WALTER L. FISHEL AND MARTIN KENNEY

Challenge to Studies of Biotechnology Impacts in the Social Sciences

Much has been written in recent months about the impending technological revolution in agriculture that will result from biotechnological innovations (NRC 1982; NAS 1984). Even the more conservative among these writers foresee changes in agriculture and related economic and social institutions that overshadow even that of the often discussed Green Revolution in developing countries. Unlike the Green Revolution, this set of technological changes will have even greater, if not different, impacts on the economic and social structures of the developed countries (Kenney forthcoming). In addition, there will be few economic and social components of agriculture and related institutions and infrastructures unaltered to some degree because of the source, nature and rate of change in biotechnology introductions (Kenney 1984).

This paper contends that social scientists interested in the consequences of technical change on agriculture and related economic and social infrastructures, whether in developed or developing countries, must begin now to analyse the implications of the new product introductions and processes resulting from biotechnology. This includes the biotechnologies already on stream and at least those that may be readily anticipated from the research now under way in the biological sciences. Several factors differ from the circumstances that have been involved in past studies of technological change that suggests no small degree of urgency in this endeavour. Further, this paper will indicate a number of characteristics of biotechnology that have significant implications to the study of impacts and suggests the need for added attention being given to the study perspective and methodology.

A CHANGING ENVIRONMENT FOR TECHNOLOGY ASSESSMENT IN AGRICULTURE

Economists and sociologists have a rich history in the study of technological change and its impact on agriculture and related institutions and structures (Hayami and Ruttan 1971). Consequently, there already exists a solid foundation of studies and methodologies applicable to most technological change situations encountered. Yet, in reviewing the relatively sparse literature relating to biotechnology applicable to agriculture, some concern with the adequacy of this foundation arises. There are a number of characteristics and factors associated with the advent of biotechnology and its adoption that strongly suggests the need for careful reappraisal of both our perspective and our methodology for assessing the impacts of biotechnology on agriculture.[1] In the following discussion, it is important to note that for the most part these characteristics and factors are not conjectural, nor are the direction of effects; the extent and rate of change necessarily must be conjectural, based on the limited amount of study done to data.

The principal source of change in the study environment originates from the extent to which biotechnologies are being developed and disseminated outside the traditional sources of agricultural technologies. While many technologies have come from other than public sector research institutions, especially in recent years, nothing approaching such a stream of private sector technologies has ever been encountered before in agriculture. Certainly, such a change extends well beyond that experienced in the Green Revolution. The significant effect of this will be reflected in a radical change in the source of control of technology related information, in its relative dependence on the information source and consequently its relative objectivity, and in its price and relative availability. Both developed and developing countries face many dilemmas from this shift in the transport of new knowledge (Kenney 1984).

In addition, the nature of the technical changes will be much different than most of the past technological changes that have been studied. Biotechnology innovations and introductions are being driven by large infusions of capital from outside the traditional sources of new technologies, namely from the private sector. These efforts are being applied only to areas of high technology in which the high risk of development is associated with high expectations of profits, and all that goes along with it. Technologies to be developed are being selected on this basis. The resulting biotechnologies will have incremental and disjointed impacts on agricultural productivity. Only the hybridisation of corn and possibly the current adoption of computers and microprocessor control systems can be expected to have a comparable impact to what may become commonplace for many biotechnologies.

Nearly all past technical changes in agriculture have been gradual enough for adjustments to be partially governed by tolerable rates of capital consumption. The decline of marginal operations has been at a rate that acceptable, of not preferable, adjustments could be made, short of impending disaster. The nature of the high tech, capital and knowledge intensive biotechnology based systems will greatly aggravate the adjustment problems by accentuating the differences in levels of productivity between capital and knowledge intensive versus more labour-intensive systems and units. Rates of capital consumption will be less important as a decision factor in adoption and, consequently, adoption rates will be greater to an as yet unknown degree than for most new technologies. The significant implication of this is that issues related both to management decisions and to governmental adjustment programmes will need to be anticipatory rather than reactive.

