Chapter 2
Technological Change and Productivity Growth in Agriculture

Abstract This chapter has analysed various aspects of technological change in agriculture, identified the factors that determine the rate of adoption of a new technology and examined the impact of the new technology on productivity growth and resource use in the farming sector. The production functions have been estimated using the Generalised Stochastic Formulation of production functions to capture the input related risks in production. It has explained the effect of risk and uncertainty in production, farm size, risk preference, credit supply and education in the determination of the rate of adoption of a new technology in agriculture. Using the results of econometric analysis this chapter has shown that all the inputs do not increase risk in production. An input that increases mean output does not necessarily increase risk. The rate of adoption of high yielding variety technology is higher in small farms under some favourable conditions. The results show that as a result of technological change, the productivity has significantly increased in Indian agriculture. Irrigation, specially ground water irrigation, has played a crucial role in the technological change and productivity growth. At the same time, excessive depletion of ground water, intensive farming and use of chemical inputs have caused serious damage to natural resources.

2.1 Introduction

Agriculture has been playing an important role in the Indian economy since the time of independence. Although the share of agriculture in national income in India has declined to less than 15 % more than 50 % of the population of the country are still dependent on agriculture for employment and livelihood. Agricultural production is divided into two major components: foodgrains and non-foodgrains. The former accounts for approximately two-thirds of the total production. In the foodgrains category the major crops are paddy, wheat, maize, bajra, etc. Although agriculture

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plays a big role in the Indian economy, productivity in agriculture has remained very low compared to major food growing countries. The production of rice per hectare in India was 2000 kg in 1987, while it was 6190 kg in Japan and 5410 kg in China in the same year. For wheat, India's production per hectare in the same year was 2000 kg, whereas in France and China it was 5560 and 3030 kg respectively (Source: Tata Service Limited 1989). However, the scenario has changed over time and the productivity has increased in Indian agriculture in the last 30 years. The yield of rice and wheat per hectare has increased to 3721 and 3177 kg respectively in 2012. But despite growth the productivity in India is still much lower than the major countries. The productivity of rice in China and Japan has reached the figures of 6775 and 6739 kg respectively per hectare in 2012. The same is true for wheat and other major crops (Source: Agricultural Statistics at a Glance 2014, Government of India). Before the introduction of high yielding variety (HYV) technology in the mid-sixties India's foodgrains production was only 72.35 million tonnes in 1965–66 and it was not at all sufficient for the growing population of the country. From 1950 to 1965, the average rate of growth of agricultural production (all crops) in India was 3.02 % per annum while from 1965 to 1980, this average growth rate declined to 2.8 % per annum and it further declined to 0.8 % per annum during the period from 1980 to 1987 (Rao et al. 1988; World Development Report 1989).

Therefore, the growth rate of agricultural production in India was not only low but also it was declining over the years. Among the factors responsible for low productivity in Indian agriculture, technological backwardness is a major one. The uses of fertilizers, HYV seeds and other modern inputs are extremely low. Irrigation facilities are also very limited. The application of fertilizer per hectare of arable land in Japan, China, UK and USA was 427, 174, 378 and 91 kg respectively in 1987, whereas in India it was only 57 kg in the same year (Source: World Development Report 1989). Only 24 % of net cropped area under foodgrains in Inida was under irrigation in 1970–71 and in the same year the gross cropped area under foodgrains using the HYV technology was only 12.38 % (Source: Government of India 1991).

A technological breakthrough was a necessary condition for stepping up of agricultural production in India in 1960s and 1970s. The study of Hayami and Ruttan (1971) on productivity differences among countries shows that the differences in technical inputs and human capital do account for a very substantial share of agricultural productivity gaps among them. In their consideration, a common basis for achieving success in rapid growth in agricultural productivity is the capacity to generate an ecologically adapted and economically viable technology in each country. Schultz (1964) expresses the view that significant growth in productivity can not be brought about by reallocation of resources in a traditional agriculture. According to him, significant opportunities for growth would become available only through changes in technology. Mellor (1966) describes that the traditional agriculture is characterized by low capital investment and low productivity. A reallocation of resources through price changes may have some weak and temporary effects on production but a strong and long lasting effect will be forthcoming only in a situation of technological change. Lee (1971) on the basis of her study on Taiwanese agriculture, concludes that in the development of Taiwanese agriculture, technology played a crucial role. The postwar advances in technology in Taiwanese agriculture consisted of mainly extension of uses of fertilizers, pesticides, new crop varieties and new cultivation practices. Fan (1991) shows that in the development of Chinese agriculture in the last few years, technology had an important role.

Relative endowments of the two primary resources, land and labour are critical elements in determining a viable pattern of technological change in agriculture. Land constraint is much stronger in agricultural production than in any other sector of the economy. Agricultural growth can be viewed as a process of easing the constraints on production imposed by inelastic supplies of land and labour. So, generally two types of technologies are developed: (i) Biochemical technology and (ii) Mechanical technology. The former is land-augmenting in nature, while the latter is labour-saving in character. In a land scarce and labour abundant country like India, what was needed was to develop and adopt an appropriate biochemical technology. Mechanical technology involving tractors and power tillers, irrigation pumps and similar farming devices might be used only as a supplement to the former.

The acute food crisis of 1961–66 propelled the introduction of the HYV technology in Indian agriculture in the mid-sixties. It was a package programme consisting of HYV seeds, chemical fertilizers, pesticides, assured supply of water and a new agricultural practice. One important feature of this new technology is that the yield potential of the modern varieties is remarkably higher than that of the traditional varieties. The new technology was initially introduced mainly in the cultivation of rice and wheat. Since the new technology was risky, another important aspect of the new agricultural strategy was that, it was first introduced in less risky areas and among the farmers who were willing and capable of taking risk. It was expected that with the spread of knowledge of the new technology, uncertainties and risks would gradually decline and then it would spread in other parts of the country and be adopted by all other farmers.

The policy makers, planners, economists and researchers mostly supported the policy of such a technological change in Indian agriculture. However, some of them raised questions regarding the adaptability of the new technology to the given economic and institutional conditions of the Indian farmers and also with respect to the distribution of gains from the new technology. Rao (1968) suggested that along with institutional reforms, extension of irrigation and supply of credit to the farmers, due importance should be given to modernisation of agriculture for rapid growth in production. Minhas and Srinivasan (1968), while commenting on the official strategy for increasing agricultural production in India, remarked that the new agricultural strategy based on the introduction of new crop varieties and the use of chemical fertilizers, was in the right direction and necessary for the country. Krishna (1967), Narain (1977) recognized the role of price as an incentive for higher production but at the same time they suggested that the main emphasis should be given on technological change.

Dantwala (1986), strongly defended the policy of introducing the new technology in Indian agriculture. He remarked that the food-crisis in India in the mid-sixties was so acute and unprecedented that it was compelling for India to grow more food as quickly as possible by adopting the new technology, irrespective of where it was grown and by whom. It was however admitted that although the new technology is technically scale-neutral, in Indian socio-economic conditions, it has a class-bias in favour of large farmers. The Working Group of the Indian Council of Social Science Research analysed the alternative ways of agricultural growth in India and recommended the spread of the HYV technology in Indian agriculture, irrespective of whatever alternative is chosen.

The adoption of modern technology, particularly the land-augmenting biotechnology became more important in India in view of the fact that the demand for food and other agricultural products was increasing rapidly in India with population growth. But the scope for increasing agricultural production through extensive cultivation was almost exhausted by 1965. Gross area under foodgrains in India has remained more or less constant at 124 million hectares over the years (Source: Government of India 2001). In this backdrop, it was very difficult to increase the total production of the country without increasing the productivity per hectare. Again, productivity could be increased by adopting the HYV technology on a wider scale. Since the introduction of the HYV technology in the mid-sixties, the Government of India has been spending large sums of money on irrigation, extension services, rural electrification and subsidies on agricultural inputs like fertilizers and pesticides. Nevertheless the degree of adoption of the new technology by the farmers could not reach a significant level by 1980. In 1970–71, only 12.38 % of the gross area under foodgrains was under the HYV scheme and this proportion rose to 49 % in 1989–90 and it further increased to 61 % in 1997–98 (Source: Government of India 2000). The factors generally identified as the main constraints to the rapid adoption of a new technology in agriculture were lack of irrigation, lack of credit, small farm-size, lack of knowledge about the technology, lack of education, uncertainty in yield and aversion to risk of the farmers. This section investigates into the factors which really acted as constraints to the adoption of a productivity enhancing new technology in agriculture in countries like India.

2.2 Major Issues of Technological Change in Agriculture

2.2.1 The Adoption of a New Technology

A large volume of literature, both theoretical and empirical, is available to explain the rate and pattern of technological changes that are taking place in agriculture in the developing countries and to identify the factors causing such changes. The theoretical studies define the adoption variables rigorously, set precise relationships for estimation, suggest hypotheses and help interpreting the empirical results in a proper way. Feder et al. (1985) have made a comprehensive survey of the important studies on the adoption and diffusion of technological innovations in agriculture.

The survey provides an analytical framework for investigating the adoption behaviour of the farmers and suggests a quantitative definition of adoption of a new technology making a difference between individual (farm) level adoption and aggregate adoption. Final adoption by the individual farmer is defined as the degree of use of a new technology in the longrun when the farmer has full information about the new technology and its potential. Aggregate adoption is measured by the aggregate level of use of a specific new technology within a given geographical area or a given population. The 'diffusion of a technology' on the other hand is defined as the cumulative process of adoption of the technology measured in successive time periods.

There is a distinction between technologies that are divisible (such as HYVs, chemical fertilizers, etc.) and innovations that are not divisible (say, tractors, harvesters, etc.). The intensity of adoption for the former type of innovation can be measured at the individual level in a given period by the amount or share of farm area utilizing the technology or by the per hectare quantity of input used. Analogous measures may apply at the aggregate level for a region. For non-divisible innovations, the extent of adoption at the farm level in a given period is necessarily dichotomous (i.e. use/no-use) but in the aggregate, the measures become continuous.

The analytical framework for analyzing technological change in agriculture includes a model of farmer's decision making regarding the extent of use of a new technology. Generally, the farmer's decisions in this regard are assumed to be derived from the maximization of expected utility of income (or profit) subject to the constraints like land availability, supply of credit and so on. Profit is a function of the farmer's choices of crops and technology in each period. Given the discrete choice of a technology, income or profit is a continuous function of land allocation among crop varieties, the production functions of these crop varieties, the variable inputs and the prices of inputs and output. Given the discrete choice, land and input values, the perceived income of the farmer may be regarded as a random variable embodying both subjective and objective uncertainties. In this type of adoption model, generally, the production function can be assumed to be the only source of uncertainties. So, proper specification of uncertainties in production function is very important for analysis of technological change.

2.2.2 Uncertainty in Production

Agricultural production is uncertain by nature. This is due to uncertainties in rainfall, climatic conditions and other natural factors. But when a new technology is introduced, uncertainty in production generally arises due to lack of information and inefficient use of modern inputs. So, it is important to incorporate risk and uncertainty in production function properly. Just and Pope (1978, 1979) have developed a production function to accommodate properly the uncertainties in production. In their view, the popular econometric specification of the

Cobb-Douglas production function with log-linear disturbances can not properly reflect risk in production. It incorrectly imposes an a priori restriction on the production function that if the marginal contribution of an input to the mean output is positive, then a positive marginal effect on the variance of output is also imposed. Following Just and Pope (1978) the Cobb-Douglas form of the function with stochastic term is expressed as

$$Y = A\left(\prod_{i=1}^{n} x_i^{\alpha_i}\right)e^{\varepsilon}$$

where, Y is output, X_i is a factor input ($X_i > 0$), ε is a stochastic disturbance term with E(ε) = 0, V(ε) > 0 and A is a constant term. The marginal effect of input use on production variability is defined as $V(Y) = A^2\left(\prod_{i=1}^{n} X_i^{2\alpha_i}\right)V(e^{\varepsilon})$. Just and Pope (1978) demonstrate that

$$\frac{\delta V(Y)}{\delta X_i} = \frac{2\alpha_i A^2}{X^i}\left(\prod_{i=1}^{n} X_i^{2\alpha_i}\right)V(e^{\varepsilon}) \; > \; 0, \quad \text{assuming } \alpha_i > 0.$$

Thus, an increase in input use always increases the variability of output if the marginal productivity of the input is positive. They have also pointed out that other functional forms like Transcendental, Translog, CES and Generalised Power Function have the same limitation when they are used with log-linear disturbances.

It needs to be noted that all inputs do not increase risk in production; on the contrary, there may be some inputs like irrigation, pesticide, equipments, etc., which are likely to reduce risk in production. Besides, the inputs which were risky at the early stage of their application may become risk-neutral subsequently. So, the production function must possess sufficient flexibility such that differential effects of an input on the mean and the variance of output are accommodated. Just and Pope (1978) have developed such a Generalised Stochastic Formulation (GSF) of the function which can be expressed as

$$Y = f(x) + h(x)\varepsilon, \quad E(\varepsilon) = 0,\; V(\varepsilon) = \sigma,$$

where *Y* is actual output, *X* is set of inputs, *f*(*x*) is mean output, *h*(*x*) is a term capturing the variability of output and is assumed to be positive and ε is a random term.

Here the production function has two components: (i) the Deterministic Component, *f*(*x*) and (ii) the Stochastic Component, *h*(*x*) ε. The former specifies the effects of inputs on the mean output and the latter specifies the effects of inputs on the variance of output. These two components are independent. Hence,

$$\frac{\delta V(Y)}{\delta x_i} = h_i(x) \; > \; = < 0.$$

Thus the authors have shown that the effect of an input on the variability of output may be positive, zero or negative. In a separate paper, Just and Pope (1979) have explained the estimation procedure of the production function, specifying it in the form

$$Y = f(X) + h^{\frac{1}{2}}(X)\varepsilon, \quad E(\varepsilon) = 0,\ V(\varepsilon) = 1;$$

where the mean output, $E(Y)$ is $f(x)$ and the variance of output, $V(Y)$ is $h(x)$. Here $\delta V(Y)/\delta x >\ = <0$.

2.2.3 Uncertainties, Learning and Adoption of a New Technology

Most of the theoretical studies on the adoption behaviour of individual farmers use a static framework that relates the degree of adoption to factors affecting it. These studies investigate the properties of the solution to particular cases of the temporal optimization problem of the farmer. In these optimization problems, the farmer is to choose between two technologies: the traditional technology and a modern technology (such as HYVs and the inputs associated with them). Models dealing with such problems investigate how much land is allocated to modern technology and the amounts of modern inputs to be applied per unit of land under different circumstances. The uncertainties in production may be higher at the early stage of adoption of a new technology because the farmers do not have complete knowledge about the new technology at the initial stage. So the farmers may be more risk-averse about the technology. However, as time passes, learning takes place and the farmers are encouraged to adopt the technology on a larger scale.

Hiebert (1974) has used a stochastic production function and assumed risk aversion to examine the effects of uncertainty and imperfect information on fertilizer use and allocation of land to HYVs. In his approach farmers have different and incomplete information about the characteristics of new and improved inputs. So, there is the possibility of allocative errors and hence there are greater risks and uncertainties in production. Learning, here, has been interpreted to mean gaining more information about the technology. In Hiebert's formulation, the stock of information increases as the adoption process proceeds. This reduces risks and uncertainties in production and as a result the probability of adopting a new technology increases.

The likelihood of adopting a new technology also depend on the physical environment of cultivation. A more favourable environment such as better soil, water availability and efficient irrigation system increases the expected utility of net income from modern cultivation and thereby increases the probability of adopting the new technology. When irrigation is available both in the dry and rainy seasons, the probability of adoption is greater in the dry season compared to the rainy season. This is because mean yield is higher and variance of yield is lower in the dry season due to better agro-physical conditions.

2.2.4 Farm Size, Risk Aversion and the Adoption of a Modern Technology

There is a debate that the small farmers will be reluctant to adopt a new technology because the production under modern technology is uncertain and the small farmers are risk averse. In a model constructed by Feder (1980) it is assumed that production under the new technology is uncertain whereas yield of the traditional variety is certain. It is also assumed that there is risk aversion and that adoption of the new technology requires no fixed initial cost. In the model, if there is no credit constraint, fertilizer use per acre is independent of farm size. But the allocation of land to modern cultivation is affected by risk factors. The relationship between the share of land allocated to modern variety and farm size depends on the relationship between the relative risk aversion and income. It is demonstrated that if the adoption of modern technology involves some fixed cost, it is likely that the relationship between the proportion of land allocated to modern cultivation and farm size will be positive.

Feder and O'Mara (1981) have shown that a positive relationship between farm size and the share of modern farming can be explained by the existence of some fixed cost associated with the adoption of the new technology. As the new technology is perceived as more risky, it is argued that the small farmers will be less inclined to adopt the innovation as they are more risk averse. But the study considers risk aversion as a deterrent to innovation adoption by small farmers only to the extent that adoption entails fixed costs. In their reasoning fixed adoption costs do exist and such costs are not a characteristic of the HYV technology itself but are a result of information acquisition requirements, inefficient input distribution systems, etc. In their model the interaction between risk aversion and fixed costs can explain the differential and farm-size dependent pattern of technology adoption in both static and dynamic perspectives. In addition, there may exist a lower limit on the size of the adopting farm such that the farms smaller than this critical minimum will not be able to adopt the new technology due to higher adoption cost. The size of critical minimum may, however, decline over time if adoption cost declines due to learning and dissemination of information about the technology.

Just and Zilberman (1983) have developed a more generalized model to examine the relationship between the share of land allocated to modern variety and farm size. The model recognizes that production under both traditional and modern varieties are uncertain and assumes that production under the modern technology is more uncertain: It considers the fact that there may be some fixed cost of adoption of the new technology and land holding has some role in the risk-preference of the farmer. Given these specifications, the model shows that if the correlation of output under old and new technologies is low or negative and if the modern technology is sufficiently more risky than the traditional one, the larger farms will allocate more land in absolute terms but less land in proportionate terms to the new technology compared to the smaller farms when relative risk aversion is increasing and absolute risk aversion is decreasing with the farmer's income.

2.2.5 Adoption of Interrelated Technologies in Agriculture

The technologies may be interrelated or there may be some degree of complementarity among them. Feder (1982) has analysed the nature and extent of adoption of interrelated technologies in agriculture taking into account the complementarity among them, credit constraint and uncertainty in production. In his framework there are two types of modern technologies: one is scale-neutral (say HYVs) and the other is a lumpy one (say, tubewell) with a fixed capacity and a fixed installation cost. The farmers can use either of the two or both at the same time. The production is uncertain under both technologies. The yield under traditional system is however assumed to be riskless. The use of lumpy technology increases mean production and reduces the uncertainty of production under both traditional and modern crops.

