product of capital. In that case the economic interpretation of bias is 'simple and appealing. A labour-saving innovation makes labour in some sense more plentiful relative to capital than it was previously, with the result that the marginal product of labour must fall relative to capital' (Thirtle and Ruttan, 1987, p. 15).

It should be noted that in most of the economics literature, the analysis of technological change is quite narrowly focussed, since it is concerned solely with changes in the physical production process. There is little or no reference to the impact of technological change on political and social structures, on institutional and administrative systems, and on the physical infrastructure. However, as we will see below, many agricultural economists are now taking a broader perspective. It is also the case that in orthodox economic theory, technology is viewed as a factor outside the control of the entrepreneur and of the industry and so technological change is simply an *exogenous* shift in the production process. Nevertheless, in a development context in which sustained economic growth is sought, it is pertinent to ask: where is the technological change to come from?

BOX 4.2
Characteristics of technological change in the agricultural sector

Technological change has occurred in every sphere of agriculture. Much of it has been embodied in capital, i.e. in machinery, drainage, irrigation and buildings, but there have also been significant advances in the form of high yielding varieties (HYVs) of crops, improved strains of livestock, better feeds, and more effective fertilisers, pesticides and insecticides. Moreover, technological progress has been evident in cultivation and husbandry methods and in the overall managerial skills of the farmer.

Much of the technological change which has taken place in the agricultural sector has been biased, often being labour-saving (in the case of most new machinery) or land-saving (as with the HYVs and fertilisers). This does not necessarily imply that less of these factors are used. For example, with a labour saving technological change, theory suggests that the producer will employ less labour, for a given output level. However, as the marginal cost of production has fallen, the producer will wish to increase output, in order to maximise profits, and so employ more of all factors of production. There will then be a tradeoff between the initial displacement of labour due to the technological change and the increased employment of labour due to the

increase in production. In some cases, the net effect may be that more, not less, labour is employed. Nevertheless it should be noted that this type of prediction rests on the factor price ratio remaining constant, whereas in a number of developing countries, governments have chosen to subsidise the use of machinery. The reduction in the relative price of capital encourages a much greater displacement of labour and the net effect in these cases is almost certainly a reduction in labour usage. A specific case study is presented in Box 4.3.

BOX 4.3
Some consequences of farm mechanisation in Pakistan

McInerney and Donaldson (1975) analysed the major economic consequences of introducing large scale tractor technology to farms in Pakistan. Their research was based on a survey of 202 farms, just over 5% of the total number of farms which received tractors (financed by World Bank lending) in 1967–68. The economic incentives for the individual farmer to adopt the new technology were exceptionally favourable. The price of many crops had been set by the government well above world market levels, credit was made available at artificially low interest rates, and the imported tractors were free of duty and sales taxes. Of course the assessment of technological change goes beyond the calculation of the change in adopters' profits, and McInerney and Donaldson examine the wider costs and benefits to society, as well as the implications for resource use and the structure of agriculture. Here we will merely summarise their results regarding the primary concern of the farm mechanisation programme, namely the impact on farm employment.

To the extent that tractor mechanisation replaces traditional operations including those associated with the use and maintenance of animal draft power, seeding, harvesting etc., labour will be displaced. However this will be counterbalanced to some extent by the increased demand for labour services arising from the increase in cultivated land area, cropping intensity and final production. Indeed the average size of farm in the sample more than doubled (from 45 acres to 109 acres). This came about as follows: some farmers (22% of the sample) reclaimed or improved land which had been previously uncultivated, some farmers (12% of the sample) bought more cultivatable land, some (24%) rented additional cultivatable land, and the remainder (42%) reduced the amount of land which had previously been rented out to other producers and farmed this land themselves. The

absorption of land into enlarged holdings displaced tenants and owner-occupiers from the land and reduced the employment of labour (both family and hired). Thus, whereas the labour that was used *per farm* increased, the use of labour *per cultivated* acre fell by about 40%. McInerney and Donaldson calculate that between 7.5 and 11.8 full time jobs were lost for each tractor used. Even when one takes account of seasonal demands for casual labour, each tractor replaced about five jobs.

4.3.2 *Sources of technological change*

The chief sources of technological change to which a developing country might have access are

(i) 'learning by using';

(ii) private and public research and development generated within the country;

(iii) imported research and development.

Some technological change will take place on the farm or within the firm as the result of experience with a given production process. In everyday operation of the farm technical problems in production are confronted and solved. In time the producer learns how to get the most out of the inputs and the production process which has been adopted. The resultant gains in output are attributed to 'learning by using'[5] and will be a function of experience and hence time.