Because relatively few biotechnologies have yet to come on stream, possibly the most deceptive and least recognised cause of concern in this changing technological environment is the sheer magnitude of the number of new biotechnologies that are or will be developed. Changes will be coming from many directions simultaneously. As a later section of this paper indicates, virtually every biological aspect of agriculture is the subject of biotechnology innovations. And these are occurring concurrently. At no time in the history of agriculture has such a proliferation of new technologies been introduced in such a short period of time with each one having potential for substantial impact on productivity. Such an occurrence presents few possibilities for segmenting out relatively narrow areas of agricultural technology for individual study.

SOURCES OF CHANGES IN THE BIOSCIENCES

All changes start with altered technical relationships in agriculture and related industries, whether these are productivity changes or commodity or product substitutes. Sources of change from biotechnologies can be grouped in four major categories: (1) plant genetic manipulation and improvements, (2) advances in animal husbandry, (3) industrial tissue culture and (4) genetically engineered micro-organisms. Each category includes a number of heterogeneous techniques and each will have particular impacts based on the component of the farming system that it will affect. Certain of these techniques will be economically and socially more important than others, some in the short term, others in the longer term. The following overview provides only a brief summary of the power biotechnology has to transform both the production and distribution of agricultural products.

Plant breeding was the key to the Green Revolution and still remains the single most important discipline in agricultural research. However, in the last ten years, the increased capabilities of molecular and cellular biologists have provided new techniques to manipulate plant genetic material. Potentially, the most impressive of these techniques is the ability to move selected genes from one species to another. Researchers are attempting to move the gene complex for nitrogen fixation from legumes to cereal grains. However, this research may be most successful initially in moving single gene traits from one species to another. These genetic engineering techniques are still at the research stage and useful products probably will not be available before 1990.

Other less sophisticated techniques for plant improvement using tissue culture are already in use in both developed and developing countries (Sondahle 1984). The techniques using tissue culture range from the growth of potato microcuttings in a liquid medium to protoplast fusion involving the fusing of two cells to secure a more complete genetic mixing than is achievable by traditional sexual means. A 'pomato' having the roots of a tomato but the stem and leaves of a potato has been grown using protoplast fusion. Potatoes, cassavas, orchids and a number of other plants have been grown commercially using tissue culture. The International Rice Institute is currently field testing a cold-tolerant high-yielding rice variety in Korea that was developed using another culture. There is no doubt that tissue culture will hasten the spread of high-yielding varieties into areas formerly outside their growth range because of environmental constraints. These new plant propagation techniques, as with those that undergirded the Green Revolution, provide the stimulus for new social, political and economic arrangements.

The application of biotechnology to animal husbandry is already making an important contribution to increasing livestock productivity. Genetic engineering has provided researchers with new tools for developing vaccines against animal diseases, many of which are endemic in developing countries. Researchers in two companies in the United States are near to developing a microbially-produced foot and mouth disease vaccine. Other researchers have developed microbially-produced animal growth hormones and bovine interferon with the expectation that these will increase the efficiency of animal production. Farmers can now hormonally induce élite cows to superovulate and then manually extract and transfer these embryos to surrogate mothers. Commercial operations can sex and freeze the extracted embryos, transfer them anywhere in the world, thaw and then implant them into surrogate mothers. The possibilities for drastically upgrading the quality of cattle herds in developing countries are considerable.

Industrial tissue culture, keeping single plant or animal cells alive in a nutrient medium, makes it possible for scientists to select a single plant cell producing a desirable chemical, grow the cell *in vitro* and harvest the cells. This is an expensive process, but any plant chemical costing greater than $600 per kilogram is a candidate for displacement by industrial tissue culture. The first tissue culture plant chemical was shikonin, an Asian medicinal herb developed by one Japanese firm and already being used as a colouring agent in cosmetics by another. Tissue culture produced berberine will also shortly enter the market in Germany. The displacement of agriculturally produced plant chemicals by bio-industrially produced identical substitutes can have a substantial impact on regional economies (Kenney forthcoming).