The model of Feder indicates that while HYVs will be adopted by all farmers (in the absence of fixed adoption cost and credit constraint), there will be a critical farm size such that only the farms which are above this critical size will adopt the lumpy innovation for a given risk aversion. When HYVs are used combined with lumpy innovation, risk of HYVs declines. This encourages comparatively small farmers also to adopt lumpy innovation in association with HYVs. That means, the critical minimum size for the adoption of lumpy innovation declines. What proportion of land will be used for HYVs in association with the lumpy innovation depends on the nature and degree of complementarity between the two technologies (defined not only in terms of cross-yield effects but also in terms of cross-risk effects). This model further states that if there is a binding credit constraint, an element of substitutability between the technologies may be introduced. Then the adoption of one technology may retard the adoption of the other.

2.2.6 Education and Human Capital in the Adoption of a Risky Technology

In the adoption of a new technology education and human capital have some role. Schultz (1975) has explored that in a static traditional agriculture, experience is more valuable for the farm manager than education. But in a modernizing agriculture, education is important because it enhances the farmer's 'ability to deal with the disequilibria' arising out of the dynamics of innovation. Rahm and Huffman

(1984) have presented a model which examines the role of human capital in the adoption of reduced tillage practices in Iowa state. The results show that the human capital variables like education, health, extension services, etc., enhance the farmer's allocative skills and also the efficiency of the farmer in taking adoption-decisions.

Lin (1991) used the diffusion of F_1 hybrid rice as a case for examining the effects of education on the adoption of new technology in agriculture in China. He has presented a simple behavioural model where the adoption of a new technology is treated as a portfolio selection. In the model it is assumed that production under traditional farming is certain, whereas the yield under the new technology is uncertain. In Lin's study production process changes with the introduction of a new technology. But as the farmer's information is imperfect there is the possibility of allocative errors and hence the adoption of the new technology becomes risky. So, Lin's hypothesis is that as education enhances one's ability to receive, decode and understand information, the level of education has a positive impact on the adoption of a new technology. The empirical results based on micro level data confirm this hypothesis.

2.2.7 *Role of Price in the Adoption of a New Technology*

Hayami and Ruttan (1971), in their famous "induced innovation model", hypothesized that advances in both mechanical and biochemical technologies respond to changing relative prices of factors and to changes in the prices of factors relative to products. In their analytics, the technical change is guided along an efficient path by price signals in the market, provided that the prices efficiently reflect the changes in demand and supply of products and factors and there exists effective interaction among farmers, public research institutions and private agricultural supply firms. However, in practice, all these conditions are not always fulfilled.

Feder (1980) demonstrates that a decline in input price or an increase in output price does not necessarily lead to allocation of greater amount of land to modern cultivation or to application of greater amount of fertilizer per unit of land. Price will have a favourable effect on the use of a new technology only when the technology is not highly risky and adequate infrastructural facilities are available.

2.2.8 *Diffusion of a New Technology*

While the adoption of a new technology is defined as the amount of land or the share of land allocated to modern cultivation in a particular point of time, the diffusion of the technology is the cumulative process of adoption of the new technology in agriculture over time. It considers the problem of adoption at the aggregate level in a dynamic perspective. Griliches (1957) made a pioneering study of the factors responsible for the wide cross-section differences in the rates of use of hybrid seed corn in the USA. It is an econometric study where the logistic growth function has been fitted to the data. Three parameters of the function viz. origin, slope and ceiling have been estimated. The origin indicates the date of first adoption, the slope indicates the rate of adoption and the ceiling indicates the maximum cumulative percentage of adoption or long-run upper limit of adoption. The estimates have shown a S-shaped pattern of aggregate diffusion of the hybrid seed.

Griliches has remarked that it is not a single invention immediately adaptable everywhere. In contrast, the breeding of adaptable hybrids are to be done separately for each region. In the breeding process, some areas may be lagging behind the others. The results of the study indicate that the differences in the rates of adoption (slopes) and in the long run equilibrium uses of hybrid corn (ceilings) in different areas are explained, at least in part, by the differences in the profitability of the shift from the open pollinated to hybrid varieties in different parts of the country. The profitability of entry is again a function of market density, cost of innovation and cost of marketing. Jarvis (1981) has made a similar study on the diffusion of improved pastures in Uruguay. In his fitted logistic function both the rate of adoption and the maximum limit of adoption are positively related to the profitability of the technology.

Kislev and Shchori-Backrach (1973) have constructed a diffusion model to explain the process of an innovation cycle. They have considered comparative advantages, dynamic as well as static, to be crucial in determining the pattern of adoption of innovations. In the model it is assumed that the innovation is either a new product or a new method that appreciably affects the supply of an existing product. The industry is competitive and is composed of small firms. The model demonstrates that the producers with highest skills will be the early adopters of the innovation because they are more efficient in the acquisition of knowledge about the innovation. On the other hand, the less skilled firms will wait until sufficient experience is accumulated at the industry level. With the passage of time as output expands, knowledge about the new technology diffuses to the less skilled firms and the new technology is ultimately adopted. But with the joining of the less skilled firms in the rank of adopters, if the market supply increases substantially and prices fall the more skilled producers who have a higher opportunity cost for their labour and other resources may switch to a new product or a new method of production. Thus a new innovation takes place and hence, it is called an innovation cycle. Such a theory is well recognized in industrial sector and international trade. The present model shows that this theory is applicable to the agricultural sector also.

Feder and O'Mara (1982) have developed a model on 'information and innovation' using a Bayesian approach. They are of the view that learning and information accumulation play a major role in innovation diffusion. The hypothesis of the model is that the individual farmers revise their beliefs in a Bayesian fashion. It demonstrates that the Bayesian learning can generate a characteristic sigmoid-shaped adoption function for a dominant innovation.

2.2.9 Tenurial Arrangement and Technological Change in Agriculture

There is a large volume of literature which show that tenurial arrangement may have an important role in the decision-making with respect to the adoption of an innovation in agriculture. Bhaduri's theoretical model (1973) in the context of the production relations prevailing in Indian agriculture considers a semi-feudal agricultural system where the landlord exercises two modes of exploitations—usury and landownership. As the income of the tenant falls short of their consumption needs they are forced to take consumption loans from the landlord who charges high rate of interest on such loans. The landlord takes a share of the total crop as landowner. Another part of the crop is taken by him as interest and repayment of loan. As a result, the tenants are to take further loan for consumption. Thus, they are forced to be in perpetual indebtedness. Bhaduri's proposition is that in such a semi-feudal agricultural system, the landlord class will always resist the introduction of an improved technology which raises agricultural productivity. The reason is that if agricultural productivity increases, the tenant's income will rise and then their dependence on the landlord for consumption loan will decline. This will reduce the landlord's income from usury. So, Bhaduri concludes, the semi-feudal tenurial arrangement acts as a barrier to technological progress in agriculture.

Newbery (1975) has criticized Bhaduri's analysis with the argument that if the landlord has sufficient monopoly power to exploit the tenants and withhold innovations in agriculture, he ought to have sufficient power to extract the extra profit generated by the innovation. Srinivasan (1979) shows that Bhaduri's conclusion does not follow from his model. Using the same model he demonstrates that landlord's income will increase with the total output in all cases. So, the landlord will have an incentive in introducing an yield increasing innovation.

Bardhan and Rudra (1978) made an empirical survey on agrarian relations in eastern part of India which shows that Bhaduri's description of landlord-tenant relations has no empirical basis. Their evidences strongly suggest that incidence of usury as the main mode of exploitation is very rare. On the contrary, the landlords are, in general, found to take lot of interest in raising agricultural productivity by making productive investments and introducing new innovations. Using a theoretical model Braverman and Stiglitz (1986) show that the institutional structure of the agricultural sector in less developed countries may be an important determinant of whether a particular innovation is adopted or not. But what will actually happen depends on a number of conditions.

2.2.10 The Role of the Government

Feder and Slade (1985) have reviewed in a theoretical model the rationale of and scope for public sector involvement in the diffusion of a new technology in agriculture. They are of the view that the generation of an improved technology is not sufficient for agricultural growth. It is also necessary to diffuse the knowledge of the new technology among the farmers. Their model shows that in the initial stage, the farmers have limited information about the new technology. So, there will be a divergence between the true distribution and the perceived distribution of the net benefits from the technology and this may discourage the farmers to adopt it. In this situation they have suggested that the government could take an active role in the diffusion of knowledge of the new technology through extension services and other measures. The government intervention in the output and input markets through taxes and subsidies has been justified in the early stage of adoption. They suggest that government expenditure on infrastructure like irrigation and transportation and supply of credit from government sources may be also helpful for the diffusion of the new technology.

2.2.11 The Distribution of Gains from Technological Change

Bell (1972) demonstrates that the changes in the distribution of income after the introduction of new innovations in agriculture are only partly explained by the nature of innovations themselves. The factors which govern the rate and pattern of diffusion of the innovations and the consequent changes in income distribution are rooted substantially in the character of the prevailing socio-economic system. In a purely technical sense, the green revolution technology is scale neutral but the prevailing socio-economic conditions are such that they have some bias in favour of large farmers. The large farmers are in an advantageous position to adopt the new technology at an early stage and at a higher rate compared to the small farmers. So, the distribution of gains from technological change may not be equitable.

2.2.12 Evidences from Empirical Studies

The empirical study of Herdt (1987) on the use of modern technology in rice farming in Philippines reveals that the modern varieties have been almost universally adopted and farm size has no effect on the rate of adoption. Only in certain parts of the country the small farms lagged behind larger ones in fully adopting modern varieties but eventually caught up. The study also shows that technologies were adopted in Philippines as individual components, not as a package. Another finding of the study is that the biochemical technology has been, in general, more widely adopted by the farmers than the mechanical technology giving an indication that labour use per hectare has increased after the introduction of the HYV technology.

Antle and Crissman (1990) have analysed the growth of technical efficiency of the farmers over time under a situation of technological change in Philippines. According to them, the adoption of a new technology is a dynamic process and in this process, the efficiency of the farmers increases as learning takes place. At the early stage of adoption, the farmers may be less efficient because they do not have full knowledge about the new technology. But over time as learning takes place, the efficiency among the early adopters increases. The efficiency of the late adopters also increases if they have access to the information acquired by the early adopters. With increase in efficiency of the farmers the rate of adoption increases. The empirical results show that nitrogen fertilizer is not necessarily risk-increasing; on the contrary, it is risk-reducing under favourable conditions. This study also reveals that irrigation has improved technical efficiency in all cases and the modern varieties have benefitted relatively more from irrigation than the traditional varieties.

Byerlee and Polanco (1986) have tested a hypothesis that the farmers adopt improved technological components in a stepwise manner. In order to raise productivity in agriculture the researchers and extension-agents have developed technological package consisting of components such as crop varieties, fertilizers, planting method and weed control. The proponents of the package-approach argue that a package is needed to reap the positive interactions between several components. But Byerlee and Polanco have remarked that the farmer may not be in a situation to adopt a complete package due to capital scarcity, considerations of risk or supply constraints. So, they have proposed that the package may be disaggregated into clusters of one or two components and the farmers can rationally follow a process of stepwise adoption of the technological components in a sequential manner.

Perrin and Winkelman (1976) have summarized some of the important findings of the farm level studies on the adoption of new wheat and rice varieties in Kenya, Colombia, El Salvador, Mexico, Tunisia and India. The studies show that the differences in the adoption behaviour of the farmers are only partly explained by the differences in information, availability of inputs, market opportunities for the crop and risk aversion of the farmers. In most cases, little relationship is found to exist between farm size and adoption rate. The pattern of adoption among large and small farms is generally consistent with the proposition that small farms may lag behind larger ones in the early stage of adoption but soon they catch up. The most important finding of these studies is that the rate of adoption differs across farms and across areas due to differences in yield owing to differences in soil, climate, water availability and other biological factors. The result has the implication that agricultural technology is basically site-specific and hence, natural resources and environmental factors have important role in technological change.

Bera and Kelley (1990) have estimated the rate of diffusion of the high yielding varieties of rice in Bangladesh using logistic-type econometric models. The results show that the diffusion rate is not constant over time. The rate and level of adoption have been found to be influenced by flood damage, relative prices of competing crops like jute and traditional varieties of rice. One important result of the study is that the greater and more intensive is the damage to HYV (due to flood and other natural adverse conditions) the greater is the likelihood of farmers shifting from HYV to traditional varieties. The most important finding of this study is that the ceiling adoption level of HYV has nearly been reached in Bangladesh. So, unless new HYVs are developed with wider adaptability specially for drought and flood prone areas, little scope exists in Bangladesh for increasing production through increase of acreage under HYV of rice.

The study of Anderson and Hamal (1983) in the context of Nepal conclude that perception of risk and aversion to risk provide only a very partial explanation of the farmer's decision regarding the use of a new technology. The other factors like farmers' attitude towards bureaucrats, their access to factor markets, the procedures and preferences of implementing agencies are much more important in this regard.

Ruttan (1977) has drawn several important generalisations on the basis of a large number of empirical studies on the adoption of new technology in agriculture. Some of the generalisations are:

(i) the HYVs have been adopted at exceptionally rapid rates in those areas where they are technically and economically superior to local varieties.
(ii) neither farm size nor tenure has been a serious constraint to the adoption of new HYVs. The smaller farms and tenants might have lagged in the early phase of adoption but within a few years they have come to catch it up.
(iii) the use HYVs has intensified the use of labour in production.
(iv) Landowners have gained relatively more than the tenants.

It has been acknowledged that these are broad generalisations and there may be exceptions to these observations depending on differences in economic, socio-political and environmental factors.

2.2.13 The Indian Experience

Rao (1975) has made a comprehensive study of the magnitude and pattern of technological changes that have taken place in Indian agriculture since mid-sixties and of the factors influencing such changes. His study reveals that the rise in the prices of agricultural commodities and labour inputs relative to the prices of fertilizers, machineries and other equipments led to the adoption of both biochemical and mechanical technologies. This study shows that irrigation has positive impact on the use of HYVs. The profitability of HYVs is higher and uncertainty is lower in the Rabi-season (dry season) than in the Kharif Season (rainy season) and this is due to the fact that environmental factors are more suitable for HYVs in the Rabi-season. As regards the relationship between farm size and the use of biochemical inputs, Rao's argument is that although HYV seeds and fertilizers are scale-neutral in technical sense they are not resource-neutral. So, the adoption of biochemical technology will be more extensive among the large farmers than the small ones. The empirical findings of the study support this hypothesis.

Harriss (1972) made an empirical study on the adoption of HYV technology in India and identified the factors influencing the adoption process. He is of the view that irrigation itself is a primary innovation and it can be treated as a precondition for and stimulus to further innovation. Her analysis shows that as water-management is better in tubewell irrigation than in canal irrigation, the adoption rate of HYV is higher under the former than under the latter. The relationship between farm size and adoption rate is ambiguous in this study. Under certain conditions the small farmers have been found to be equally efficient in adopting the innovation. It has been also pointed out that given the costs and risks of the new technology the prevalent tenurial system may be a deterrent to innovations. The study reveals that the financial return from the new technology is the main motivation for adopting the new innovation. The prices of inputs and output appear to be very important in this regard. Another important finding of her study is that the acquisition of primary education has the greatest influence on fertilizer use. In the study of Harriss, the use of HYV seeds has intensified the use of labour. Hence, insufficient labour supply may turn out to be a constraint to the adoption of the HYV technology. The credit facilities, however, have not been able to create much incentives for using the innovations.

Muthiah (1971) has found that small and medium-size farms in India have adopted HYVs on a larger proportion of acreage than did the large farms. In respect of HYV adoption in wheat cultivation in India, it is also found that tenants are not only as innovative as landowners but also sometimes they use more fertilizers per hectare than do the owners of land. Bhalla (1979) shows in a study on Indian agriculture that lack of credit is a major constraint to the use of fertilizer. He concludes that access to credit might be responsible for the gain in income (and HYV area) made by the large farmers. A case study by Sidhu (1974) in Punjab shows that the new wheat-technology is neutral with respect to farm size. He finds that the new technology is neither labour-saving nor capital-saving in nature.

Bhalla and Chadha (1982), on the basis of their study in Punjab, have found that the advent of green revolution in Punjab has brought about an overall prosperity to its peasantry. As a result of the creation of an assured irrigation base and its fairly equitable distribution, all categories of cultivators have been able to record substantial increase in their output and income by adopting the new technology. The gains from the new technology is found to be distributed among the farmers more or less proportionately with their initial land holding positions. The study also reveals that the per hectare application of input resources of different farm-size groups is, in general, strikingly similar although some differences are noticed in paddy cultivation.

2.2.14 Summary

This section considers the major issues of technological change in agriculture in the developing countries like India. Here we have mainly considered the adoption of land-augmenting biotechnology in agriculture by the farmers. It makes a difference between adoption and diffusion of a new technology. The adoption is defined as the amount or share of land allocated to modern technology whereas diffusion of a new technology is described as the cumulative process of adoption of a new technology in an area over time. The productivity under modern cultivation is higher than the traditional variety. But production under modern variety is uncertain. So, risk and uncertainty and farmer's attitude to risk play important role in the adoption of a new technology in agriculture. The specification of risk in production function is important for explaining input related risk properly. The uncertainty in yield needs to be so incorporated in production function that an input does not necessarily become a risk-raising factor in production. Uncertainty in yield and risk of production may be a deterrent to the adoption of a modern technology in the initial stage. But as adoption process proceeds the farmers gathers more information and knowledge about the technology and as a result the probability of adopting a new technology increases. The government has important role in the diffusion of a new technology in agriculture through extension services, dissemination of knowledge and development of infrastructure. Equally, the spread of education and formation of human capital may be helpful for technological change in agriculture.

There is a debate that small farmers may not be able to adopt a new technology specially when the farmers are risk-averse and the adoption of the technology involves a fixed cost. But theoretical and empirical studies demonstrate that the adoption rate of the technology may be even higher in small farms under certain favourable conditions. Similarly tenancy farming is not always a constraint to technological change in agriculture.