The second source of technological change is research and development (R & D) which may be conducted in both private and public institutions. Research may be *basic*, in which case it is undertaken with no specific commercial objective, or it may be *applied* i.e. directed to an immediate commercial end. In the *development* stage the most commercially promising research is selected and used to create new processes or products. In the industrial sector, a large number of private firms will have R & D teams; indeed private industry will be responsible for most R & D expenditure in manufacturing. In contrast, most agricultural R & D activities are undertaken by public agencies. Governments are often willing to provide the financial support for R & D because a new technology may take several years to develop, the research input may be too costly for an individual farmer to bear, and it may also be costly to disseminate information on a new process. In addition, if it proves difficult to patent or otherwise protect the researcher's interest in the new process, R & D for the private entrepreneur may not prove commercially viable. It is this latter reason which is often cited as an explanation for the observation that public agencies have been engaged on research into new breeds of livestock and new crop varieties, whereas private companies have succeeded in the development of new farm machinery and agrochemicals where patents are more easily applied.

Governments and producers in LDCs can engage in R & D in an effort to promote technological change in the agricultural sector. However it must be admitted that most of this work is conducted in the industrialised countries and many LDCs rely on the import of foreign technology. One option would be to screen foreign technology and adopt the 'best' without adaptation. The transfer of technology in this way has created some concern that the foreign technology may not always be appropriate to the needs and conditions in the recipient countries and may generate indirect costs, as well as benefits, through its impact on the social, political and physical infrastructure. An alternative, which may have fewer indirect costs, would be to select foreign technology for subsequent modification, through adaptive research, to suit local conditions.

4.3.3 *Adoption and diffusion of new technologies*

Because of the opportunities for increased output and higher income levels which technological change can offer, agricultural economists in the development field have made a particular study of the adoption and diffusion of technical innovations. *Adoption* studies relate to the use or non-use of a particular innovation by individuals (say farmers) at a point in time, or during an extended period of time. Adoption therefore presupposes that the innovation (source of technological change) exists, and studies of the adoption process analyse the reasons or determinants of whether and when adoption takes place. By convention individuals within a population are classified into (i) innovators, (ii) early adopters, (iii) the early majority, (iv) the late majority, and (v) laggards, according to the date of adoption. *Diffusion* is defined in relation to the spread of an innovation at the aggregate level viewed over time. That is, diffusion is defined as the cumulative process of adoption measured in successive time periods.

The decision of whether or not to adopt a new technology will be based on a careful evaluation of a large number of technical, economic and social factors. In this section we cannot address the full complexity of that process but we will suggest some of the elements which may influence it.

The technical attributes of a new technology may have a direct bearing on the decision making process. Specifically the more technically complex the innovation, the less attractive it may be to many farmers. Moreover, if the technology is divisible[6] (as is the case with HYVs), the farmer is able to try out the innovation on a small scale. On the other hand, if the technology is 'lumpy' (as is the case with large machinery such as tractors and harvesters), small scale trials are not possible and the farmer may be more reluctant to adopt. Moreover, the minimum scale of operation for the lumpy technology to be feasible may be too large for many farmers.

The economic potential of the new technology, in terms of yields, costs of production and profit, will also be most important. Typically, however, the economic impact of the innovation is not known with certainty. Unfamiliarity with the new technology will make the initial impact on yields and input usage uncertain. In addition the new technology may affect the extent to which the farmer is exposed to the vagaries of nature. For example, some HYVs may be more susceptible to disease than traditional varieties, whereas irrigation equipment may offset the effects of drought. Since the adoption decision must take place in an uncertain environment, the farmer's attitude to risk and in particular the degree of risk aversion must be taken into account.

As well as the technical and economic attributes of the technology, the characteristics of the farmer and the farming enterprise may influence the adoption decision. We have already noted that the farmers' attitude to risk will have a bearing on the adoption decision. Age, experience and education, the factors comprising '*human capital*', may also determine the farmer's awareness and interest in the new technology, as well as his ability to implement it. Moreover the potential adopter may be confronted with constraints in terms of purchasing power, of access to credit and information, and of poor communication links with product and input markets. With regard to the latter, the availability of complementary inputs in the quantity and at the time required may prove to be an important consideration in the adoption decision.

The diffusion process occurs over time and relies to some extent on the interaction between farmers in a given region. The process is often depicted as one of learning. Whilst a few producers will adopt the innovation rapidly, the majority will take time to become aware of the new technology and to evaluate its benefits. In this the demonstration effect of the early adopters may be important. The rate of diffusion will also depend on the extent to which the technology is location specific or is adaptable to the conditions under which most farmers operate. In addition, it is clear that the social, cultural and institutional environment will influence the speed at which the use of a new technology will spread through the farming community.[7]