The final area in which biotechnology will affect agriculture is in the use of micro-organisms to develop products that will displace agricultural commodities. The successful commercialisation of fructose corn sweetener to replace sugar through the use of immobilised enzymes is in many respects the seminal example of the potential for a significant impact on existing agricultural production systems from industrial biotechnology. The USSR is attempting to genetically engineer micro-organisms to convert methanol into single cell protein more efficiently. If the research is successful, the USSR will become self-sufficient in protein for animal feed (OTA 1981). This would have a severe impact on plant protein exporters such as Senegal, Brazil, Argentina and the United States. At the same time, if more efficient ethanol-producing micro-organisms were engineered, developing countries likewise would have the capacity to 'grow their own' feedstocks.

The complexity of bioscience research and development provides many difficulties for social scientists attempting to anticipate the future of biotechnology. So much of the main thrusts in biotechnology remain in the basic research stage. An increasing share of new developments are in industrial laboratories hidden behind the cloak of proprietary information (Kenney forthcoming). The varied nature of the biotechnologies makes it inevitable that many of these technologies will compete against each other. While a number of companies are preparing to microbially produce bovine growth hormones for dairy herds, other scientists are attempting to genetically engineer cattle to produce more growth hormone internally. Such a lack of any semblance of stability in the state-of-the-art for anticipated biotechnologies provides innumerable hurdles to realistic technology assessment studies.

CHALLENGES TO THE STUDY OF BIOTECHNOLOGY IMPACTS

The presumption in the following is that technological assessments of biotechnology impacts are performed to provide decision and policy makers with information that will be beneficial in their respective activities. This presumption specifies that the information required, and not the theoretical constructs of economics and sociology, is the predominant driving force in the design and conduct of biotechnology impact studies. As such, the parameters of the information required are specified first and only then are the dimensions of the study model, data acquisition and analytical methodologies determined. The latter will be varied both in design and degree of measurement precision as necessary to provide the required information. This is contrary to the usual approach in agricultural economics and rural sociology studies. Typically, information to be produced by a study is seldom determined with any degree of finality until after data availability is determined and analytical precision requirements are met. Rigorously reversing these roles may be the hardest of the challenges, especially for academic researchers. However, proper and rapid response to anticipated impacts of biotechnology introductions will be much too important not to provide less than the best possible information that is clearly oriented to the decision- and policy-maker's needs.

There are three additional factors related to perspectives about technology assessment studies that need to be carefully considered. All three have a significant effect on how one approaches the development of models, data acquisition and selection of analytical methods. The first of these is the need to orient one's perspective to the fact that both decision-makers and policy-makers will have to pre-act rather than react or respond to anticipated impacts of biotechnology. Both the rate and pervasiveness at which impacts will occur as well as the scale of effect of the impact will not permit waiting for the occurrence before studies are conducted and counter action is taken. A greater stress on anticipation (not projection!) rather than measurement will need to characterise our studies.

A second challenge to perspectives about biotechnology impact studies will be to attitudes about change itself. Anticipated impacts arising from the introduction of new biotechnologies should not be viewed as positive or negative. The object of concern should be how the economic and social systems will change as a result of the adoption of a particular biotechnology. Then, how do the units or components of that system change or adapt to the system changes? Up front neutrality of perspective will be necessary in order to preserve study objectivity in confronting the complexity of issues and effects that are presented in studies of biotechnology impacts. Changes resulting from biotechnology will be so pervasive that the *status quo* cannot be considered a relevant base for comparison.

The third factor related to perspective is the need to realise that the topic being studied is inherently multidisciplinary. Consequently, studies of biotechnology impacts must reflect this characteristic in their design and conduct. Multidisciplinary involvement must start with the conceptualisation of the problem, be reflected in the design of the study model and be present in the data acquisition procedures and analysis. There will be few biotechnologies that will permit a single discipline approach to assessments with any degree of usefulness in the information produced.