Technically the HYV technology is scale-neutral in nature but economically, it may have some bias in favour of large farmers. So far as the distribution of gains from higher productivity of modern farming is concerned, all groups of farmers are found to be benefitted from higher productivity due to technological change although in some cases, the large farmers have gained more. While price is not found to have much influence on the diffusion of a technology, irrigation plays a key role in this regard in all cases. The geo-physical conditions also have significant impact on the adoption of a new technology in agriculture.

The new bio-technology popularly known as high yielding variety (HYV) technology puts huge stress on natural resources like land and water. This section highlights the major aspects of using HYV technology although there are other technologies which are interrelated and sometimes complementary in nature. For example, irrigation technology and technologies for water management and soil conservation are also very important in the present context. Irrigation is very important for productivity growth. The conservation of soil fertility and management of water resource are very important for sustainable growth. So, technology not only plays an important role in enhancing productivity but also help maintaining sustainable growth in agriculture through conservation of natural resources.

2.3 Modern Technology, Input Related Risk and Estimation of Production Functions

The adoption of a modern technology in agriculture depends on many factors among which risk and uncertainty in production and farmer's attitude towards risk are very important. Agricultural production is always uncertain. Natural and agro-climatic conditions create this uncertainty. This uncertainty may increase under a new technology. The new inputs of the modern technology like HYV seeds, chemical fertilizers and pesticides enhance agricultural productivity and at the same time, they may make production more uncertain and risky due to lack of adequate knowledge about the use of the inputs properly or some inherent properties and external effects of the inputs. So, risk becomes an important element in the decision-making with respect to the amount of land to be allocated to modern cultivation and the amounts of inputs to be used per unit of land. Naturally, it becomes important to examine the effects of the inputs not only on the mean output but also on the variability of output. The stochastic specifications of input-output relationship are examined in many ways. The most familiar and commonly used formulation for estimating production functions in such cases is the log-linear Cobb-Douglas (C-D) production function. But Just and Pope (1978) have demonstrated that the popular econometric specification of the C-D production function with log-linear disturbances incorrectly imposes a risk-increasing effect of an input on output. It puts a restriction that if an input has positive marginal effect on mean output, then a positive marginal effect on variance of output is also imposed. They further mention that the other functional forms like Transcendental, Translog, CES and the Generalised Power Function also will have the same limitation if they are used with log-linear disturbances.

But all inputs do not increase risk in production. On the contrary, there may be many inputs like irrigation, pesticide, equipments, etc., which generally reduce risk in production. Besides, the inputs which are risky at the early stage of their application may be subsequently risk-neutral or risk-reducing over time. So, the production function must possess sufficient flexibility such that differential effects of an input on the mean output and the variance of output are accommodated. Considering all these features in agricultural production Just and Pope (1978) have developed a Generalised Stochastic Formulation (GSF) of the production function which is expressed as

$$Y = f(X) + h(X)\varepsilon, \quad E(\varepsilon) = 0,\ V(\varepsilon) = \sigma$$

where Y is actual output, X is set of inputs, $f(X)$ is mean output, $h(X)$ is a term capturing the variability in output and is assumed to be positive and ε is a random term. Here, the production function has two components: (i) the Deterministic Component, $f(X)$ and (ii) the Stochastic Component, $h(X)$ ε. The former specifies the effects of inputs on the mean output and the latter specifies the effects of inputs on the variance of output. These two components are independent. This formulation satisfies the postulate that

$$\frac{\partial V(Y)}{\partial X} > \, = \, < \quad 0 \text{ where } V(Y) = E[Y - E(Y)]^2.$$

Most of the usual production functions like Cobb-Douglas, Translog, etc., can be used for the estimation of 'f' and 'h' and they will give consistent and efficient estimates. In a separate paper, Just and Pope (1979) have explained the estimation procedure of the production function, expressing the function in the following form:

$$Y = f(X) + h^{\frac{1}{2}}(X)\varepsilon, \quad E(\varepsilon) = 0, V(\varepsilon) = 1,$$

where the mean output $E(Y) = f(X)$ and the variance of output, $V(Y) = h(X)$ and $\frac{\partial V(Y)}{\partial X} > \, = \, < 0$.

Just and Pope (1979) have explained the estimation procedure of GSF in three steps and the technique of estimation has been used in this book to estimate the production functions empirically.

2.3.1 The Estimation Procedure

For the purpose of empirical estimation,[1] it is supposed that both 'f' and 'h' follow the standard Cobb-Douglas form, i.e.,

$$f(X) = \alpha_0 X_1^{\alpha_1} X_2^{\alpha_2} \cdots X_k^{\alpha_k}$$

and

$$h^{\frac{1}{2}}(X) = \beta_0 X_1^{\beta_1} X_2^{\beta_2} \cdots X_k^{\beta_k}$$

Now, the regression equation to be estimated is:

$$Y_t = \alpha_0 X_{1t}^{\alpha_1} X_{2t}^{\alpha_2} \cdots X_{kt}^{\alpha_k} + h^{\frac{1}{2}}(X_{1t}, X_{2t} \cdots X_{kt}, \beta)\varepsilon_t$$
$$t = 1, 2, \ldots T$$

where ε_t is a spherical random disturbance term having $E(\varepsilon_t) = 0$, $E(\varepsilon_t \, \varepsilon'_t) = 0$, for $t \neq t'$ and $E(\varepsilon_t^2) = \sigma^2$ for $t = 1, 2, \ldots T$.

[1]The estimation procedure is based on the paper, Just and Pope (1979).

The parameters to be estimated are:

(i) $\alpha_0, \alpha_1, \alpha_2, \ldots \alpha_k$,
(ii) $\beta_0, \beta_1, \beta_2, \ldots \beta_k$.
and
(iii) σ, along with standard errors of the estimated coefficients.

To estimate the heteroscedastic non-linear regression equation, the following 3-step procedure may be used:

Step-I: The regression equation,

$$Y_t = \alpha_0 X_{1t}^{\alpha_1} X_{2t}^{\alpha_2} \cdots X_{kt}^{\alpha_k} + \varepsilon_t^*, t = 1, 2, \ldots T$$

is estimated by non-linear least-squares (assuming $E\left(\varepsilon_t^* \varepsilon_{t'}^*\right) = 0$ for $t \neq t'$).

Here, $\varepsilon_t^* = h^{\frac{1}{2}}(X_t, \beta)\varepsilon_t$. In other words, $\alpha_0, \alpha_1, \alpha_2, \ldots \alpha_k$ are estimated by minimizing $S_1^2 = \sum_{t=1}^{T} \left(Y_t - \alpha_0 X_{1t}^{\alpha_1} \cdots X_{kt}^{\alpha_k}\right)$ with respect to α's using some iterative procedure. The parameters $\alpha_0, \alpha_1, \alpha_2 \ldots \alpha_k$ may be estimated by the OLS method using the log-linear regression equation:

$$\log Y_t = \log \alpha_0 + \alpha_1 \log X_{1t} + \cdots + \alpha_k \log X_{kt}$$

and the OLS estimates of α's can be used as initial values in the iterative process.

Step-II: Suppose, the estimates obtained from Step-I (NLS) are $\hat{\alpha}_0, \hat{\alpha}_1, \ldots \hat{\alpha}_k$. Now one can compute the estimated value of $\hat{Y}_t = \hat{\alpha}_0 X_{1t}^{\hat{\alpha}_1} \cdots X_{kt}^{\hat{\alpha}_k}$. Let $e_t = Y_t - \hat{Y}_t$, $t = 1, 2, \ldots, T$ be the computed residuals. To have the estimates of β's the following regression is estimated by OLS:

$$\log|e_t| = \beta_0 + \beta_1 \log X_{1t} + \cdots + \beta_k \log X_{kt} + V_t$$

(logs are here natural logarithms) where V_t's are assumed to be spherical random disturbances.

Thus in Step-II, one obtains the OLS estimates $\hat{\beta}_0, \hat{\beta}_1, \ldots \hat{\beta}_k$ of the corresponding parameters. Here, actually, the estimates of the parameters β's are obtained by estimating the regression equation,

$$\varepsilon_t^* = h^{\frac{1}{2}}(X_t, \beta)\varepsilon_t, \text{ by log-linear OLS.}$$

Step-III: In Step-III, a weighted non-linear least-squares regression of Y_t on X_t with weights $h^{\frac{1}{2}}\left(X_t, \hat{\beta}\right)$ can attain asymptotic efficiency in estimates of α's. Using the estimates of β's, the dependent variable for the Step-III non-linear regression is constructed as

$$Y_t^* = Y_t \cdot h^{\frac{1}{2}}\left(X_t, \hat{\beta}\right) - \left(\hat{\beta}_0 + \hat{\beta}_1 \log X_{1t} + \cdots + \hat{\beta}_k \log X_{kt}\right)$$

for $t = 1, 2, \ldots T$ and the following regression equation is estimated:

$$Y_t^* = e\{(\alpha_0 - \beta_0) + (\alpha_1 - \beta_1)\log X_{1t} + \cdots + (\alpha_k - \beta_k)\log X_{kt}\} + W_t,$$

treating W_t to be a spherical random disturbance term. In other words, in Step-III, the estimates $\alpha_0, \alpha_1, \ldots \alpha_k$ are obtained by minimizing the non-linear least squares

$$S_2^2 = \sum\left(Y_t^* - e^{\left\{\left(\alpha_0 - \hat{\beta}_0\right) + \left(\alpha_1 - \hat{\beta}_1\right)\log X_{1t} + \cdots + \left(\alpha_k - \hat{\beta}_k\right)\log X_{kt}\right\}}\right)^2$$

with respect to $\alpha_0, \alpha_1, \ldots \alpha_k$. These and the corresponding estimates of standard errors will be the final estimates.

2.3.2 The Empirical Estimation of Production Functions

Using the specification, $Y = f(X) + h^{\frac{1}{2}}(X)\varepsilon$ and following the procedure explained above, the production functions have been estimated for both traditional (Aman) and high yielding varieties (HYV) paddy to find out the effect of inputs on mean and variability of output. The results will indicate which inputs are increasing risk. While the production function for Aman paddy has been estimated for the rainy season only, the production functions for HYV paddy have been estimated for both the rainy and dry (Boro) seasons separately.[2] Again, the production functions for HYV paddy have been estimated separately for different irrigation systems in the dry season. The efficiency of irrigation under different systems of water supply is different. In the estimation of the production functions, four inputs have been included here and they are: X_1 is seed, X_2 is labour, X_3 is fertilizer and X_4 is pesticide. Y is output. The inputs and output have been considered in terms of per acre of land. Although irrigation is an important element in HYV paddy cultivation, the present study could not include it in the production function as an input. However, the impact of quality of irrigation on the mean and variance of output and also on the efficiency of inputs have been captured by estimating production functions under different modes of irrigation separately.[3]

[2] Aman is traditional local variety paddy. The dry season is also called Boro season in many parts of India.

[3] In the empirical estimation of the production functions using the formulation of Just and Pope (1979), the OLS estimates of α's have been used as initial values in the iterative process.

2.3.3 Source of Data

The data used in this study are primary data collected by a field survey in Daspur Block-I of Midnapore district in West Bengal (an eastern state in India).[4] Farm level disaggregated data are very appropriate for estimating the production functions. So, farm level data were collected by a field survey. Daspur Block–I is predominantly an agriculture-based area. The total cultivated land in this Block is 13,000 ha, of which 10,020 ha are under irrigation. Irrigation is available from canals, tubewells (deep, mini deep and shallow), River water-lift schemes (RLI), boro-bandh, tanks etc. Most of the irrigation projects are in the public sector. Under boro-bandh irrigation, temporary reservoir is constructed on the river to store water and water overflows through canals to the fields in the dry season. Under RLI, water is lifted from river by diesel-run heavy pumps placed in a boat.

Out of the total 13,000 ha of cultivated land, 330 ha are high lands, 3200 ha are medium lands and the rest 6500 ha are low lands. The low lands in many cases are prone to flood and water-logging. The cropping intensity in this Block is very high and it is 169.47. The cropping intensity is defined as the ratio of gross cropped area and the net cropped area. High cropping intensity means that the practice of double or triple cropping is high.

The HYV technology has been in use in paddy cultivation in this Block since late sixties. The government has provided huge extension services for the diffusion of knowledge of the new technology among the farmers. The programmes adopted in this regard consisted of Trial Programmes, Demonstration Centres, Farmers Training Meetings, etc. The farmers in this Block are quite familiar with this new agricultural technology. In 1991–92, 5700 ha of land were under HYV paddy cultivation indicating that the rate of adoption of the HYV technology in the area was very high at that time.

Apart from irrigation and extension services, other facilities are also available in this Block. There are 21 Agricultural Cooperative Societies which provide improved seeds, agricultural inputs (like fertilizers) and financial credit to the farmers. The numbers of licensed dealers for supplying agricultural inputs to the farmers are as follows: fertilizers 172, pesticides 65, seeds 30. Other infrastructural facilities like transportation and rural electrification are also fairly good. All these factors helped the farmers to adopt the new technology. Most of the farmers in this Block are marginal farmers. The average cultivated land per farming household is 0.47 ha. Power tiller is used on a wide scale for cultivation of land in this Block. The farmers mainly use the hired services of power tillers against the payment of some rental charges. Another equipment which is also used on a large scale is irrigation pump, mainly run by electricity.

[4]The survey was conducted in 1989–90 in connection with the author's doctoral research and it was financed by the University Grants Commission (India).

2.3.4 Methodology of Data Collection

The primary data were collected by a field survey using the method of multi-stage stratified random sampling. There are 157 villages in Daspur Block—I. Some of them were excluded from the list on the ground that either they were in highly flood-prone areas where normal agricultural activities are not possible or they were in remote areas where the collection of data is difficult. Out of the remaining villages 14 were selected in the first stage on the basis of random sampling. The lists of farmers along with their farm sizes of the selected 14 villages, were supplied by the Gram Panchayats.[5]

In the second stage, all the farmers in each of the randomly selected villages were classified into three categories: marginal, small and big. According to the local panchayat norms, the farmers having cultivated land up to 2.50 acres are marginal farmers, the farmers possessing cultivated land from 2.51 to 5.00 acres are small farmers and the farmers possessing cultivated land exceeding 5.00 acres are big farmers. Most of the farmers in each village have been found to be belonging to the category of marginal farmers. Some of them are possessing so little amounts of land that proper farming behaviour is not expected from them. So, in consultation with the villagers and local experts, the farmers possessing very small amount of land were excluded from the list. The number of farmers in each category for the 14 randomly selected villages taken together are as follows:

Marginal farmers	980
Small farmers	100
Big farmers	15
Total sample farmers	1095

Finally, 30 % farmers from each category in each of the randomly selected villages were selected as samples on the basis of random sampling. The sample size stood at 329. In the total sample the numbers of marginal, small and big farmers are 294, 30 and 5 respectively.

Cross-section farm level data on various aspects of paddy cultivation were collected from the sample farmers through a primary survey. An appropriate and well defined questionnaire was used for this purpose. Before the final survey was conducted, a 'Pilot-survey' had been done in the area. The 'various concepts' relating to the survey have been defined following standard literature and having consultations with the local experts. The data were collected for the year 1989–90 which was a normal year from the viewpoint of agricultural production. The variables for which data have been collected, are as follows:

[5]These lists were prepared by the Gram Panchayats (local government) for planning purposes.

(i) *Farm size* total amount of cultivated land possessed by the farm family. It includes both irrigated as well as non-irrigated lands and it has been measured in acres.
(ii) *Area under irrigation* amount of land (measured in acres) under any form of irrigation. It has been recorded for the dry season and rainy season separately.
(iii) *Area under HYV* amount of land (measured in acres) used for the cultivation of high yielding varieties of paddy. It has also been recorded for the dry and rainy seasons separately.
(iv) *Amount of agricultural credit received by the farmer* agricultural credits are broadly classified into two categories—short term and long term. The former is taken for the purchase of variable inputs like fertilizers, pesticides, etc., whereas the latter is received for the purchase of fixed capitals like Power tiller, irrigation pump, setting up of shallow tube-wells etc. Data on both types of credits have been collected and they have been collected for the dry season and the rainy season separately. They have been measured in terms of Rupees.
(v) *Output of paddy per acre* it has been measured in terms of kilograms. The data on this variable have been collected for both traditional as well as high yielding varieties and they have been collected for the dry and rainy seasons separately.
(vi) *Input used per acre in paddy cultivation*

   (a) **Seed**—it has been measured in terms of value (in Rupees) where a higher value implies better quality of seed. As the physical amount of seed used per acre is more or less the same, it has been measured in terms of value to reflect the differences in quality.
   (b) **Labour**—It has been measured in terms of man-days of adult male workers.
   (c) **Fertilizer**—as heterogeneous types of fertilizers are used in cultivation, it has been measured in terms of value (in Rupees).
   (d) **Pesticides**—it has been also measured in terms of value (in Rupees).
   (e) **Use of Power tiller**—amount of land (measured in acres) prepared for cultivation by power tiller.
   (f) **Literacy rate**—the percentage of literate persons in the farming household. It has been taken as an 'index of education' of the farm family in this study.

2.3.5 Summary Statistics

The summary statistics in Table 2.1 are very revealing. The yield under HYV in the rainy season is higher than the traditional variety (Aman) but variance is also higher in the former. That means, under the new technology productivity is higher and at

Table 2.1 Mean values of different inputs used per acre of land for the cultivation of paddy, 1989–90 (at 1989–90 prices)

Crop variety and season	Seed (Rs.)	Labour (man-days)	Fertilizer (Rs.)	Pesticide (Rs.)
(1)	(2)	(3)	(4)	(5)
Aman in rainy season	84	62	106	Nil
HYV in rainy season	136	71	350	100
HYV in dry season	164	97	679	185

Source Calculated from primary survey data in Sasmal (1992)

Table 2.2 Mean and standard deviation of output of paddy, 1989–90

Crop varieties in different seasons and under different irrigation systems	Mean output per acre (kg)	Standard deviation of output
(1)	(2)	(3)
Aman in rainy season (all forms of irrigations taken together)[a]	987.44	180.40
HYV in rainy season (all forms of irrigations taken together)	1413.28	238.73
HYV in dry season (all forms of irrigations taken together)	1972.09	231.37
HYV in dry season (under bandh irrigation)	1762.38	244.93
HYV in dry season (under RLI)	1936.76	186.00
HYV in dry season (under tubewell irrigation)	2052.30	157.22

Source Calculated from primary survey data in Sasmal (1992)
[a]It includes production under non-irrigated land also

the same time uncertainty is also higher. Table 2.2. shows that mean output of HYV paddy in the dry season is highest and variance of output is lowest under tube-well irrigation. It is because of controlled system of water supply indicating highest efficiency of irrigation in this system. On the contrary, mean output is lowest and variability is almost highest in the rainy season when efficiency of water supply is very low. Among the three modes of irrigation bandh irrigation has the lowest efficiency in the dry season with lowest mean and highest variance of output. Water supply is uncontrolled in this system because water overflows to the fields from river.

