_{1i}\gamma_1) \bullet F(W_{2i}\gamma_2)\right) + \left(1 - \bar{I}_i\right) \log\left(1 - F(W_{1i}\gamma_1) \bullet F(W_{2i}\gamma_2)\right)\right] \quad \text{(A.5)}$$

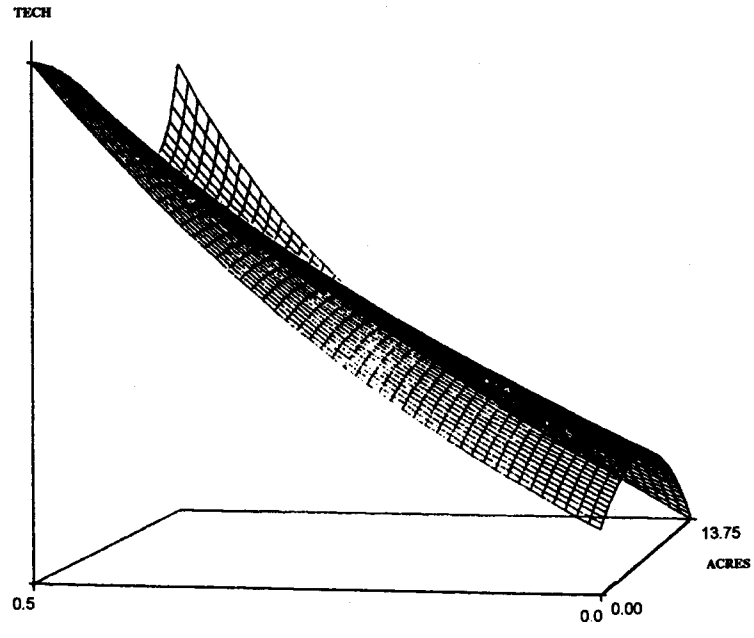
where N is the number of observations.

Poirier (1980) showed that γ_1 and γ_2 are identified as long as W_{1i} and W_{2i} do not contain exactly the same variables and the explanatory variables exhibit sufficient variation.

APPENDIX 2
Diagrams Made with Use of a Kernel Density Estimation

FAISALABAD





Explanation diagrams Appendix 2.

The diagrams are made with a software programme for non-parametric (kernel density) estimation.[18]

Y-axis: TECH, yes or no adoption of recommended wheat varieties.
X_1-axis: LAND, landownership.
X_2-axis: ACRES, amount of acres on which wheat was produced.

The values for LAND and ACRES related to TECH are estimated, with the other variables in Table 4 kept fixed at a given level. These variables are: COUNCIL, ROTA, FERT and OWNS. This means that for these variables the most likely value is assigned. For both districts, the fixed variables have the same value. For COUNCIL this is 0, i.e. do not know someone from the union council. For ROTA this is 1, i.e. do use the rotation pattern described. For FERT this is 1, i.e. did use the

[18]Keyzer and Sonneveld (1998).

Heisey, P. W. (ed) (1990) Accelerating the Transfer of Wheat Breeding Gains to Farmers: A Study of the Dynamics of Varietal Replacement in Pakistan. Mexico, D.F.: CIMMYT. (Research Report No. 1.)

Heisey, P. W., K. A. Tetlay, Z. Ahmed, and M. Ahmad (1990) Farmers Characteristics, Varietal Choice and the Spread of New Wheat Releases. In P. W. Heisey (ed) Accelerating the Transfer of Wheat Breeding Gains to Farmers: A Study of the Dynamics of Varietal Replacement in Pakistan. Mexico, D.F.: CIMMYT. (Research Report No. 1.)

Hoff, K., A. Braverman, and J. E Stiglitz (1993) *The Economics of Rural Organisation—Theory, Practice, and Policy.* World Bank Publication, Oxford: Oxford University Press.

Husain, T. (1992) Modelling Varietal Choice in a Farming Systems Context: The Diffusion of New Wheat Varieties in Gilgit. In D. Byerlee and T. Husain (eds) *Farming Systems of Pakistan.* Islamabad: Vanguard Books Pvt. Ltd.

Keyzer, M. A., and B. G. J. S. Sonneveld (1998) Using the Mollifier-method to Characterise Data Sets and Models: The Case of the Universal Soil Loss Equations. In *ITC-journal*, 97-04. 263–272.

Lieftinck, P., A. R. Sadove, and T. C. Creyke (1968) *Water and Power Resources in West Pakistan, A Study in Sector Planning* (3 Vol.), Volume I, The Main Report. Baltimore: Johns Hopkins University Press for the World Bank.

Maddala, G. .S. (1983) *Limited Dependent and Qualitative Variables in Econometrics.* Cambridge: Cambridge University Press.

North, D. C. (1981) *Structure and Change in Economic History.* New York: W. W. Norton & Company.

Poirier, D. J. (1980) Partial Observability in Bivariate Probit Models. *Journal of Econometrics* 12: 209–217.

Praag, M. van (1996) Determinants of Successful Entrepreneurship. Ph. D. thesis, Tinbergen Institute, Amsterdam. (Research Series No. 107.)

Comments

The paper has four main findings: (i) access to improved wheat seeds is often a problem; (ii) social networks are important for the adoption of recommended wheat seeds; (iii) to adopt recommended wheat seeds, it is important to know a large landowner, i.e., to know someone with more than 20 acres of land; (In the literature on the adoption of new technologies this is often called the trickling down principle, i.e., large landowners often are the first ones to get an improved wheat variety, and after the harvest they give (sell) it to others.) and (iv) high prices of seed are cited as the main constraint on the adoption of new wheat varieties.

Although the paper makes no policy recommendations, these follow directly from the above findings.

I would tend to agree with the main conclusions of the paper, especially those related to profitability and institutional development as factors in the adoption of new wheat varieties. However, I would also like to seek certain clarifications. First, it is not clear from the paper as to what is the relative significance of profitability and institutional factors in determining the adoption rates of new wheat varieties. In other words, which of the two factors was more important. Secondly, the International Food Policy Research Institute (IFPRI) have collected similar data for a number of years. Why did the authors did not use IFPRI's panel data to substantiate the findings following from their own survey data. Thirdly, low seed prices in the public sector relative to the private sector, apart from subsidies, could also be the result of the poor quality of seeds available there. While the authors do not refer to the latter factor, I would like to know if they are familiar with illicit practices in the public sector seed agencies. If so, it would be worth the effort to look into the extent of the problem. Finally, private sector may be more effective in Attock district than in Faisalabad district, and would accordingly affect the adoption rates of new wheat varieties in the two areas.

M. Ghaffar Chaudhry

Pakistan Institute of Development Economics,
Islamabad.