The foregoing is not intended to suggest that existing technology assessment methods should be abandoned. Existing methods will still be as useful and necessary in future studies as they have been in past. The contention here is that there must be some analytical extensions to these methodologies in order to generate the kind of information that is going to be required by decision- and policy-makers.

For most studies of biotechnology impacts, the model design will need to become a more explicit activity of the total study. It is common in economics and sociology to take a single category of economic or sociology theory as the given logical construct and then build the data and analysis methods based on its assumptions. Even for studies on biotechnologies having a relatively specific application, the model will need to be more explicit, larger and more involved. The design of the model will need to reflect the disciplinary inputs of bioscientists, institutional or organisational theorists and possibly the business component, as well as that of economists and sociologists. This suggests more of a discipline-free systems or systems analysis approach to the design of the overall model structure as a bridge to multidisciplinary participation. Although properly designed studies will still permit individual problem analysis within a single discipline, the critical element in the analysis is a notable reduction in the number of assumed conditions by the overall study structure. The latter point is a critical error to be avoided in studying biotechnology impacts.

Accepting the anticipatory goal in biotechnology impact studies and the pre-eminance of information requirements, a significant problem encountered is that data bases are either totally lacking or at best inadequate. Basically we are faced with a situation in which not only the impacts exist in the future but so do the data needed to determine the probable impacts. Further, with so much of the biotechnology research being conducted under a proprietary mantle, data that does exist simply will not be available to other researchers. Both of these conditions require some significant rethinking, especially on the part of social scientists, about their techniques for acquiring data. Absolute reliance on secondary data is not possible. Even budgeting techniques are limited in their application. The concept of precision in data measurement, as well as its currently pre-eminent role in study design, must be reconsidered. It is suggested that a greater reliance may need to be placed on subjective data sources.

In conclusion, it is our contention that the challenges to social scientists involved in biotechnology impact assessment studies are substantial ones. The nature of the environment within which biotechnologies are being developed is different than is commonly realised and certainly different from that of agricultural technologies experienced in the past. The nature of the resulting impacts will be more pervasive, more complex and occur at a more rapid rate than anything previously experienced. The practice of making management and policy adjustments *after* an impact has occurred and its effects become clearly visible in the market place or to the general public will result in very great economic and social losses. The role of and challenge to the social scientists, as it has been in the past, is in providing the information that will help anticipate these changes and impacts and their economic and social costs. The circumstance that is different now is that the task of providing truly useful information will require a significant re-examination on the part of social scientists of how they go about conducting their studies.

Undoubtedly, the greatest challenge will come in modifying the way in which we conceptualise the overall problem and formulate our analytical structures. The information required by decision- and policy-makers must become the pre-eminent force in study design. Expected disjointedness in impacts suggests the need to re-examine traditional techniques of data acquisition and analysis. More than ever, we will need to consider including the methodologies used in other disciplines. At the same time, we must develop theories that better anticipate the general trajectories of technological, economic and social change that evolve out of the peculiar circumstances created by biotechnologies. Finally, there is a great deal of urgency in getting social scientists started on examining these issues. There are a number of methodological problems in particular to be resolved before social scientists can expect to provide a steady flow of useful information to managers and policy-makers.

NOTE

[1]Only the principal factors are indicated here. A more complete discussion of these factors is contained in Kenney (1984), Swaminathan (1982), Kenney and Buttel (1985) and Buttel *et al.* (forthcoming).

REFERENCES

Buttel, Frederick, Kenney, Martin and Kloppenburg, Jack, Jr., 'From Green Revolution to Biorevolution: Some Observations on the Changing Technological Bases of Economic Transformation in the Third World', *Economic Development and Cultural Change*, (forthcoming).

Hayami, Yujiro and Ruttan, Vernon W., *Agricultural Development: An International Perspective*, Johns Hopkins Press, Baltimore, 1971.

Kenney, Martin, 'Biotechnology and Third World Farming Systems', Symposium on Science and Technology as Factors of Change, UNESCO, Paris, 1984.

Kenney, Martin and Buttel, Frederick H., 'Biotechnology: Prospects and Dilemmas for Third World Development', *Development and Change*, January 1985.