2.3.6 Estimation of Production Functions for HYV Paddy in the Dry and Rainy Seasons

The estimates of the production function for HYV paddy in the dry and rainy seasons using the generalized stochastic formulation (GSF) have been presented in Table 2.3 (deterministic component) and Table 2.4 (stochastic component).

Table 2.3 Third-stage estimates of the deterministic component of the production function for HYV paddy in the rainy and dry seasons using GSF

Inputs		Coefficients of inputs in mean output		t-value of the coefficients	
		Rainy season	Dry season	Rainy season	Dry season
(1)		(2)	(3)	(4)	(5)
X_1	α_1 =	0.37 (0.13)	0.11 (0.07)	2.84[a]	1.57
X_2	α_2 =	0.79 (0.09)	0.83 (0.08)	8.77[a]	10.37[a]
X_3	α_3 =	0.17 (0.07)	0.41 (0.07)	2.42[a]	5.85[a]
X_4	α_4 =	0.52 (0.08)	0.48 (0.07)	6.50[a]	6.85[a]
Constant term	α_0 =	33.56 (7.71)	31.45 (4.54)	4.35[a]	7.06[a]
		R^2 = 0.99	R^2 = 0.99		
		n = 137	n = 263		

Similar results have been found in Sasmal (1993). The source of the results is Sasmal (1992)
Source Estimated from primary survey data in Sasmal (1992)
Figures in parentheses are standard errors
[a]significant at 5 % level

Table 2.4 Second-stage estimates of the stochastic component of the production function for HYV paddy in the rainy and dry seasons using GSF

Inputs		Coefficients of inputs in mean output		t-value of the coefficients	
		Rainy season	Dry season	Rainy season	Dry season
(1)		(2)	(3)	(4)	(5)
X_1	β_1 =	−1.18 (0.94)	−0.82 (0.56)	−1.25	−1.46
X_2	β_2 =	1.34 (0.72)	−1.15 (0.65)	1.86[a]	−1.76[a]
X_3	β_3 =	−0.54 (0.56)	−0.09 (0.56)	−0.96	−0.16
X_4	β_4 =	0.44 (0.62)	1.40 (0.59)	0.70	2.37[a]
Constant term	β_0 =	2.18 (1.56)	2.93 (1.15)	1.39	2.54[a]
		R^2 = 0.05	R^2 = 0.03		
		F = 1.68	F = 1.95		
		n = 137	*n* = 263		

Similar results have been found in Sasmal (1993). The source of the results is Sasmal (1992)
Source Estimated from Primary Survey data in Sasmal (1992)
Figures in parentheses are standard errors
[a]Significant at 5 % level

Table 2.3 shows the estimates of the magnitude and direction of the effects of inputs on the mean output of HYV paddy in the dry and rainy seasons. It shows that R^2 is very high implying that the variation in mean output is highly explained by the regression equation. The results also indicate that all the coefficients are positive and statistically significant. The most important factor in mean output is labour both in the dry and rainy seasons. Fertilizer and pesticide are the two most important ingredients of the HYV technology in paddy cultivation. They are found to have significant impact on mean output. Fertilizer becomes more effective in the dry season due to better irrigation and suitable agro-climatic conditions. Since HYV plants are more vulnerable to pests and disease in the rainy season pesticide is seen to have a greater role in mean output in the rainy season. Seed is another important component of the new technology. The amount of seed to be used per acre is more or less technically fixed. But the quality of seed differs and it is reflected in the cost of seed. In the present study, seed is represented in terms of cost, a higher cost implies better quality of seed. As the coefficient of seed is positive and statistically significant, it implies that better quality of seed leads to higher mean production.

Labour has appeared to be the most important factor in mean output. This result suggests that as the cultivation of HYV paddy is highly labour intensive (Harriss 1972; Ruttan 1977), proper cultivation is possible only when sufficient labour is employed particularly when the uses of labour-substituting machineries and equipments are limited.

Table 2.4 show the relative contributions of the sample inputs to the variability of output in the rainy and dry seasons. The very low R^2 indicates that the inputs do not explain the variability of output by any significant extent. The 'goodness of fit' of the regression equation to the observed data is also very weak. This may be due to the fact that there is inadequacy in the specification of the regression equation in the sense that many factors which may be really responsible for variability in output such as rainfall, nature of irrigation, weather conditions and physical environment have not been included in the regression equation.

Nevertheless, some factors have appeared to be significant in explaining the variability of output. Judging by the t-values, the coefficients of labour and pesticide are statistically significant. It is important to note that fertilizer has no risk-raising effect on production and it is consistent with the finding of Antle and Crissman (1990).[6] According to their explanation, in the short run the farmers may be inefficient in using the modern inputs like fertilizer. But over time as learning takes place, the farmer's efficiency, both technical and allocative, will improve and as a result the input which was risky at the early stage, may be ultimately risk-neutral or risk-reducing. The HYV technology has been in use, in paddy cultivation in the present situation for quite a long period. So, it is very likely that the farmers have acquired sufficient knowledge about the use of the input by this time. The coefficient of seed in variability of output is statistically insignificant implying that quality of seed has failed to explain the uncertainty in production. It is interesting that labour is risk-reducing in the dry season and risk-raising in the rainy season. This result can be explained in the following way: The rainy season is the main cropping season of paddy in India and paddy being a labour intensive crop, the local demand for labour remains very high in the rainy season. This demand is further increased by the cultivation of HYV paddy. So, the farmer's dependence on

[6]Antle and Crissman (1990) have concluded that nitrogen fertilizer does not necessarily increase risk in production; on the contrary, it may reduce risk under favourable conditions. Their study is based on pooled time series and cross-section data in the context of Philippine agriculture.

'hired labour' increases and in that case, not only the uncertainty in timely availability of labour increases, but also, the possibility of unskilled labourers getting employed in large numbers increases. In effect, uncertainty in production may increase with increase in employment of hired labour.

Another interesting result is that the coefficient of fertilizer in mean output is much higher in the dry season than in the rainy season. The implication of this result is that the use of fertilizer becomes more effective in raising mean output in the dry season. This is possibly due to better physical and agro-climatic conditions and controlled supply of water. For the same reason, the relative importance of pesticide declines in the dry season compared to the rainy season. The coefficient of seed in mean output in the dry season is insignificant implying that the quality of seed does not matter so much in the dry season as it does in the rainy season. Another possible explanation of this result is that the farmers are using almost similar quality of seed in the dry season.[7] As the inter-farm variation in the quality of seed is low it fails to explain the variation in output per acre across farms. Although pesticide is risk neutral in the rainy season, surprisingly the coefficient of pesticide is positive and statistically significant in the dry season. Pesticide is generally supposed to reduce risk in production by controlling pests and disease. But here the effect is just reverse. It is a chemical input and it has some optimal doses of application. A favourable climatic condition may also be necessary for its effectiveness. Possibly the input could not be used properly in the dry season.

2.3.7 *Estimation of Production Functions for HYV Paddy Under Different Irrigation Systems in the Dry Season*

The three major irrigation systems in use in the area selected for this study are: bandh irrigation, river water-lift irrigation (RLI) and tube-well irrigation. Efficiency in water supply varies under these three systems (see Table 2.2). The most effective system is tube-well irrigation and RLI comes next in the rank of efficiency. Production functions for HYV paddy under these three systems in the dry season have been estimated separately. The estimates presented in Table 2.5 (deterministic components) and Table 2.6 (stochastic components) give idea about the efficiency of irrigation on output and input use.

Table 2.5 exhibits the input coefficients in mean output under different forms of irrigation. It shows that the coefficient of fertilizer is positive and significant under all the three systems of irrigation. It is also revealed that fertilizer becomes comparatively more effective under RLI and tube-well irrigation due to better water management. Pesticide has been found to have no significant impact on the mean output under RLI. The physical environment and the water management under this

[7]Mean and standard deviation of seed in the dry season are Rs. 164 and 17 respectively, whereas they are Rs. 136 and 24 respectively in the rainy season.

Table 2.5 Third-stage estimates of the deterministic component of the production function for HYV paddy under different irrigation systems in the dry season using GSF

Inputs		Coefficients of inputs in mean output			t-value of the coefficients		
		Bandh irrigation	River lift irrigation	Tube-well irrigation	Bandh irrigation	River lift irrigation	Tube-well irrigation
(1)		(2)	(3)	(4)	(5)	(6)	(7)
X_1	$\alpha_1 =$	0.009 (0.108)	0.15 (0.11)	0.13 (0.14)	0.08	1.36	0.92
X_2	$\alpha_2 =$	1.356 (0.232)	1.14 (0.13)	0.63 (0.16)	5.84[a]	8.76[a]	3.94[a]
X_3	$\alpha_3 =$	0.319 (0.172)	0.43 (0.10)	0.44 (0.15)	1.85[a]	4.30[a]	2.93[a]
X_4	$\alpha_4 =$	0.328 (0.109)	0.13 (0.10)	0.29 (0.07)	3.00[a]	1.30	4.14[a]
Constant term	$\alpha_0 =$	21.240 (5.267)	32.01 (7.18)	63.79 (18.12)	4.03[a]	4.45[a]	3.52[a]
		$R^2 = 0.99$	$R^2 = 0.99$	$R^2 = 0.99$			
		n = 67	n = 68	n = 65			

Source Estimated from primary survey data in Sasmal (1992)
Figures in parentheses are standard errors
[a]Significant at 5 % level

Table 2.6 Second-stage estimates of the stochastic component of the production function for HYV paddy under different irrigation systems in the dry season using GSF

Inputs		Coefficients of inputs in the variability of output			t-value of the coefficients		
		Bandh irrigation	River lift irrigation	Tube-well irrigation	Bandh irrigation	River lift irrigation	Tube-well irrigation
(1)		(2)	(3)	(4)	(5)	(6)	(7)
X_1	$\beta_1 =$	−0.51 (1.62)	−1.78 (1.33)	−0.80 (1.28)	−0.21	−1.28	−0.62
X_2	$\beta_2 =$	−1.04 (3.15)	−2.39 (1.60)	3.08 (1.40)	−0.33	−1.49	2.20[a]
X_3	$\beta_3 =$	−0.31 (2.50)	0.32 (1.28)	−0.98 (1.36)	−0.12	0.25	−0.72
X_4	$\beta_4 =$	0.51 (1.66)	1.94 (1.38)	1.90 (0.67)	0.30	1.40	2.83[a]
Constant	$\beta_0 =$	4.36 (3.53)	4.93 (2.47)	4.15 (2.42)	1.23	1.99[a]	1.71[a]
		$R^2 = 0.02$	$R^2 = 0.05$	$R^2 = 0.26$			
		F = 0.28	F = 0.91	F = 5.36			
		n = 67	n = 68	n = 65			

Source Estimated from primary source data in Sasmal (1992)
Figures in parentheses are standard errors
[a]Significant at 5 % level

form of irrigation may be such that plants are less susceptible to pests and diseases. So, the application of pesticide becomes less important. It may be also true that this input could not be used properly in this case. In fact, pesticide will have significant contribution to mean output and it will have risk-reducing effect on output only when it is used properly and under favourable conditions. However, the coefficients of pesticide in mean output are positive and statistically significant under tube-well and bandh irrigations. The coefficient is higher under bandh irrigation indicating that the importance of pesticide is higher when water management is poor. For the same reason, the contribution of labour to mean output is highest under bandh irrigation.

Table 2.6 shows the coefficients of inputs in variability of output under different irrigation systems in the dry season. As before, R^2 is low under all the three systems. While F-statistics is insignificant under bandh and river water-lift irrigations, it is significant only under tube-well irrigation. It has been already discussed that there may be inadequacy in the specification of the regression equation in the sense that many factors which are really contributing to uncertainty in production, have not been included in the function. This inadequacy is likely to be more pronounced under bandh irrigation where water management is very poor. As a result, under this system all the input coefficients including the constant term of the function are found to be insignificant. Under RLI, water management is little better. But here also, the input coefficients are insignificant, although the constant term is significant and positive.

F-statistic is significant only under tube-well irrigation. This is explained by the fact that the external factors which are likely to have significant impact on the variability of output viz., waterlogging, attacks of pests and disease, uncertainty in water supply, etc. are less prominent in this system of irrigation. So, the specification of the function improves and the explanation of the uncertainty in production by the inputs slightly improves. It needs to be noted that labour is a risk-reducing factor in HYV cultivation in the dry season when all modes of irrigation are taken together (see Table 2.4). But if labour is considered for tube-well irrigation only, it becomes a risk-raising factor. Explanations have been provided for the results in Table 2.4. So far as the effect of labour on the variability of output under tube-well irrigation is concerned it may be mentioned that the areas served by tube-well irrigation are nearer to the town in the present study. Here, employment opportunities are high throughout the year and there is scarcity in labour supply. The supply of labour is also influenced by the labour organisations and the political parties. So, the supply of labour becomes more uncertain and this factor contributes to uncertainty in production.

2.3.8 Estimation of Production Function for Aman (Traditional) Paddy in the Rainy Season

The estimates of the production function for Aman paddy in the rainy season using the GSF have been presented in Table 2.7. The input set of this production function excludes pesticide because, the use of pesticide under the traditional variety is very rare. Table 2.7 shows that the coefficients of all the three inputs, seed, labour and fertilizer in mean output are positive and statistically significant. The most important factors are seed and labour. It is also revealed that the contributions of labour and seed to mean output are greater under traditional variety than those under high yielding varieties in the rainy season (see Table 2.3). Fertilizer is not an essential input for Aman paddy. But if it is used, it will have a mean-raising effect on production. However, the effect is smaller as compared to that under high yielding varieties.

Table 2.7 also shows the coefficients of inputs in the variability of output of Aman paddy. The very low R^2 indicates that as before the inputs considered here fail to explain the variability of output by any considerable extent. The 'goodness of fit' of the regression equation to the observed data is also very poor. All the factor coefficients including the constant term of the function are found to be insignificant. That means, the variability in output is explained by the factors other than the inputs considered here.

Table 2.7 The estimates of production function for Aman paddy in the rainy season

Inputs		Third-stage estimates of the deterministic component			Second-stage estimates of the stochastic component	
		Coefficients of inputs in mean output	t-values of the coefficients		Coefficients of inputs in mean output	t-values of the coefficients
(1)		(2)	(3)		(4)	(5)
X_1	$\alpha_1 =$	1.25 (0.15)	8.33[a]	$\beta_1 =$	−0.59 (0.72)	−0.81
X_2	$\alpha_2 =$	1.25 (0.10)	12.50[a]	$\beta_2 =$	0.80 (0.68)	1.17
X_3	$\alpha_3 =$	0.14 (0.02)	7.00[a]	$\beta_3 =$	0.19 (0.20)	0.95
Constant term	$\alpha_0 =$	6.94 (0.98)	7.03[a]	$\beta_0 =$	0.79 (0.99)	0.82
		$R^2 = 0.99$			$R^2 = 0.012$	
		n = 223			F = 0.92	
					n = 223	

Source Estimated from primary survey data in Sasmal (1992)
Figures in parentheses are standard errors
[a]Significant at 5 % level

2.3.9 Summary

In this sub-section we have estimated production functions for Aman (Traditional) paddy and HYV paddy using the generalized stochastic formulation (GSF) of production function developed by Just and Pope (1978, 1979). The GSF shows the differential effects of the inputs on the mean and variability of output. In GSF, an input which has positive marginal effect on mean output, does not necessarily have positive marginal effect on the variability of output. The functions have been estimated using farm level primary data. The results show that fertilizer and labour have significant positive impact on mean output under all irrigation systems both in the dry and rainy seasons. Fertilizer is more effective in raising productivity in the dry season and under tube-well irrigation. This is because of greater efficiency in water supply in tube-well irrigation and better agro-climatic conditions in the dry season. Among the three modes of irrigation, tube-well, bandh and river-lift, the most efficient system is tube-well irrigation. The other inputs like seed and pesticide are not found to have much impact on the mean and variability of output. The inputs have failed to explain the variability of output in these estimations. This is because there may be inadequacy in the specification of the regression equation in the sense that the factors which are really responsible for variability of output have not been included in the production function. Since mean output is higher and uncertainty in production is lower under tube-well irrigation, this mode of irrigation has been largely utilized for HYV cultivation.

2.4 Uncertainty in Production, Risk Preference and Adoption of a New Technology in Agriculture—A Theoretical Framework

The theoretical framework of adoption of a new technology in agriculture under production uncertainty in this section is based on the work of Feder (1980).[8] Following Feder it is assumed that two distinct technologies are available to a farmer: traditional technology and modern technology. The modern technology can be the high yielding variety (HYV) technology. It is also assumed that output from both technologies are homogeneous. Traditional technology requires no specialized inputs and yields a given net return per acre with certainty. In other words, there is no uncertainty with regard to the yield per acre under the traditional variety. But the production under modern technology requires some modern inputs, namely, improved seed, chemical fertilizers and pesticides. For simplicity, it is assumed that only chemical fertilizer is required for production under modern cultivation and the yield per acre under modern technology is uncertain. But the yield potential of the

[8]This section of the book largely draws from Feder (1980).

modern variety is significantly superior to that of the traditional variety. The production under modern technology is subject to both subjective and objective uncertainties. As the modern varieties are more susceptible to pests and weather conditions, there are objective uncertainties. The subjective uncertainties originate from the farmer's incomplete knowledge regarding the cultivation practice and production function parameters. So, the cultivation of modern varieties is risky.

A general specification of the production function exhibiting such uncertainties has been developed by Just and Pope (1978), the details of which have been explained in the previous section. The function can be written as

$$q = f(z) + \varepsilon g(z) \tag{2.1}$$

where,

q actual output per acre.
f mean output per acre.
z fertilizer used per acre.
g a term related to output variability and is assumed to be positive.
ε a random variable, $E(\varepsilon) = 0$.

The production function possesses the following properties:

(a) $f' = \frac{df}{dz} > 0$
(b) $f'' < 0$
(c) $g' = \frac{dg}{dz} > 0$
(d) $f(0) > 0$
(e) $g(0) > 0$

This formulation of the production function is flexible enough to allow situations where some inputs (like pesticides and irrigation) have opposite effects on mean and variance of output. The familiar Cobb-Douglas production function with log linear disturbances, can not accommodate such flexibility. It wrongly imposes a risk-increasing effect of such inputs on output. Other common stochastic production functions like Transcendental, Translog, CES, etc. also appear inadequate in this respect when they are used with log linear disturbances.

Given the above specifications of the production function, the analytical framework can be characterized by the following assumptions:

(i) The farmer is an owner cultivator.
(ii) The farmer has a fixed amount of land denoted by $\overline{L}$.
(iii) The farmer operates in a situation of perfect competition, i.e., perfect competition prevails both in product market and input market.
(iv) There is no credit constraint.
(v) There is no constraint on the supply of labour and the availability of other inputs.

(vi) The farmer is familiar with the new technology. That means, he knows that such a technology is available and he has the necessary knowledge of using it.

(vii) The farmer's objective is to maximize the expected utility of income.

Now, the income of the farmer is defined as

$$\pi = \left\{P \cdot L[f(z) + \varepsilon g(z)] + R\left(\overline{L} - L\right) - c \cdot z \cdot L\right\} \tag{2.2}$$

where

P is price of output.
L is amount of land allocated to modern cultivation.
R is value of net return per acre under traditional variety.
c is price of fertilizer per unit.

The utility function of the farmer is

$$U = U(\pi), U' > 0, \text{ and } U'' < 0.$$

The utility function is strictly concave implying that the farmer is risk averse. $\left(-\frac{U''}{U'}\right)$ is the measure of absolute risk aversion and $\left(-\frac{U''}{U'}\right) \cdot \pi$ is relative risk aversion (Arrow 1971; Pratt 1964).

$\frac{d\left(-\frac{U''}{U'}\right)}{d\,\pi} < = > 0$, implies decreasing, constant and increasing absolute risk aversion.

Here non-increasing risk aversion is assumed.

Now, the problem of the farmer is to choose the optimal values of L and z, so as to maximize the expected utility of income,

$$EU(\pi) = EU\left\{P \cdot L[f(z) + \varepsilon g(z)] + R\left(\overline{L} - L\right) - cZL\right\} \tag{2.3}$$

It is a static optimization problem. The first order conditions for maximization of Eq. (2.3) are:

$$\frac{\partial EU}{\partial L} = E\{U'[P(f(z) + \varepsilon g(z)) - R - cZ]\} = 0. \tag{2.4}$$

$$\frac{\partial\, EU}{\partial\, z} = E\{U'[P(f'(z) + \varepsilon g'(z)) - c]\}L = 0. \tag{2.5}$$

The second order conditions can be satisfied if (i) $U'' < 0$ (which is a specification about U) and (ii) $f'' < -g''[\,E(U'\varepsilon)/EU']$. By Lemma 1 of Feder (1977), $[EU'\varepsilon/EU'] < 0$. So, given the specifications of f'' and g'', $g'' \geq 0$ is a sufficient condition for ensuring second-order conditions, although $g'' < 0$ can also be accommodated. In other words, the maximum solution can be obtained if the marginal mean productivity decreases faster than the marginal contribution to the risk component (g).

Now, the optimum values of z and L (denoted by z^* and L^* respectively) can be obtained from the Eqs. (2.4) and (2.5) and are expected to depend on P, c, R, ε and $\overline{L}$ and also on the parameters of $f(z)$, and $g(z)$ and utility function $U(.)$. According to Feder (1980) the optimal level of z is independent of the degree of risk-aversion, the degree of variability of ε and the farm size ($\overline{L}$).

The main objective of this exercise is to see how the optimal level of land-allocation to modern cultivation is affected by different factors and parameters namely, risk aversion, farm size and credit constraint.

2.4.1 *The Optimal Allocation of Land and Risk-Aversion*

The area allocated to modern variety may be affected by the degree of risk aversion of the farmer and to study the impact of risk-aversion, we may assume a specific form of utility function as in Feder (1980):

$$U(\pi) = \frac{\pi^{1-\gamma}}{(1-\gamma)}; \quad 1 > \gamma > 0 \tag{2.6}$$

where γ is the Arrow (1971), Pratt (1964) measure of relative risk-aversion. The larger is γ, more risk-averse is the farmer.

Now, it can be shown that optimal allocation of land to modern cultivation declines with higher degree of risk-aversion.

Given the Eq. (2.6),

$$EU = E\left\{\frac{\pi^{1-\gamma}}{(1-\gamma)}\right\}$$

$$\frac{\partial EU}{\partial L} = E(\pi^{-\gamma} \cdot A) = 0,$$

or,

$$E(U'A) = 0, \tag{2.7}$$

where $U' = \pi^{-\gamma}$
and $A = P\{f(z) + \varepsilon g(z)\} - R - cz$

Now, totally differentiating the Eq. (2.7) w.r.t. γ and L^*, one gets

$$E\{-\pi^{-\gamma}\log \pi A\}d\gamma + E\{-\gamma\pi^{-\gamma-1}A^2\}dL^* = 0.$$

or

$$\frac{d\,L*}{d\,\gamma}=\frac{E(\pi^{-\gamma}\log\pi A)}{E(-\gamma\,\pi^{-\gamma-1}A^2)}$$
$$=\frac{E(U'\log\pi A)}{E(U''A^2)},\quad \text{where } U''=-\gamma\pi^{-\gamma-1}$$

Again,

$$\log U=(1-\gamma)\log\pi-\log(1-\gamma)$$

So,

$$\frac{dL^*}{d\gamma}=\frac{E(U'\log\pi A)}{E(U''A^2)}$$

or,

$$\frac{d\,L^*}{d\,\gamma}\ =\ \frac{E\ (U'\ \log\ U A)}{E\ \{\,(1-\gamma)\ U''\,A^2\}}\ +\ \frac{\log\ (1-\gamma)}{(1-\gamma)}\cdot\frac{E\ (U'\,A)}{E\ (U''\ A^2)}$$

or,

$$\frac{d\,L^*}{d\,\gamma}=\frac{E(U'\log U\,A)}{E\{(1-\gamma)U''A^2\}} \tag{2.8}$$

because,

$$\frac{\log(1-\gamma)}{1-\gamma}\cdot\frac{E(U'A)}{E(U''A^2)}=0,\quad \text{as}\quad E(U'A)=0$$

from Eq. (2.4).

The denominator of Eq. (2.8) is obviously negative while the numerator is positive. So, $\frac{dL^*}{d\,\gamma}<0$. Then it follows, if the degree of risk-aversion rises, the optimal allocation of land to modern cultivation declines. The farmers are mostly risk-averse and risk-aversion may increase for various reasons and in that case the adoption of a new technology will decline.

2.4.2 The Relation Between Farm Size and Adoption of a New Technology

Now, the effect of farm size on the allocation of land to modern cultivation can be examined. Feder (1980) has shown that optimum level of fertilizer (z*) per acre is independent of the farm size. So, totally differentiating only the Eq. (2.4) w.r.t. $L*$ and $\overline{L}$ one gets

$$E\left[U''\{P(f(z)+\varepsilon g(z))-R-cz\}^2\right]dL^* + E[U''\{P(f(z)+\varepsilon g(z))-R-cz\}R]d\overline{L} = 0$$

or,

$$E\left[U''B^2\right]dL^* + E[U''BR]d\overline{L} = 0$$

where

$$B = \{P(f(z)+\varepsilon g(z)) - R - cz\},$$

or,

$$\frac{dL^*}{d\overline{L}} = \frac{E(U''BR)}{-E(U''B^2)} \tag{2.9}$$

If absolute risk-aversion decreases with income (a plausible assumption), $E(U''BR) > 0$, and by the assumption of risk-aversion, $E(U''B^2) < 0$ (Feder and O'Mara 1981). So,

$$\frac{dL^*}{d\overline{L}} > 0$$

Therefore, if the farmer is a risk-averter and the absolute risk-aversion decreases with income, the large farmer will allocate a greater amount of land to modern cultivation.

Thus, a positive relationship between the amount of land allocated to modern cultivation and farm size is obtained under certain conditions. A more interesting problem is to examine the relationship between farm size and the proportion of land allocated to modern cultivation. This will be a true measure of rate of adoption of a new technology.

Let 'l' be the proportion of land allocated to modern cultivation, i.e.,

$$l = \frac{L}{\overline{L}}. \quad \text{Then,}$$

$$\frac{dl^*}{d\overline{L}} = \frac{d\left(\frac{L^*}{\overline{L}}\right)}{d\overline{L}} = \frac{\overline{L}\cdot\frac{dL^*}{d\overline{L}} - L^*}{\overline{L}^2}$$

or,

$$\frac{d\,l^*}{d\,\overline{L}} = \frac{\overline{L}\cdot E(U''\,BR) + L^*\,E(U''\,B^2)}{-\overline{L}^2 E(U''\,B^2)}$$

or,

$$\frac{d\,l^*}{d\,\overline{L}} = \frac{E\left(U''\,B\,R\,\overline{L} + U''\,B^2\,L^*\right)}{-\overline{L}^2\,E\,(U''\,B^2)}$$

or,

$$\frac{d\,l^*}{d\,\overline{L}} = \frac{E\left[U''\,B\left\{R\,\overline{L} + B\,L^*\right\}\right]}{-\overline{L}^2\,E\,(U''\,B^2)}$$

or,

$$\frac{d\,l^*}{d\,\overline{L}} = \frac{E\,(U''\,B\,\pi)}{-\overline{L}^2\,E\,(U''\,B^2)} \tag{2.10}$$

The denominator of Eq. (2.10) is positive by assumption of risk-aversion. But the numerator $E(U''\,B\,\pi) < \; = \; > 0$, depending on whether relative risk-aversion is increasing, constant or decreasing in income (π). So,

(a) If the relative-risk aversion increases with π,
$\frac{d\,l^*}{d\,\overline{L}} < 0$, i.e., the large farmer will allocate a smaller proportion of land to modern cultivation.
(b) if the relative risk-aversion decreases with π,
$\frac{d\,l^*}{d\,\overline{L}} > 0$, i.e., the large farmer will allocate a larger proportion of land to modern cultivation.
(c) if the relative risk-aversion remains constant,
$\frac{d\,l^*}{d\,\overline{L}} = 0$, i.e., the proportion of land allocated to modern cultivation will be independent of farm size.

So, relative risk-aversion becomes an important determinant of the relationship between farm size and rate of adoption of a new technology in agriculture. Whether relative risk-aversion will decrease with income or not again depends on a number of factors like, availability of irrigation, bank credit, labour supply and government support measures.

2.4.3 Extension of the Result

It has so far been assumed that there is no fixed cost in the adoption of a modern technology. Now, let us suppose that there is some fixed adoption cost (say, on irrigation pump, tractor or the cost of acquisition of information regarding the new technology) and it is denoted by 'F'. Then the expected income of the farmer becomes

$$\pi = \left[P \cdot L\{f(z) + \varepsilon g(z)\} + R\left(\overline{L} - L\right) - c \cdot z \cdot L - F\right] \tag{2.11}$$

Then, the Eq. (2.10) becomes

$$\frac{d\,l^*}{d\,\overline{L}} = \frac{E\{U''\,B(\pi + F)\}}{-E\{U''\,B^2\}\overline{L}^2} \tag{2.12}$$

Here, also, the denominator is positive. Now, if the relative risk-aversion is approximately constant, $E(U''\,B\,\pi)$ is zero. But the other term $E(U''\,B\,F)$ will be positive and then $\frac{d\,l^*}{d\,\overline{L}} > 0$

Therefore, if the adoption of a new technology involves some fixed cost and relative risk-aversion is more or less constant, the large farmers will allocate a larger proportion of land to modern cultivation.

The use of fertilizer per unit of land is also an indicator of technological change in agriculture. Feder (1980) shows that a reduction in the cost of fertilizer leads to an increase in the optimal use of fertilizer per acre (z*), i.e., $\frac{d\,z^*}{d\,c} < 0$. He also shows that fertilizer use per acre will increase with an increase in output price i.e., $\frac{d\,z^*}{d\,p} > 0$ provided the elasticity of risk-response to fertilizer is lower than the elasticity of mean output-response to fertilizer.

2.4.4 The Credit Constraint and the Optimal Allocation of Land to Modern Cultivation

The modern cultivation requires cash outlay for the purchase of inputs like seed, chemical fertilizer, pesticides, etc. and the fund is provided from farmer's own savings and credit received from different sources, both institutional and non-institutional. It has so far been assumed that there is no credit constraint in the sense that total cash available to the farmer is equal to the total cost of inputs.

If there is credit constraint, the non-availability of sufficient credit may become a constraint to the adoption of the new technology. Now let us assume that there is effective credit constraint in the sense that total cash expenditure can not exceed farmer's cash availability. Following Feder (1980), it can be expressed as

$$K = c \cdot z \cdot L \tag{2.13}$$

Where K = total cash available to the farmer (consisting of both farmer's own resource and credit received).

It is further assumed that both own resource and access to credit are proportional to the size of farm and it is expressed as

$$K = k \cdot \overline{L} \tag{2.14}$$

where k is the ratio of proportionality between availability of cash and farm size i.e., $k = \frac{K}{\overline{L}}$ and k is fixed.

Now, from Eqs. (2.13) and (2.14)

$$L = \frac{k\overline{L}}{cZ} \tag{2.15}$$

From the differentiation of Eq. (2.15) w.r.t. 'k', we get

$$\frac{dL}{dk} = \left[\frac{\overline{L}}{cz}\right]\left[1 - \frac{dz}{dk} \cdot \frac{k}{z}\right] \tag{2.16}$$

where, $\frac{dz}{dk} \cdot \frac{k}{z}$ is the elasticity of fertilizer use w.r.t. k.

Now if $\left(\frac{dz}{dk} \cdot \frac{k}{z}\right) < 1$,

$\left(\frac{dL}{dk}\right)$ becomes positive implying that if k rises, the cash availability to the farmer will increase and this will lead to greater allocation of land to modern cultivation. Therefore, if there is effective credit constraint, an increase in credit supply will encourage greater allocation of land to modern cultivation.

2.4.5 An Extension

In Eq. (2.16), it has been stated that total cash available to the farmer is just equal to the total variable cost ($c\,z\,L$). Let us now assume that cash is required for fixed cost also and it is denoted by F. It is justified on the ground that the adoption of the new technology may involve some cost for setting up of irrigation pump, purchase of power tiller etc. Then, the credit constraint becomes

$$K = czL + F \tag{2.17}$$

Now, combining the Eqs. (2.14) and (2.17), we get

$$L = \left(\frac{k\overline{L}}{c\,z}\right) - \left(\frac{F}{c\,z}\right) \tag{2.18}$$

Now, the differentiation of Eq. (2.18) w.r.t. k gives

$$\frac{d\,L}{d\,k} = \frac{\overline{L}}{c\,z}\left[1 - \frac{d\,z}{d\,k}\cdot\frac{k}{z}\right] + \left[\frac{F\cdot c\cdot\frac{d\,z}{d\,k}}{c^2\,z^2}\right] \tag{2.19}$$

$\left(\frac{\overline{L}}{c\,z}\right)\left[1 - \frac{d\,z}{d\,k}\cdot\frac{k}{z}\right]$ is positive from the Eq. (2.16). Feder (1980) has shown that if absolute risk-aversion is non-increasing and relative risk-aversion is non-decreasing (which are plausible assumptions) $\left(\frac{d\,z}{d\,k}\right)$ will be positive. Then $\left(\frac{F\cdot c\cdot\frac{dz}{dk}}{c^2 z^2}\right)$ will be positive. As a result, $\left(\frac{d\,L}{d\,k}\right)$ in Eq. (2.19) will not only be positive but also, its value will be larger than that in Eq. (2.16). The implication of the result is that the availability of credit will be more important in the adoption of a new technology when it involves some fixed cost.

2.4.6 Irrigation and Adoption of a New Technology in Agriculture

Making extension in Feder (1980) and using the structure of Mondal and Sasmal (2010) we can examine the effect of irrigation on technology adoption in agriculture. In the rainy season the HYV cultivation is possible without irrigation although the mean output may be lower and output may be subject to greater variability. If we insert irrigation into the production function as an efficiency factor it will enhance the mean output and reduce the variability of output. In the dry season irrigation is essential but the efficiency of irrigation may differ depending on the mode of irrigation. After incorporating irrigation we get the production function as

$$q = (1 + m\,I)f(z) + \varepsilon(1 - n\,I)g(z) \tag{2.20}$$

where I is some index of irrigation and $0 \leq I < 1$. 'I' increases mean output at the rate m and reduces risk in production at the rate n. It may be assumed that highest efficiency in irrigation is generally not achieved. So I is less than 1.

Now, the objective function of the farmer is to maximize

$$EU(\pi) = EU\left\{P\cdot L[(1 + mI)f(z) + \varepsilon\cdot(1 - nI)g(z)] + R\left(\overline{L} - L\right) - czL - vIL\right\} \tag{2.21}$$

where v is cost of irrigation per unit.

The first order conditions for the maximization of Eq. (2.21) are:

$$E[U'[P\{(1+mI)f(z)+\varepsilon(1-nI)g(z)\}-R-cz-vI]]=0 \tag{2.22}$$

$$E[U'[PL\{(1+mI)f'(z)+\varepsilon(1-nI)g'(z)\}-cL]]=0 \tag{2.23}$$

The second order conditions are also satisfied. Now, the optimum values of Z and L (i.e., Z^* and L^*) are obtained from the Eqs. (2.22) and (2.23).

Let us now examine the effect of change in the quality of irrigation on optimal values on Z and L. By using lemma 4 (Feder 1977), we get

$$P(1+mI)f'(z)g(z)-cg(z)-P(1+mI)f(z)g'(z)+Rg'(z)+czg'(z)+vIg'(z)=0. \tag{2.24}$$

Now, totally differentiating (2.24) w.r.t. z and I one gets

$$(P\cdot m\cdot f'g-P\cdot m\cdot f g'+vg')dI+\left\{\begin{array}{r} P(1+mI)f'(z)g'(z)+P(1+mI)f''(z)g(z)\\ -c\cdot g'(z)-P(1+mI)f(z)g''(z)-P(1+mI)\\ f'(z)g'(z)+Rg''(z)+c\cdot z\cdot g''(z)+c\cdot g'(z)\\ +vIg''(z)\end{array}\right\}dz=0 \tag{2.25}$$

The Eq. (2.25) gives

$$\frac{dz}{dI}=\frac{P\cdot m(f'g-g'f)+vg'}{P(1+mI)f''(z)g(z)+g''(z)(R+cz-P(1+mI)f(z)+vI)} \tag{2.26}$$

In Eq. (2.26), the numerator is positive (Feder 1980) and in the denominator, $P(1+mI)f''(z)g(z)$ is negative but $g''(z)(R+cz-P(1+mI)f(z)+vI)$ is indeterminate. So, $\left(\frac{dZ}{dI}\right)$ is also indeterminate. Therefore, the impact of irrigation on fertilizer use is not clear.