Kenney, Martin, *High Tech Biology: Corporate Influence on American Universities*, Yale University Press, New Haven, (forthcoming).

National Research Council, *Priorities in Biotechnology Research for International Development*, National Academy Press, Washington, DC, 1982.

National Academy of Sciences, *Genetic Engineering of Plants*, National Academy Press, Washington, DC, 1984.

Office of Technology Assessment, *Impacts of Applied Genetics*, U.S. Congress, U.S. Government Printing Office, Washington, DC, 1981.

Sondahl, Maro R., Sharp, W. R. and Evans, David., 'Biotechnology for Agriculture of Third World Countries', *ATAS Bulletin*, 1984.

Swaminathan, M. S., 'Biotechnology Research and Third World Agriculture', *Science*, vol. 218, 3 December, 1982.

DISCUSSION OPENING I – CLAUDIO GONZÁLEZ-VEGA

The unifying theme of these two papers is the impact of technological change on economic structures and on social institutions. One of the papers, by Jean-Pierre Berlan, looks at the past. It attempts to explain the historical evolution of the share of the United States in the international trade of grain by looking at the consequences of farm mechanisation and of the introduction of soybean cultivation. The other paper, by W. L. Fishel and M. Kenney, looks at the future. It urges the profession to look closely at the potential consequences of biotechnological innovations, because these may be equivalent to or even more dramatic than those examined by Berlan. Both papers are very general and highly speculative. They do not provide empirical evidence of the kind that would be required to validate their arguments, but the issues raised are very important and are treated in imaginative and provocative ways.

Berlan offers an interesting historical treatment of the evolution of grain production in the United States and of the accompanying structural transformations. It contains multiple details that it will not be possible to examine in detail here. I have no problems with the accuracy of most of the individual facts and events reported in the paper, many of them examined in an insightful way. The same events, however, can lead to a different interpretation of the dynamics of the story, particularly when one brings into the picture other facts, not sufficiently acknowledged by the author.

Increased grain production after the Second World War, for example, owes much to the hybridisation of corn and the extensive use of fertilizer. Since the late 1930s there has been at least a four-fold increase in corn productivity in the United States. These innovations made possible not only rapid growth of corn production but the release of land for soybean production. Similarly important in increasing productivity has been the increasing specialisation of American farmers.

Although Berlan recognises the cost-reducing factors that made possible the expansion of soybean production and exports, from the perspective of supply, he does not consider the equally important demand influences. As a result, he ignores the role of tastes and incomes, elasticities, and relative prices. An alternative interpretation of the events would identify demand as a driving force, as a market for meat products was created by rapidly rising incomes. Without these changes in consumption patterns, the transformations described by the author would not have been possible.

Before the War, the proportion of the world population with incomes sufficiently high to demand livestock products was minimal. Even today, 50 per cent of this population enjoys incomes per caput of less than US $400 a year. It was not until the American and European population became sufficiently affluent, that the demand for meat products increased. It has been shown that the income elasticity of demand for meat is quite high. Moreover, in the earlier days this limited demand for meat was satisfied with production from grass-fed livestock. It is only when incomes grow and consumption patterns shift, that grain is demanded for feed purposes. Similarly, the surge in poultry production can be explained by changes in relative prices and tastes.

Berlan claims that the United States has taken away the role of food producer from the Third World. The fact is that in the past the low-income countries sent little food to the industrialised nations. The periphery was never an important exporter of grain to the centre; at best, it was a supplier of desserts: sugar, coffee, bananas, cacao. Actually, during the period of decline of the American share in international grain trade, it was countries with a very similar natural resource endowment, – Canada, Australia, Argentina – that took her place. In any case, it can hardly be claimed that these were low-income countries. Moreover, policies adopted by these other countries, like the very protectionist import-substitution industrialisation strategy adopted by Argentina after the War, may explain her declining share in grain exports. I do agree, however, with his interpretation of the negative impact of PL-480 on low-income country agriculture.