Now, totally differentiating the Eq. (2.24) w.r.t. L, z and I, we get

$$E\{U''B^2\}dL+E\{U''B\cdot S\cdot L+U'S\}dz+E\left\{\begin{array}{l} U''B[P\{mf(z)-g(z)\}L-vL]\\ +U'[P\{mf(z)-\varepsilon g(z)\}-v]\end{array}\right\}dI=0 \tag{2.27}$$

where

$$B=[P\{(1+mI)f(z)+(1-nI)\varepsilon g(z)\}-R-cz-vI]$$

$$S=P\{(1+mI)f'(z)+\varepsilon\cdot(1-nI)g'(z)\}-cL$$

Now, dividing Eq. (2.27) by $E(U'' B^2)dI$ we get

$$\frac{dL}{dI} + \frac{E\{U'' BSL + U' S\}}{E\{U'' B^2\}} \cdot \frac{dz}{dI} + \frac{\{E\{U'' B[\{P \cdot m \cdot f(z) - \varepsilon g(z)\}L - vL] + U'[P\{m \cdot f(z) - \varepsilon g(z)\} - v]\}\}}{E\{U'' B^2\}} = 0$$

or,

$$\frac{dL}{dI} = \frac{-E\{U'' BTL + U' T\}}{E\{U'' B^2\}} - \frac{E\{U'' BSL + U' S\}}{E\{U'' B^2\}} \cdot \frac{dz}{dI} \tag{2.28}$$

where $T = P\{m \cdot f(z) - \varepsilon g(z)\} - v$

In Eq. (2.28) $\frac{E\{U'' BTL + U' T\}}{E\{U'' B^2\}} < 0$,

and $\frac{E\{U'' BSL + U' S\}}{E\{U'' B^2\}} < 0$ by Lemma 2, (Feder 1977) and (Feder and O'Mara 1981).

Now, as $\left(\frac{dz}{dI}\right)$ is indeterminate, $\left(\frac{dL}{dI}\right)$ is also indeterminate.

However, if $\left(\frac{dz}{dI}\right)$ is positive, $\left(\frac{dL}{dI}\right)$ will also be positive.

In Eq. (2.26) $\{P \cdot m\,(f' \cdot g - g' f) + vg'\}$ is positive (Feder 1980). In the denominator of Eq. (2.26) $\{P(1 + mI)f''(z)g(z)\}$ is negative (by specification about 'f'), and $\{R + cz - P((1 + mI)f(z) + vI)\}$ is negative (by superiority of the new technology over the traditional one). Now, if g'' is sufficiently negative, and f'' is slightly negative the denominator of Eq. (2.26) will be positive. Then both $\left(\frac{dz}{dI}\right)$ and $\left(\frac{dL}{dI}\right)$ will be positive.

Therefore, a sufficiency condition for $\left(\frac{dz}{dI}\right)$ and $\left(\frac{dL}{dI}\right)$ to be positive is that irrigation must be sufficiently risk-reducing (so that g'' is sufficiently negative) and mean productivity-raising (so that f'' is negative but magnitude is very small).

Let us now consider the impact of irrigation on the proportion of land allocated to modern cultivation (l) where $l = \frac{L}{\overline{L}}$.

Now,

$$\frac{dl}{dI} = \frac{d\left(L/\overline{L}\right)}{dI} = \frac{\overline{L} \cdot \frac{dL}{dI}}{\overline{L}^2} = \frac{1}{\overline{L}} \cdot \frac{dL}{dI}$$

Here, also, the sign of $\left(\frac{dl}{dI}\right)$ is indeterminate as $\left(\frac{dL}{dI}\right)$ is indeterminate. But under the same sufficiency conditions $\left(\frac{dl}{dI}\right)$ will be positive.

Therefore, the effect of irrigation on the allocation of land to HYV is not unambiguous. However, irrigation will lead to higher allocation of land to HYV only when it is sufficiently risk-reducing and mean productivity-raising when production is uncertain and the farmer is risk-averse.

2.4.7 Adoption of High-Yielding Variety (HYV) Technology—The Indian Experience

The HYV technology was adopted in India in 1960s and 1970s to have quick and substantial increase in foodgrains production.[9] At the initial stage this new technology was adopted in selected parts of India like Punjab, Haryana, Western Uttar Pradesh and subsequently it was extended to other parts of the country. This technology has been adopted mainly in foodcrops like paddy, wheat, maize, sorghum, etc. Many factors like farm size, irrigation, availability of credit, education in the farming household, knowledge about the new technology are found to influence the farmer's decision regarding the adoption of the new technology. In this section, we will consider the use of HYV technology in paddy cultivation. The theoretical framework of the previous section has explained the conditions under which the above factors affect the farmer's decision in this regard.

The degree of adoption of the HYV technology in paddy cultivation has been defined in the following two ways:

(a) amount of land allocated to HYV(L), and
(b) proportion of land allocated to HYV (l).

where $l = \frac{L}{\overline{L}}$ and $\overline{L}$ is total cultivated land of the farmer (i.e., farm size) and L is amount of land allocated to modern variety. The proportion of land allocated to HYV denoted by 'l' is a better measure of the rate of adoption of a new technology. So, this study explains the 'proportion of land allocated to HYV' with the help of a number of explanatory variables.

Here, we have used farm level primary data to explain the adoption rate of HYV technology in paddy cultivation. The following regression equation has been estimated using cross-section primary data at the farm level.

$$l = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + u \tag{2.29}$$

where,

l the proportion of land allocated to HYV (the dependent variable),
X_1 farm size,
X_2 the proportion of land under irrigation,
X_3 short term credit received by the farmer
X_4 literacy rate in the farm-family (an index of education).

X_1, X_2, X_3 and X_4 are the explanatory variables and α_1, α_2, α_3 and α_4 are the regression coefficients of X_1, X_2, X_3 and X_4 respectively.[10] α_0 is the constant term of

[9]A similar study has been done in Sasmal (1998).

[10]In the cross section farm level data the prices of inputs and output are same for all farmers. So, prices could not be included in the regression as explanatory variables.

the function. u is the random term with $E(u) = 0$. The parameters of regression Eq. (2.29) are estimated by the OLS method. The source and the methodology of collecting data have been discussed in Sect. 2.3. The regression Eq. (2.29) has been estimated for HYV paddy for the dry season and the rainy season separately.

2.4.8 Explanations for the Adoption of High-Yielding Variety Technology in the Dry Season

The estimates of the regression Eq. (2.29) for the dry season have been presented in Table 2.8.[11] The very high R^2 implies that the proportion of land allocated to HYV in the dry season is well explained by the chosen explanatory variables. The F-Statistic is also statistically significant indicting that 'goodness of fit' of the regression equation to the observed data is high.

The results in Table 2.8 show that the regression coefficients of X_1, X_2 and X_3 are statistically significant at 5 % level. That means, farm size, proportion of land under irrigation and supply of credit to the farmer are significant factors in the determination of the proportion of land to be allocated to HYV technology in the dry season. The regression coefficient of education is found to be insignificant. The constant term is significant and positive. These results can be explained in the following way:

(a) The regression coefficient of farm size is statistically significant and it is negative in sign. This means that the relationship between the 'proportion of land allocated to HYV' and farm size is inverse. The implication of this result is that small farmers allocate a higher proportion of land to HYV compared to large farmers. This result is very important and it contradicts the view that small farm size is a serious constraint to the adoption of a new technology in agriculture. The theoretical justification of this result is that if relative risk aversion increases with farm size, the relationship between the 'proportion of land allocated to HYV' and farm size will be negative, if there is no fixed adoption cost (Feder 1980). Now, the question why does relative risk aversion increase with farm size? It also needs to be seen whether there is any fixed cost in the adoption of this new technology in the present case. The following are the relevant explanations:

(i) This study finds that the adoption of HYV technology, by and large, involves no fixed cost in the present case. Generally, the acquisition of knowledge about the new technology, the setting up of irrigation pump, the purchase of equipments like tractor/power tiller, threshing machine, etc., involve some fixed cost. In the present case, the government has played an important role in

[11]It is observed that there is no significant multicollinearity among the explanatory variables of regression Eq. (2.1) both in the dry and the rainy seasons.

Table 2.8 Regression results showing the relationship between the 'proportion of land allocated to HYV' and the explanatory variables in the dry season

Explanatory variables		Coefficients of the variables	t-value of the coefficients
(1)		(2)	(3)
X_1	α_1 =	−2.045 (1.088)	−1.88[a]
X_2	α_2 =	0.603 (0.039)	15.32[a]
X_3	α_3 =	0.002 (0.001)	2.05[a]
X_4	α_4 =	0.004 (0.044)	0.09
Constant term	α_0 =	14.385 (4.780)	3.01[a]
	$R^2 = 0.52$, $F = 55.56$, $n = 262$		

Figures in parentheses are standard errors
Source Sasmal (1992)
[a]Significant at 5 % level

the diffusion of knowledge about the technology through extension services. As a result, the farmers have been able to gather knowledge free of cost. The services of threshing machine, spray machine and power tiller are easily available on hire against payment of rental charges in the particular area of study. In fact, a market has developed in the area to provide such services. So, the farmers, particularly the small farmers, do not require to purchase these equipments of their own. The most important item which may involve some fixed cost in the process of adoption is the setting up of irrigation pump, because without irrigation, HYV paddy cultivation is not possible, particularly in the dry season. But the government has set up huge irrigation network in the public sector in the present situation. So, most of the farmers do not have to bear any fixed cost for irrigation. Thus, the fixed cost of adoption of the HYV technology in the present study is either zero or it is borne by the government.

(ii) Apart from providing irrigation and extension services, the government also plays an important role in supplying credit to the farmers through banks and cooperative societies. In addition, there are arrangements for supplying agricultural inputs like fertilizers, seeds and pesticides to the farmers through authorized dealers at subsidized rates. As a result of these facilities, the risk and uncertainty in production and the risk aversion of the farmers specially of the small farmers decline sufficiently.

(iii) Given the above facilities, the small farmers get some additional advantages from family labour over their larger counterparts as HYV paddy is highly labour-intensive.[12]

The survey report informs that the degree of farm mechanization is very limited in the area of the study. So, the farmer's dependence on hired labour increases with increase in farm size. As a result, the uncertainty in timely

[12]The estimation of production functions for HYV paddy in Sect. 2.3 shows that HYV paddy is highly labour intensive. Similar result is also obtained by the studies of Ruttan (1977), Harriss (1972).

availability of labour increases. At the same time, the possibility of less skilled labourers getting employed in large numbers also increases. All these lead to additional risk in production for large farmers. Moreover, as the demand for hired labour increases, the wage rate rises. This, in turn, increases the wage bill paid to the workers. In effect, the large farmers decide to use HYV technology at a lower rate to avoid the risk of financial loss in the event of crop failure. Thus the large farmers are placed in a position of comparative disadvantage vis-a-vs the small farmers who depend mainly on family labour for cultivation. As a result of the above reasons, the relative risk aversion increases with increase in farm size.

Therefore, the absence of fixed cost for adoption of the new technology, the government involvement in irrigation, credit, etc., the greater intensity of labour use in HYV paddy cultivation and the limited mechanization explain an inverse relationship between the rate of adoption of the HYV technology and farm size. The result has the implication that the non-availability of labour may become a constraint to the extensive use of the technology in large farms. Another important observation of this study is that the provisions of irrigation, credit supply and extension services in the public sector enable the farmers, particularly the small farmers, to adopt the HYV technology at a larger scale. The role of the government in the diffusion of a new technology in agriculture has been explained by Feder and Slade (1985). They have argued that in the initial stage of adoption, the farmers have limited knowledge about the new technology. So, there may be a divergence between the true distribution and the perceived distribution of the net benefits from the new technology and this divergence may act as a deterring factor to adoption of the technology. Therefore, government should take an active role in the diffusion of knowledge through extension services. They also recommend government involvement in irrigation and credit supply for rapid adoption of a new technology. Moreover, in less developed countries like India, information about a new agricultural technology and provision for irrigation are considered as public goods. Public sector investment in the dissemination of information and development of irrigation is also justified on the ground of strong positive externalities. As regards the government involvement in supply of credit one has to consider the typically imperfect nature of rural credit markets in less developed countries. The market imperfection can not ensure desirable amounts of credit to the farmers. So, in a less developed country like India, the role of the government is very important for technological change and productivity growth in agriculture.

(b) The coefficient of irrigation has been found to be positive and statistically significant in Table 2.8. It means that the proportion of land under irrigation has significant impact on the proportion of land to be allocated to HYV in the dry season. As the coefficient is positive, it implies that the percentage of land under HYV will increase if the percentage of land under irrigation increases. Irrigation has appeared to be the most important factor in determining the proportion of land to be allocated to HYV in the dry season. First of all, cultivation of paddy is not possible in the dry season without irrigation.

However, it may be pointed out that an extension of irrigation does not necessarily lead to greater allocation of land to HYV. The proportion of land under HYV will increase only when the irrigation is sufficiently risk-reducing and mean productivity-raising. The irrigation systems are more effective in the dry compared to the rainy season. Besides, the physical environment and the agro-climatic conditions in the dry season are more appropriate for the cultivation of HYV paddy. In the present study, it is found that the mean output of HYV paddy is sufficiently higher and the variance of output is significantly lower in the dry season than those in the rainy season. So, it is very natural that the impact of irrigation on the rate of adoption of HYV technology will be significant and positive in the dry season.

(c) The regression coefficient of the supply of credit has been found to be positive and statistically significant. It suggests that the supply of credit to the farmers from institutional sources is helpful for allocating more land to modern cultivation. That means, effective credit constraint is there in the dry season. The study here considers the effect of short term credit only. The cultivation of HYV paddy involves a big amount of financial investment. But most of the farmers in India are poor, and they are in need of credit. Under such circumstances, if sufficient credit is made available from institutional sources, the farmers will be encouraged to devote greater amount of land to modern cultivation. This explanation is consistent with the theoretical result of Feder (1980) which suggests that in the presence of an effective credit constraint, an increase in credit supply will lead to greater allocation of land to modern cultivation. However, it may be noted that the mere expansion of credit supply will not be helpful for adoption of a new technology unless the supporting facilities like irrigation, proper knowledge about the technology, regular supply of inputs are available. In addition and more importantly, the soil and climatic conditions will have to be suitable for HYV cultivation.

(d) The coefficient of education has been found to be insignificant in determining the proportion of land to be allocated to HYV cultivation in the dry season. This result is not very unusual. The studies of Harriss (1972), Rahm and Huffman (1984), Lin (1991) show that education increases the degree of adoption of a new technology by enhancing the farmer's efficiency. Schultz (1975) also expresses the view that in a modernizing agriculture, education is more important than experience. But in a static traditional agriculture, experience is more valuable than education. Kalirajan and Shand (1985) are of the view that in cases where the new technology is well adapted to local conditions, experience and receptivity to advise may be more important than education.

Therefore, at the early stage of adoption of a new technology when the farmers do not have much knowledge about the technology, education is very important. But after the introduction of the technology, when the farmers are quite familiar with it and the technology itself gets adapted to the local conditions, education may be less important in the process of adoption. In the present case, the HYV technology has been in use in the area for a period of more than two decades. Endowed with such a long experience, the farmers are very likely to have acquired sufficient knowledge about the technology and this has been confirmed also in the survey report of the study. At this stage, one may not find much impact of education on the rate of adoption of the HYV technology in a cross section study. But depending on this result, one should not conclude that education has no role in the degree of adoption of a new technology in agriculture.

2.4.9 Explanations for Adoption of High-Yielding Variety in Paddy Cultivation in the Rainy Season

The estimates of the regression Eq. (2.29) for the rainy season have been presented in Table 2.9. The results show that R^2 is not very high, but the F-statistic is significant. The equation fits well to the observed data although the variation in the adoption rate is not significantly explained by the explanatory variables. The results reveal that only the coefficient of farm size is significant and it is negative in sign as in the dry season. But the coefficients of X_2, X_3 and X_4 are insignificant. That means, irrigation, supply of credit and education have no significant effect on the proportion of land to be allocated to HYV cultivation in the rainy season. The constant term is found to be significant and positive. These results are explained in the following way:

The reasons behind the inverse relationship between the proportion of land allocated to HYV and farm size in the rainy season are same as those of the dry season. Here again, the absence of fixed cost for adoption of a new technology, the government involvement in irrigation, credit, etc., more intensive use of labour in HYV paddy cultivation and limited mechanization explain such a relationship.

The most striking result for the rainy season is that the proportion of land under irrigation has no significant impact on the proportion of land allocated to HYV. In

Table 2.9 Regression results showing the relationship between the 'proportion of land allocated to HYV' and the explanatory variables in the rainy season

Explanatory variables		Coefficients of the variables	t-value of the coefficients
(1)		(2)	(3)
X_1	$\alpha_1 =$	−10.660 (2.295)	−4.65[a]
X_2	$\alpha_2 =$	0.018 (0.067)	0.28
X_3	$\alpha_3 =$	0.001 (0.003)	0.41
X_4	$\alpha_4 =$	0.115 (0.118)	0.98
Constant term	$\alpha_0 =$	55.490 (9.710)	5.71[a]
	$R^2 = 0.15$, $F = 4.66$, $n = 136$		

Figures in parentheses are standard errors
[a]Significant at 5 % level
Source Sasmal (1992)

explaining this result it may be pointed out that the cultivation of HYV paddy in the rainy season is highly risky and less profitable (already explained in Sect. 2.3). This is mainly because the physical environment and the agro-climatic conditions of the rainy season are, in general, not suitable for HYV paddy cultivation. The problems of excess rainfall, waterlogging, abrupt change in weather condition etc., are very common. The plants are also more vulnerable to pests and disease in the rainy season. Under such conditions, HYV paddy is less adaptable and cultivation is risky. In addition, the irrigation systems are also not very effective in the rainy season, because they are mostly designed for dry season. Given these constraints, irrigation fails to make significant impact on the rate of adoption of the HYV technology in the rainy season. This result is consistent with our theoretical argument that irrigation leads to greater allocation of land to modern variety only if the irrigation is sufficiently risk-reducing and mean-output-raising.