Given low incomes, in the past the periphery did not demand much feed grain. As incomes increased and with them the demand for meat, imports of feed grain grew. A clear example is Taiwan which faces a severe land constraint. Over the past two decades, the ratio of consumption to output of grain increased from 1 to 1.6. That is, while in the 1960s domestic production was sufficient to meet her needs, Taiwan today imports 40 per cent of her consumption of grain. Does this reflect a poor performance? No, it does not, as Mellor suggested earlier. During these two decades, productivity in grain doubled, output was growing at 5 per cent per year, but consumption increased well in excess of this, given high income elasticities of demand.

The alternative interpretation, that a driving force in the growth of American exports of grain has reflected a demand expansion, has important implications. As one looks at the evolution of world patterns of production and consumption, it becomes clear that the market for grain may be potentially greater than is usually recognised. As incomes per caput increase in other parts of the world, the newly industrialising countries will generate an accelerating demand for meat. At present this demand is met with livestock fed on grasslands and on waste products, the supply of which is extremely limited and will not expand sufficiently. Livestock and poultry producers will turn to feed grain, but these countries do not possess comparative advantages in grain production. Their demand may become an important factor in alleviating the overproduction syndrome highlighted in Berlan's paper.

My main concern with the paper is a methodological one. One cannot justify an argument on the basis of isolated facts and events, while ignoring others, and on cleverly selected citations. I would have preferred to see some reference to tastes and preferences, incomes, relative prices, elasticities, and comparative advantages. From this perspective one cannot claim, as Berlan does, that the economic recovery of Europe and Japan, trade liberalisation, and the rise of real incomes have been 'factors of the second-order of magnitude'.

The difficulties associated with the analysis of the impact of technological change on economic structures and social institutions are also examined in the informative paper by Fishel and Kenney. If the interpretation of past history and a determination of the relative contribution of the multiple determinants of structural adjustments is a difficult task, anticipation of future impacts and adjustments is even more complex and risky. The researcher not only does not know the precise nature of the innovation itself, but must also project the constellation of relative prices and public-sector interventions that will influence the pace of adoption and counterbalancing reactions.

Fishel and Kenney claim that the biotechnological innovations in the pipeline are numerous, will be introduced simultaneously, will have a major impact on productivity, and will require rapid and substantial adjustments. They insist that their potential impact requires not only urgent study, but also anticipatory management and policy action. Their paper, unfortunately, does not even suggest what some of these actions may look like. It would be important to discuss what some of the predictable consequences of this revolution may be, if the dislocations announced by the authors are going to be properly dealt with.

For example, the authors insist that these developments raise important questions about property rights. They claim that the new technologies are being developed mainly by the private sector, protected by secrecy, patents and other proprietary restrictions. At the same time, they require enormous infusions of capital and have a high risk of development. The usual dilemmas resulting from the imperfections of the market for knowledge are evident. It is in the social interest to protect the profitability of these endeavours, to promote investment in this kind of research and innovations, while at the same time guaranteeing the widest adoption. Divergences between private and social costs and benefits must be compensated for in ways that do not slow down the pace of progress. Fishel and Kenney implicitly suggest that existing mechanisms for the generation and diffusion of innovations are no longer adequate, but their paper does not even outline the measures that must be taken to improve them.

Although the authors challenge the adequacy of existing methodologies for the study of technological change and of its impact, again they do not spell out explicitly and precisely what the deficiencies are and what is the nature of the corrections and extension required. They claim that larger and more complex models will be needed, with exceptionally high information requirements, but this is a change of magnitude, not of approach. Their recommendations of up-front neutrality, a multidisciplinary approach, and relevancy of the data one can hardly disagree with. At times it seems that the authors are unhappy about existing theoretical paradigms, but they do not state it explicitly.

There is a clear link between the two papers. If indeed biotechnological innovations will be as significant as Fishel and Kenney claim, largely increasing the productivity of firms and activities relatively intensive in knowledge, capital and management, they will have a substantial impact on the comparative advantages of the United States in world agricultural markets. Developments like these will further increase American dominance and will have significant consequences on the direction and pattern of international trade.

DISCUSSION OPENING II – W. J. MARTIN

Unless we learn the lessons of history, we are doomed to repeat the mistakes of the past. For this reason, it is fortunate that the two papers presented this morning are extremely complementary. As Claudio González-Vega noted in his comments, the first analyses the historical impacts of a major technological change while the second considers the likely effects of future technological advances.

The two papers each cover three main topics:

(1) Technological change
(2) Its economic effects
(3) Social and policy effects.

Turning first to M. Berlan's paper, the technological advance considered was power farming – the mechanisation of US agriculture. Interestingly, this technological advance was largely the result of research and development undertaken in the private sector. The patent system defined property rights over most technical advances and made investment in research worthwhile for the private sector.

The economic effects of power farming were both direct and indirect, with the indirect effects being considerably more important in the long term. The indirect effects required that considerable endogenous technical change take place to exploit newly profitable opportunities in soybean and livestock production. These advances included development of new varieties, development of soybean meal and hydrogenation of soybean oil, and involved both public and private research investments.

M. Berlan has pointed out that power farming brought farmers further into the market economy – 'subverting the simple exchange into a capitalist one'. He goes much further than this, suggesting that the capitalist system is inherently prone to a crisis of overproduction because of capital accumulation on farms and in agribusiness. This claim *completely* ignores the role of relative prices in balancing supply and demand – a role which they perform adequately if not distorted by policy. I am afraid I do not understand how this important balancing item can be ignored in developing a framework for analysing technical change, particularly when the role of lower prices in increasing the demand for meat is acknowledged. Any analysis of future technological change must surely consider the role of price in balancing supply and demand.

In the second paper, Fishel and Kenney argue that biotechnology is likely to have a greater impact on agriculture than the Green Revolution. They would probably argue that it is likely to be comparable in impact to the power farming revolution discussed earlier. The authors describe a range of technological advances such as tissue culture and genetic engineering, and point out that most research is taking place in the private sector. This raises an important question of whether today's institutions are adequate to allow efficient allocation of research resources. Patent systems generally do not provide property rights so that private investments in agricultural research can be recouped. Other systems such as Plant Variety Rights are only in their infancy.

As we have seen in the case of power farming, the economic effects of technological advance are likely to extend well beyond the direct effects. Even the direct effects of advances which transfer production of agricultural commodities from the farm to the factory will, of course, be substantial.

Fishel and Kenney argue that a great deal of research into biotechnology impacts is needed and that this research should be problem-oriented, should use a systems approach and should be subjective, if necessary, to overcome data limitations. I endorse most of their suggestions about methodology, particularly their argument that research should be addressed to the important policy problems, rather than merely those that are readily solved given current data availability. However, I have some concerns about their orientation to forecasting, or even anticipating, the effects of technological change. While providing some general information on technological developments is likely to be useful to decision-makers, I simply do not believe that the impacts of new technology can be forecast with any degree of accuracy. This is particularly the case with the indirect effects which can be very complex, as we have seen in the first paper. A far more important issue, I believe, is ensuring that the policy environment allows needed adjustments to take place. Any welfare problems resulting from rapid technological change can be dealt with directly by compensation policies which do not distort prices. Agricultural policies which do not allow prices to move in line with market trends can severely inhibit adjustments needed to respond to emerging market opportunities. The problems of over-production currently evident in Europe are indicative of how costly such interventions can be.

The actual conduct of research also requires an appropriate institutional framework. If research is to be undertaken efficiently in the private sector, careful attention needs to be given to the design of property rights for research achievements. For the public sector, research is needed to ensure that scarce research resources can be efficiently allocated.

In summary, it is clear from the two papers that technological change has caused, and will continue to cause, massive change in agriculture. As history has shown, these effects are extremely complex, involving long chains of indirect effects. Because of this complexity, and the difficulty of forecasting future technical change, I do not believe that we can accurately predict where we will end up. However, as long as we have the right institutional environment, I am confident that our journey will be a welfare-maximising one.