The impact of short term credit on the degree of adoption of the HYV technology is insignificant in the rainy season. It has already been explained that if there is an effective credit constraint, an increase in credit supply will lead to greater allocation of land to modern cultivation. But mere expansion of credit may not be effective in raising the degree of adoption, unless the supporting facilities like effective irrigation system, etc. are available and agro-climatic conditions are suitable for HYV cultivation. But these conditions are not fulfilled in the rainy season. It has been already explained that the HYV paddy is risky and less adaptable in the rainy season due to adverse physical and agro-climatic conditions. So, credit supply has no role in the adoption of the new technology in the rainy season. As in the dry season, in the rainy season also, education has been found to have no significant impact on the degree of adoption of the HYV technology. The explanation is the same as before.

2.4.10 *Irrigation and the Adoption of HYV Technology at the National Level—A Time Series Analysis*

The HYV technology has been adopted in India on a large scale mainly in foodgrains production. The percentage of area under HYV cultivation in foodgrains production has increased from 15 % in 1970–71 to 61 % in 1997–98. The use of chemical fertilizer, an important component of HYV technology, has increased from 17.74 kg per hectare in 1970–71 to 115.25 kg in 2007–08 (Source: Economic Survey, Government of India, various issues). The extension of irrigation, particularly tube-well irrigation, has played a significant role in this technological change. The percentage of net irrigated area in the country has increased from 22.17 to 44.2 % during this period. In this sub-section, the relationship between irrigation and the use of HYV technology in foodgrains cultivation has been empirically verified by time series analysis. The variables considered here are percentage of area under HYV cultivation (PERCENT_HYV), net cropped area under irrigation

(N_IRRI_A), area under tube-well irrigation (T_WELL_IRRI_A) and fertilizer (Fert). The sources of data are Economic Survey, Government of India (several issues), Centre for Monitoring Indian Economy (CMIE) (2002 2010). The period of analysis ranges from 1970–71 to 2007–08. The time series analysis has been done using methods outlined in Enders (2004).

2.4.11 Methodology of Analysis

To check stationarity of the series of the variables Augmented Dickey-Fuller (ADF) Unit Root Test has been done. Engle-Granger Cointegration Test has been done to examine whether the series are cointegrated or not. After cointegration, Granger Causality Test and OLS Regression have been done to examine the direction and magnitude of the relationship among the variables over time. The results show that there is meaningful and significant relationship between irrigation, HYV cultivation and fertilizer use. The results of ADF Unit Root Test in Table 2.10 show that the series PERCENT_HYV, N_IRRI_A, T_WELL_IRRI_A and Fert are stationary at first difference.

In Engle-Granger Cointegration Test in Table 2.11, it is found that the series PERCENT_HYV and N_IRRI_A are Cointegrated i.e., PERCENT_HYV and N_IRRI_A are C (1, 1). That means, there is meaningful relationship between the two variables. The pair-wise Granger Causality Test of Table 2.12 suggests that there is bi-directional causality between them. If the variables are cointegrated the OLS regression coefficients give efficient estimates. The results in Table 2.13 show that R^2 is very high. The high value of F-Statistic shows overall significance of the regression. The coefficient of N_IRRI_A is positive and statistically highly significant. That means, expansion of area under irrigation significantly explains the adoption of HYV technology in foodgrains production in India over time.

One interesting feature of expansion of irrigation is that the area under irrigation has increased mainly due to increase of tube-well irrigation. The share of tube-well irrigation in net irrigated land increased from 12 to 42 % in the last four decades. On the other hand, area under canal irrigation has remained more or less constant and irrigation from tanks has declined (Centre for Monitoring Indian Economy, CMIE 2010).

The results of Engle-Granger Cointegration Test of Table 2.14 show that T_WELL_A and N_IRRI_A are cointegrated at first difference i.e. C (1, 1). That means, there is meaningful relationship between them. The series are stationary at first difference (see Table 2.10). The OLS regression of N_IRRI_A on T_WELL_A shows that the increase of net irrigated area is explained positively and significantly by the expansion of area under tube-well irrigation. The result has the implication that it is the expansion of tube-well irrigation that has significantly helped the adoption of HYV technology in India in foodgrains production on a wide scale (Table 2.15).

Table 2.10 Augmented Dickey_Fuller unit root test of the series of variables

	t-statistic	Prob*
Null hypothesis: D (PERCENT_HYV) has a unit root[a]		
Time period: 1970–1996		
ADF test statistic	−6.0529	0.000
Test critical values		
1 % level	−3.7378	
5 % level	−2.9918	
10 % level	−2.6355	
Null hypothesis: D (N_IRRI_A) has a unit root		
Time period: 1970–1996		
ADF test statistic	−10.0632	0.000
Test critical values		
1 % level	−3.6267	
5 % level	−2.9458	
10 % level	−2.6115	
Null hypothesis: D (T_WELL_IRRI_A) has a unit root		
Time period: 1970–1996		
ADF test statistic	−7.0314	0.000
Test critical values		
1 % level	−3.6267	
5 % level	−2.9458	
10 % level	−2.6115	
Null hypothesis: D (Fert) has a unit root		
Time period: 1970–2007		
ADF test statistic	−5.5357	0.000
Test critical values		
1 % level	−3.6267	
5 % level	−2.9458	
10 % level	−2.6115	

*Mackinnon (1996) one sided p-values
[a]We have been able to collect appropriate data on HYV cultivation in foodgrains production from Economic Survey, Government of India, upto 1996–97. The data available from other sources after this period are not very consistent

Table 2.11 Engle-Granger cointegration test between PERCENT_HYV and N_IRRI_A

Series: PERCENT_HYV N_IRRI_A				
Time Period: 1970–1996				
Null hypothesis: series are not cointegrated				
Dependent	tau-statistic	Prob*	Z-statistic	Prob*
PERCENT_HYV	−4.8238	0.003	−24.1363	0.003
N_IRRI_A	−4.9230	0.002	−25.6596	0.001

*Mackinnon (1996) p-values

Table 2.12 Pair-wise Granger causality test between PERCENT_HYV and N_IRRI_A

Period: 1970–1996		
Lag: 2		
Null hypothesis	F-statistic	Prob
N_IRRI_A does not Granger cause PERCENT_HYV	2.9085	0.077
PERCENT_HYV does not Granger cause N_IRRI_A	3.3187	0.056

Table 2.13 OLS regression of PERCENT_HYV on N_IRRI_A

Dependent variable: PERCENT_HYV			
Observation: 27			
Variable	Coefficient	t-statistic	Prob.
N_IRRI_A	0.0017	16.7194[a]	0.000
C	−34.3681	−7.5985	0.000
R^2 = 0.91			
Adjusted R^2 = 0.91			
F-statistic = 279.53			

[a]Significant at 1 % level

Table 2.14 Engle-Granger cointegration test between T_WELL_IRRI_A and N_IRRI_A

Series: T_WELL_IRRI_A N_IRRI_A				
Null hypothesis: series are not cointegrated				
Dependent	tau-statistic	Prob*	Z-statistic	Prob*
T_WELL_IRRI_A	−3.9217	0.0198	−22.3673	0.012
N_IRRI_A	−4.1277	0.0122	−23.6541	0.008

Table 2.15 OLS regression of N_IRRI_A on T_WELL_IRR_A

Dependent variable: N_IRRI_A				
Variable	Coefficient	t-statistic	Prob.	R^2
T_WELL_IRRI_A	1.4112	24.6528[a]	0.000	0.94
Constant	26080.77	28.4747[a]	0.000	

[a]Significant at 1 % level

The use of chemical fertilizer (Fert) is an important part of HYV technology and technological change in agriculture. In the last four decades there has been nearly seven-fold increase of fertilizer use per hectare in the country. The expansion of irrigation and use of HYV seeds are significantly responsible for the increase of fertilizer use. The results in Table 2.16 shows that N_IRRI_A and Fert are cointegrated at first difference i.e. C (1, 1). So, there is meaningful long-run relationship between them. The OLS regression in Table 2.17 shows that fertilizer use is positively and significantly affected by irrigation. So, it can be concluded that expansion of tube-well irrigation has not only increased the area under irrigation but also significantly helped the adoption of HYV technology and fertilizer use (Table 2.18).

Table 2.16 Engle-Granger cointegration test between N_IRRI_A and Fert

Null hypothesis: series are not cointegrated				
Time period: 1970–2007				
Dependent	tau-statistic	Prob*	Z-statistic	Prob*
Fert	−4.2787	0.0084	−25.0848	0.005
N_IRRI_A	−4.5700	0.0040	−26.4428	0.003

Table 2.17 OLS regression of Fert on N_IRRI_A

Dependent variable: Fert			
Variable	Coefficient	t-statistic	Prob.
N_IRRI_A	0.0030	25.0027	0.000
Constant	−86.2349	−14.6017	0.000
$R^2 = 0.94$			
F statistic = 625.13			
Sample size = 38			

Table 2.18 Cropped area and production of foodgrains and some major crops in India

	1970–71	1990–91	2000–01	2012–13
Gross cropped area under foodgrains (million hectares)	124.32	127.84	121.05	120.78
Total production of foodgrains (million tonnes)	108.42	176.39	196.81	257.13
Gross cropped area under rice (million hectares)	37.76	42.69	44.71	42.75
Total production of rice (million tonnes)	43.07	74.29	84.98	105.24
Gross cropped area under wheat (million hectares)	19.14	24.17	25.73	30.00
Total production of wheat (million tonnes)	23.83	55.14	69.68	93.51
Gross cropped area under pulses (million hectares)	22.02	24.66	20.35	23.26
Total production of pulses (million tonnes)	11.82	14.26	11.08	18.34
Gross cropped area under oilseeds (million hectares)	16.64	24.15	22.77	26.48
Total production of oilseeds (million tonnes)	9.63	18.61	18.44	30.94

Source Agricultural statistics at a Glance 2014, Government of India, Ministry of Agriculture, Oxford University Press 2015a

2.4.12 Summary

Following Feder (1980) it has been theoretically explained how the optimal share of land allocated to modern cultivation and the amount of fertilizer to be used per unit of land are determined under production uncertainty. The degree of risk and risk preference of the farmers play important role in the decision of adoption of a new technology. The adoption rate of the new technology may be higher in small farms under certain favourable conditions. The degree of risk and effective credit constraint may act as obstacles to technological change in agriculture. Irrigation is important for reducing uncertainty in production and increasing mean output. However, irrigation will lead to higher adoption of a modern technology only when irrigation is sufficiently risk-reducing and mean output-raising.

The empirical study based on farm level primary data in paddy cultivation, the use of HYV technology is explained significantly by irrigation, credit supply and farm size. Irrigation plays the most important role in this regard. The relationship between adoption rate of HYV technology and farm size is found to be negative implying that small farmers use the new technology at a higher rate compared to the big farmers. At the aggregate level, irrigation specially tube-well irrigation has played a crucial role in the spread of HYV technology and use of fertilizer in India.

2.5 Technological Change and Productivity Growth in Indian Agriculture

The Indian agriculture has undergone significant technological changes in the last four decades leading to remarkable growth in productivity in the cultivation of major crops. The technological change can be conceived as a package programme consisting of use of modern variety seeds, chemical fertilizers, pesticides and expansion of irrigation, specially tube-well irrigation. The HYV technology was first introduced in foodgrains production and subsequently it has been extended to other crops. The net cropped area in India has remained more or less fixed at 1,40,267 thousand hectares in the last 40 years although the gross cropped area has increased from 1,65,791 thousand hectares in 1970–71 to 1,95,835 thousand hectares in 2007–08 due to intensive farming. The gross cropped area under foodgrains has remained unchanged around 124 million hectares during this period. But the production of foodgrains has increased from 108.42 million tonnes in 1970–71 to 257.13 million tonnes in 2012–13 (Source: Centre for Monitoring Indian Economy 2002, 2010). That means, the production of foodgrains has been more than doubled and this remarkable increase in production can be largely attributed to productivity growth. The yield per hectare in foodgrains production has increased from 872 kg in 1970–71 to 2128 kg in 2012–13 (See Table 2.19). It is also revealed in Table 2.19 that the two major foodcrops rice and wheat have achieved noticeable growth in productivity in India in the last four decades. However, pulses and sugarcane could not show much progress in productivity. The increase in yield in cotton is found to be very high although the productivity in the cultivation of oilseeds has remained moderate in the same period. On the whole, the productivity of all crops has increased over the years. But the productivity growth in the cultivation of foodgrains specially in rice and wheat is found to be very impressive.

Table 2.19 Yield of major crops per hectare in India (kilogram per hectare)

Crop	Year		
	1970–71	1990–91	2012–13
Foodgrains	872	1380	2128
Rice	1132	1740	2462
Wheat	1307	2281	3117
Pulses	524	578	789
Oilseeds	579	771	1168
Sugarcane	48	65	70
Cotton[a] (Bales of 170 kgs per hectare)	106	225	486

Source Economic Survey, Government of India (2015b)
[a]Yield is measured in terms of Bales per hectare

Let us now see how various components of technological change have contributed to this productivity growth. The use of HYV seeds has played an important role in the present context. Table 2.20 shows that the gross area under foodgrains brought under HYV scheme has increased from 18.70 million hectares in 1970–71 to 76 million hectares in 1997–98. That means, nearly 62 % of the gross cultivated area under food-grains are using HYV seeds and other related inputs. In the cultivation of rice and wheat in particular, the use of HYV seeds is very high (see Table 2.21). The major food-producing states like Uttar Pradesh, Punjab, Haryana, Andhra Pradesh, Madhya Pradesh, West Bengal have largely adopted the modern variety of seeds in foodgrains cultivation (See Table 2.22).

The HYV technology is closely associated with irrigation and fertilizer use. Table 2.23 shows that net irrigated area in the country has increased from 31,103 thousand hectares in 1970–71 to 62,286 thousand hectares in 2007–08 which is 44.22 % of the net cropped area of the country. The area under irrigation in India has increased largely banking on tube-well irrigation. The share of tube-well irrigation in the total irrigated land of India has increased from 14.34 to 41.91 % in the last four decades (See Table 2.23). The three-fold increase of tube-well irrigation has greatly facilitated HYV cultivation and fertilizer use. The use of HYV seeds and fertilizer combined with irrigation have resulted in significant growth of productivity in the farming sector. Table 2.24 shows that total fertilizer consumption has increased from 2657 thousand tonnes in 1970–71 to 25,536 thousand tonnes in 2007–08 with the result that fertilizer use per hectare has increased from 17.74 to 130 kg during this period. The significant increase of nitrogen fertilizer over the years is also an indicator of technological change in Indian agriculture.

Table 2.20 Gross area under HYV scheme in foodgrains production of India (million hectares)

1970–71	1980–81	1990–91	1997–98[a]
18.70	43.10	65.00	76.00

Source Economic survey, Government of India, several issues
[a]After 1997–98, systematic and consistent data on HYV cultivation are not available

Table 2.21 Crop-wise increase of area under HYV scheme in foodgrains production of India (million hectares)

Year	Rice	Wheat	Jowar	Bajra	Maize
1970–71	5.59	6.68	0.80	2.05	0.46
1989–90	26.16	20.29	6.87	5.59	2.26

Source Indian Agriculture in Brief, 24th edition, Ministry of Agriculture, Government of India (1992)

Table 2.22 State-wise area of using HYV seeds in major food crops of India in 1990–91 (lac hectares)

States	Rice	Wheat	Bajra
Andhra Pradesh	36.51	–	–
Bihar	16.43	15.00	–
Madhya Pradesh	27.50	20.00	–
Punjab	18.24	32.40	–
Haryana	–	18.30	–
Orissa	26.00	–	–
Maharashtra	–	–	37.59
Uttar Pradesh	48.61	82.00	–
West Bengal	34.43	–	–
Tamil Nadu	17.80	–	–

Source Indian Agriculture in Brief, 24th edition, Ministry of Agriculture, Government of India (1992)

Table 2.23 Increase of net irrigated area in Indian Agriculture over time (000 ha)

	1970–71	1990–91	2000–01	2007–08
Net irrigated area	31,103 (22.17)[a]	48,023 (33.61)[a]	55,133 (39.00)[a]	62,286 (44.22)[a]
Area under tube-well irrigation	4461 (14.34)[b]	14,257 (29.68)[b]	22,569 (40.93)[b]	26,105 (41.91)[b]

Source Centre for Monitoring Indian Economy, CMIE (1998, 2010)
[a]Figures in parentheses are percentage shares of irrigated area in total cultivated land
[b]Figures in parentheses are percentage shares of tube-well irrigation in total irrigated land

2.5.1 Technological Change and Productivity Growth—A Time Series Analysis

The technological change has taken place mainly in foodgrains production and like in other developing countries foodgrains production is the major farming sector of India. So, we are interested in the yield of foodgrains production (Yield) in the present study. We have explained the growth in Yield by fertilizer use (FERT) and

Table 2.24 Use of chemical fertilizers in Indian agriculture over time (000 tonnes)

	1970–71	1990–91	2000–01	2007–08
Total consumption of fertilizers	2657	12,546	16,631	25,536
Total consumption of nitrogen (N)	1798	7997	10,862	16,820
Total consumption of phosphate (P)	558	3221	4212	6653
Total consumption of potassium (K)	201	1328	1557	2061
Consumption of fertilizers per hectare (kg)	17.74	67.55	89.73	130

Source Agricultural statistics at a Glance 2014, Ministry of Agriculture, Government of India, Oxford University Press 2015a

expansion of net irrigated area (N_IRRI_A) using time series techniques as outlined in Enders (2004). The series of Yield, FERT and N_IRRI_A are stationary at first difference in Augmented Dickey-Fuller Unit Root Test (see Tables 2.25 and 2.29). The results in Table 2.26 show that the series of Yield and FERT are cointegrated of the same order in Engle-Granger Cointegration Test i.e. the series are CI(1, 1). Since the variables are cointegrated, there is meaningful long-run relationship between them and the OLS regression gives efficient estimates of their relationship. Here, the results of OLS regression of Yield on FERT in Table 2.28, show that the coefficient of FERT is positive and statistically significant at 1 % level. That means, yield in foodgrains production is significantly explained by fertilizer use. Moreover, we find a Granger causality between the two variables. There is two-way causality. FERT Granger causes Yield and the other way round (See Table 2.27). The economic interpretation is that fertilizer use enhances

Table 2.25 Augmented Dickey-Fuller unit root test on D (Yield) and D (FERT)

	t-statistic	Prob*
Null hypothesis: D (Yield) has a unit root		
Period: 1970–2012		
Augmented Dickey-Fuller test statistic	−6.7263	0.000
Test critical values		
1 % level	−3.6009	
5 % level	−2.9350	
10 % level	−2.6058	
Null hypothesis: D (FERT) has a unit root		
Period: 1970–2012		
Augmented Dickey-Fuller test statistic	−5.2616	0.000
Test critical values		
1 % level	−3.6155	
5 % level	−2.9411	
10 % level	−2.6090	

*Mackinnon (1996) p-values

Table 2.26 Engle-Granger cointegration test

Series: Yield FERT				
Period: 1970–2012				
No. of observation: 42				
Null hypothesis: series are not cointegrated				
Dependent	tau-statistics	Prob	z-statistic	Prob*
YIELD	−3.7441	0.028	−16.042*	0.079
FERT	−4.1493	0.010	−17.023*	0.061

*Mackinnon (1996) p-values

Table 2.27 Pair-wise Granger causality test between yield and FERT

Null hypothesis			
		F-statistic	Prob*
FERT does not	Granger cause yield	8.209	0.001
Yield does not	Granger cause FERT	6.055	0.005

*Mackinnon (1996) p-values

Table 2.28 OLS regression of yield on FERT

Dependent variable: yield			
No. of observations: 42			
Variable	Coefficient	t-statistic	Prob
FERT	9.7907	32.104[a]	0.000
C	719.1439	31.235[a]	0.000

$R^2 = 0.96$
F-statistic = 1030.72
[a]Significant at 1 % level

Table 2.29 Augmented Dickey-Fuller unit root test On D (Yield) and D (N_IRRI_A)

	t-statistic	Prob*
Null hypothesis: D (Yield) has a unit root		
Period: 1970–2007		
Augmented Dickey-Fuller test statistic	−6.7233	0.000
Test critical values		
1 % level	−3.6009	
5 % level	−2.9350	
10 % level	−2.6058	
Null Hypothesis: D (N_IRRI_A) has a unit root		
Period: 1970–2007		
Augmented Dickey-Fuller test statistic	−10.0632	0.000
Test critical values		
1 % level	−3.6267	
5 % level	−2.9458	
10 % level	−2.0115	

*Mackinnon (1996) p-values

productivity of land and at the same time, higher productivity encourages more use of fertilizer per hectare.