GENERAL DISCUSSION – RAPPORTEUR: GERT VAN DIJK

The reactions to Berlan's paper were concerned with the theoretical approach and the interpretation of data and also with specific facts. Quite a few questions took the implications of Fishel and Kenney's paper into account and applied these to Berlan's analysis.

Regarding the surplus problem in US agriculture, it was stressed that conversion of foodstuffs into livestock products was an important feature. However, although international trade in these products was important, the meat trade was in fact rather restricted. Possible favourable effects were thus impeded.

The more general observation was made that international trade was strongly influenced by differences in rates of change in technology. The effects of these differences might be more important than the differences in resource endowment or comparative advantages. Countries lacking competitive power needed political power in order to compensate. The question was raised whether this necessitated other production models.

Related to the previous point it was pointed out that the well known Public Law 480 led to the shipment of large quantities of grain to countries like India. The discussant stressed that this had many negative effects in the sense of depressed prices and disincentives to agriculture in importing countries. Smaller acreages were more under wheat than necessary, development policies were based on food aid, most cheap grains were consumed by the urban population.

Some discussants applied Fishel and Kenney's paper to Berlan's subject. The main line of reasoning was that the role of biotechnology was thought to be important for future world food supplies. For example, fractioning of biomass might in due course improve the conversion ratios of animal production, also more fibres might become suitable. The origins of raw materials for human food would similarly broaden because of applying biotechnological methods to biomass. New technology might, in total, increase the competitiveness of agricultural raw materials versus non-renewable natural resources in the field of agrochemistry and agro-energy. The examples of latex, alfalfa, forestry products and alcohol were mentioned. Such new opportunities could help to overcome the surplus problem. Other more specific points on Berlan's paper were the following:

Thanks to new varieties of soya and their adaptation to climatic conditions in Western Europe this crop has expanded rapidly in the recent past. A continuation of this explosive increase may occur, as happened with maize.

The idea of capital accumulation in agriculture was questioned; currently capital volume is stagnant or decreasing both in the US and Belgium.

In the early 1950s US agriculture not only lost the feedstuff market for draft animals but also textiles were substituted for by plastics.

It was considered difficult to judge in retrospect the assertion that Third World countries had now become the dumping ground of agricultural surpluses.

Doubts were cast on the applicability of Fishel's paper. Was this not too speculative? Could the future be sufficiently quantified?

Berlan's reply could not deal with all points raised because of time limitations. He unfolded his analytical framework and added that instead of gathering all relevant demand elasticity estimates, discussions with farmers – who had to make use of the opportunities for change – might be more relevant. He stressed once more that a static approach was not fruitful. Instead one was dealing with long-term historical processes. In our time social forces might need new economic policies. A new model by which new markets were developed by, among others, agronomic research had to be judged in the light of historical processes. As a way of getting rid of surpluses it should be remembered that currently 85 per cent of US oil exports is shipped as food aid. Consequently oil production in LDCs is under severe pressure. Berlan agreed that the international meat trade was restricted. The multiplying effect of meat exports with regard to surplus disposal was moreover reduced because of improved conversion ratios. Solutions of the problem now were therefore bound to be different from those in the 1980s.

In response to the discussion openers and the audience, Fishel recognised the lack of examples in the paper about the problems of methodology, data sources and acquisitions. This was due to space limitations. Against the scepticism as regards the relevance of analysis as stressed in the paper, the author maintained that we indeed could quantify the future. There was a difference, however, in the view of the past-oriented world of economists and sociologists and the future which existed in the minds of our bio-scientists who could rather easily perceive what was possible. Our methodologies had therefore to be adapted from a concern about precision and an approach was required which permitted the concept of anticipation – not always correct, but more often correct than not. Was it justified to consider future problems that might not even happen? Things could be worse and could be better, but would, anyhow be different. If we as agricultural economists did not provide policy-makers with more information about what it might mean, who would?

Participants in the discussion included J. M. Boussard, G. Bublot, D. Farris, M. S. Kenal and E. Tollens.