The Engle-Granger Cointegration Test in Table 2.30 shows that the series of Yield and N_IRRI_A are cointegrated of the same order i.e. the variables are CI (1, 1). Therefore, there is meaningful long-run relationship between 'net area under irrigation' and yield in foodgrains production. Since the variables are cointegrated the estimates of OLS regression between them will be efficient. The results in Table 2.32 show that irrigation has strong positive impact on yield in foodgrains cultivation. In Engle-Granger Causality Test, it is found that N_IRRI_A Granger causes Yield (see Table 2.31). In fact, irrigation has been found to be the main driving force in productivity growth.

Using the same data set and taking log of the variables we have estimated the elasticity of Yield with respect to FERT, N_IRRI_A and HYV following the equation:

$$\log Y = \alpha_0 + \alpha_i \log X_i, \quad i = 1, 2, 3$$

Table 2.30 Engle-Granger cointegration test

Series: yield N_IRRI_A				
Period: 1970–2007				
Null hypothesis: series are not cointegrated				
Dependent	tau-statistic	Prob*	z-statistic	Prob*
YIELD	−4.7291	0.002	−28.0433	0.001
N_IRRI-A	−4.9838	0.001	−29.5895	0.001

*Mackinnon (1996) p-values

Table 2.31 Fair-wise Granger causality test between N_IRRI_A and yield

Null hypothesis		
	F-statistic	Prob*
N_IRRI_A does not Granger cause yield	2.8616	0.072
Yield does not Granger cause N_IRRI_A	2.1754	0.130

Table 2.32 OLS regression of yield on N_IRRI_A

Dependent variable: yield			
No. of observations: 37			
Variable	Coefficient	t-statistic	Prob
N_IRRI_A	0.0329	26.3054[a]	0.000
C	−237.8337	−3.9889[a]	0.000

R^2 = 0.95, F-Statistic = 691.97

[a]Significant at 1 % level

where Y = Yield, X_1 = FERT, X_2 = N_IRRI_A, X_3 = HYV. α_1 = elasticity of Yield w.r.t. FERT, α_2 = elasticity of Yield w.r.t. N_IRRI_A, and α_3 = elasticity of Yield w.r.t. HYV. The estimated results are as follows:

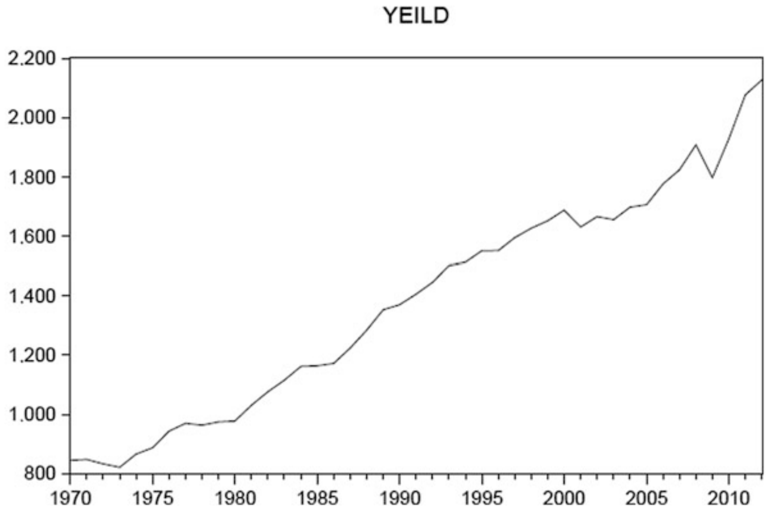

Fig. 2.1 Yield of foodgrains production in India over the period from 1970–71 to 2012 (kilogram per hectare)

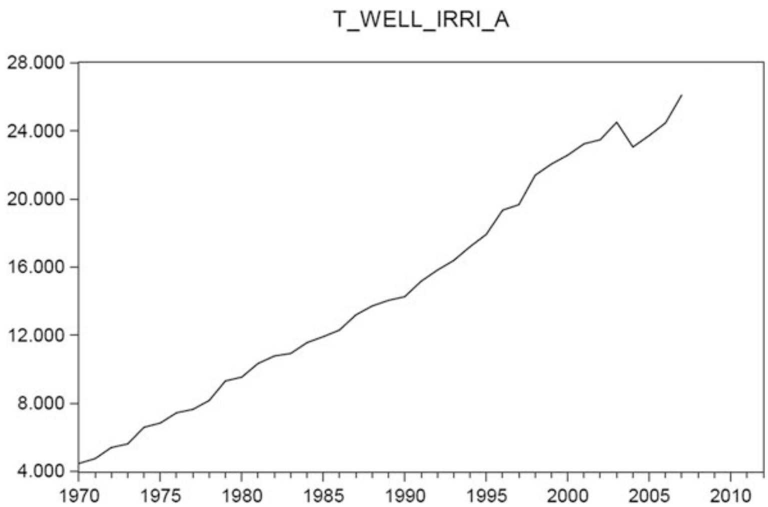

Fig. 2.2 Net irrigated area in India (000 ha) over the years

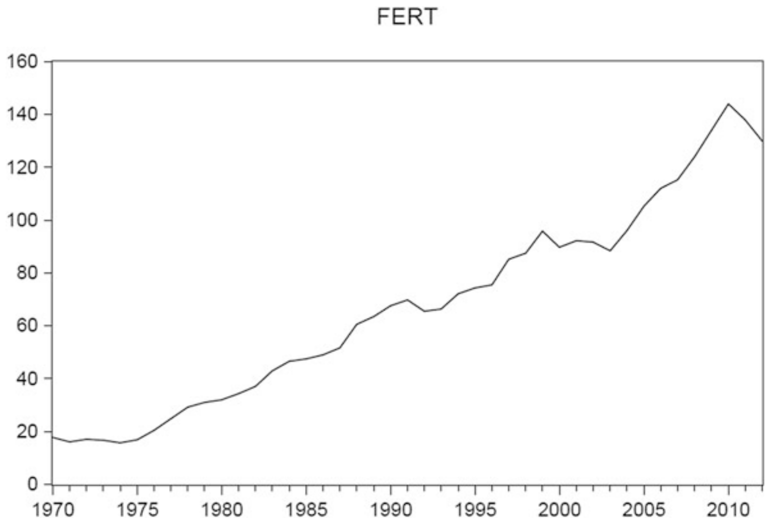

Fig. 2.3 Consumption of chemical fertilizer in Indian agriculture (kilogram per hectare)

$$\alpha_1 = 0.41\, \alpha_2 = 1.18\, \alpha_3 = 0.53$$

$\alpha_1 = 0.41$, $\alpha_2 = 1.18$, $\alpha_3 = 0.53$

It is important to note that elasticity of yield with respect to irrigation is highest and it is 1.18. The implication is that if area of irrigation is increased by 100 %, the yield will increase by 118 % (Figs. 2.1, 2.2 and 2.3).

2.5.2 Summary

The technological change in Indian agriculture is characterised by significant expansion of irrigation and use of HYV seed and chemical fertilizer on a large scale. As a result of technological change, productivity in agriculture, specially in foodgrains production, has significantly increased. Irrigation, specially tube-well irrigation has been found to be the most important factor in productivity growth.

2.6 Technological Change, Productivity Growth and Resource Degradation

The use of modern technology has enhanced productivity of land significantly through intensive cultivation and application of HYV seeds and chemical inputs like fertilizer and pesticides. The greater intensity of cultivation and the requirement of controlled supply of water in modern cultivation have put excessive stress on natural resources like land and water. Headley (1972) explains clearly that there are a number of environmental problems which are related to the pressure for the productivity growth and the resulting adoption of industrial products and techniques. The technical externalities and under valuation of resources make excessive use of the natural resources. He elaborates the problem by saying that intensive cultivation has been criticized for its contribution to sedimentation problems as well as the alteration of landscape through removal of natural vegetation. Similarly, chemical pesticide use has been seriously attacked for the discharge of toxic chemicals into the environment. Fertilizer use on the other hand has been suspected as a possible source of nitrates in streams and underground water supplies. Side by side with the challenge of providing adequate food and maintaining the income of the farmers, there is now an additional challenge of finding and maintaining the right relationship between agriculture and the natural environment. It has been noted that agriculture is not using the least cost bundle of resources. The inputs such as fertilizers are underpriced because the costs of pollution are not accounted for at the time of their use.

No doubt, the adoption of HYV technology has resulted in remarkable increase in productivity growth in Indian agriculture. But excess depletion of ground water, use of chemical inputs in increasing doses and intensive cultivation have weakened the resource base of the country putting a question mark before the sustainability of growth in agriculture. The total area of degraded land in India is nearly 90 lakh hectares which accounts for 20 % of total cultivated land. The states with large areas of degraded land are Madhya Pradesh (1663 thousand hectares), Rajasthan (879 thousand hectares), Karnataka (779 thousand hectares), Maharashtra (767 thousand hectares), Andhra Pradesh (607 thousand hectares), Gujarat (550 thousand hectares) and West Bengal (526 thousand hectares). In Haryana which is one of the most successful states in India in HYV cultivation, the share of degraded land in total operated area is 34 % against the national average of 20 % (Source: Compendium of Environment Statistics, India 2011). Apart from greater intensity of cultivation, the use of chemical inputs like fertilizers and pesticides is one of the

Table 2.33 Consumption of pesticides in major states of India in 2007–08

States	Total quantity (in metric tonnes)	Use per hectare (kg)
Andhra Pradesh	1381	0.12
Bihar	951	0.13
Gujarat	2650	0.28
Haryana	4288	1.21
Punjab	5760	1.35
Rajasthan	3333	0.21
Tamil Nadu	2317	0.43
Uttar Pradesh	8968	0.53
West Bengal	4100	0.75
All India	43,860	0.31

Source Compendium of Environment Statistics, India (2011)
Ministry of Statistics and Programme Implementation
Government of India

major causes of soil degradation. The use of fertilizers per hectare in agriculturally important states of India are as follows: 216 kg in Punjab, 189 kg in Haryana, 197 kg in Andhra Pradesh, 185 kg in Tamil Nadu and 150 kg in Uttar Pradesh. The national average is 115 kg per hectare (Source: Centre for Monitoring Indian Economy, CMIE 2010). The consumption of pesticides in major states of India is given below in Table 2.33.

The large quantities of use of fertilizers and pesticides not only pollutes food and water but also causes degradation of soil and biodiversity.

The tube-well irrigation has played a very crucial role in the technological change and productivity growth in Indian agriculture. The share of well-irrigation in net irrigated area of the country has increased from 12 % in 1970–71 to 60 % in 2007–08. But excessive extraction of ground water has not only caused a threat to future growth in agriculture but also resulted in contamination and salinization of water and soil. In agriculturally successful states like Punjab and Haryana, the extraction of ground water has crossed the permissible limits. The depletion of ground water is 45 % and 9 % higher in Punjab and Haryana respectively than the permissible limits. In Rajasthan, excess depletion is 25 %. In states like Uttar Pradesh, Tamil Nadu, Karnataka and Gujarat, the extraction of water is more than 70 % of the full potential of ground water irrigation. For the country as a whole, 58 % of the potential of ground water irrigation has been utilized by this time. The remaining 42 % can be utilized for future production and that is mainly in eastern part of India. If water level in the aquifer declines below 10–20 m from the ground level, it becomes difficult or impossible to extract ground water for irrigation. The percentage of wells showing 10–20 m water depth below ground level is very high in states like Punjab (39 %), Haryana (30 %), Rajasthan (29 %), Gujarat (28 %) and Madhya Pradesh (22 %) (Source: Government of India 2009). This is the outcome of excessive dependence on tube-well irrigation. Since India's agricultural growth is largely dependent on ground water irrigation and expansion of surface water irrigation is very limited, the scarcity of water supply has become a serious constraint to future growth. It needs special mention that in Punjab, a state of India, which is known as foodbed of India and where the green revolution technology has been most successfully implemented, the extraction of ground water has crossed the sustainable limit and the use of fertilizer and pesticide is the highest per hectare in the country. The Steering Committee of the Planning Commission observes that the use of nitrogen in excessive doses is adversely affecting the soil profile having its negative impact on land productivity (Bhullar and Sidhu 2006).

According to the World Development Report (2008), the green revolution in Asia has significantly increased cereal production in the continent after 1970. India also has achieved remarkable success in foodgrains production in the last four decades. However, the intensification of farming has brought environmental problems in various ways. The on-site and off-site effects of intensive agriculture have caused soil degradation in the forms of salinization, nutrient depletion, loss of soil organic matters (SOM), agrochemical pollution and loss of local biodiversity. Tilman et al. (2002) estimate that since 1945, approximately 17 % of vegetated land has undergone human induced soil degradation and loss of productivity often through poor fertilizer and water management, soil erosion and shortened fallow periods. The study also notes that continuous cropping and inadequate replenishment of nutrients have caused soil organic matter levels to decline. Land is the most important ingredient of agricultural production and the level of soil fertility depends on the rate of depletion, natural regeneration and artificial replenishment. The depletion rate is determined by intensity and technique of farming. Regeneration, on the other hand, depends on a number of factors like crop rotation, fallow system, application of organic fertilizers etc. (Krautkraemer 1994; Barrett 1991; Sasmal and Weikard 2013).

Sustainability has become an increasingly important issue and there are many definitions of sustainability. Perhaps the most widely acceptable definition of sustainable development is that of the Brundtland Commission that 'sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Kolstad 2000). Sustainability requires nondecreasing utility over time or preservation of the opportunity sets available to the future (Krautkraemer and Batina 1999). In optimal growth models using non-renewable resources, capital accumulation and technological progress are engines of economic growth while finite endowments of natural and environmental resources act as drag on economic growth. In such models non-negative growth is feasible if there is enough technological progress, sufficient elasticity of substitution between natural resource inputs and reproducible capital and there are renewable resources that can substitute for the non-renewable resources (Dasgupta and Heal 1974; Solow 1974; Stiglitz 1974; Krautkraemer and Batina 1999). In case of agricultural production where growth depends largely on renewable resources like land and water, the conservation of such resources is very important for sustainability of growth. Rosegrant and Sombilla (1997) have given projection of future global food supply and demand with possible resource limitations including land and land degradation, energy and fertilizer, water availability and global climate change. Although global per capita arable land has been decreasing steadily due to urbanisation and other factors, it is not going to pose a serious threat to future global food production. But land degradation can be devastating in some localities, specially in fragile environments. However, on the global basis, the yield impact of land degradation will be very small relative to crop yield growth from technological change and increased quantity and efficiency of input use. According to their projection, water scarcity is going to be the most serious threat to attainment of projected yield growth in agriculture. Global water withdrawals will increase by 35 % by 2020 and particularly serious pressure on water resources will occur in developing countries where water withdrawals are projected to rise by 43 % in 2020.

The farmers specially in the developing countries, are generally not much serious about maintaining soil health and adopting measures for replenishment of soil nutrients. Lynch and Lovell (2003) have identified the factors that affect the landowner's decision to participate in agricultural land preservation programmes. In this study, the factors like farm size, growing crops, distance to the nearest city, percentage of income from farming, available information etc. are found to be important in this respect. Since conservation of soil generates ecological services and protects the biodiversity, the policy intervention of the government is required to increase positive externalities of soil conservation and ensure sustainable growth in agriculture (Sasmal and Weikard 2013). In case of conservation of water resource also the government has a big role to play. Dasgupta and Mäler (2009) draw attention to the externality problems associated with the use of natural resources. They also point out the problem of under valuation of natural resources by private agents. Apart from these aspects, the government projects for conservation of natural resources are of public good nature. So, the market will not bring the optimal solution to the problems of resource degradation. Here, government intervention and public investment are very important. The conservation of resources are very important for future production in agriculture. Equally important is the technological change in various fields for productivity growth and resource conservation. Here again, the public policies have crucial role to play.

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