The economics of agricultural research

Some recent developments

Yoav Kislev

In this non-technical review of agricultural research the author points to the geographical and economic distribution of research efforts, the problems of transfers of knowledge and technologies, consequent adjustment problems, and resource allocation in agricultural research.

Yoav Kislev is at the Levi Eshkol School of Agriculture, The Hebrew University, Rehovot, Israel.

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Agricultural research is an economic activity utilising scarce economic resources – skilled workers, capital and other factors – and producing new knowledge which, in turn, affects farm productivity and increases food supply. Technological and productivity changes in agriculture were essential to the development of modern civilisation with large manufacturing and service sectors. Not all these changes originated in agricultural research – a long array of innovations, in transportation, energy utilisation, structures and chemistry originated in other sectors of the economy – but without the deeper understanding of the biological foundations of farming, without the development of the new varieties and methods of cultivation, the modern revolution in agricultural practices and rural life could not have occurred.

Being an economic activity, research can be subjected to economic analysis in an effort to understand the factors that affect its success or failure, to estimate the contribution of investment in research to productivity and to analyse the consequences of the process of technological change research entails. Though, as a scientific activity, the economics of research is of a recent origin, many studies have already accumulated in this field. However, the scope of this non-technical review does not permit coverage of all available contributions. Instead, I shall concentrate on a few selected topics revealing, undoubtedly, my own personal biases and ignorance.

Background and date

A recent compilation of data on agricultural research is provided by Boyce and Evenson[1]. Table 1 shows some of their findings. Since data on agricultural research are not published regularly by government agencies, the figures in Table 1 are probably less accurate even than the usual international statistics. However, they do reflect the main features of the agricultural research industry. World-wide expenditures on agricultural research are today around $4000M – five times more than in the early 1950s. Three quarters of this activity takes place in Europe and North America, ie, in the temperate climate zones of the world. Since agricultural research is, at least partly, geo-climate specific, the potential contribution of the knowledge created in the developed countries to the developing world, where the majority of the needy population resides, is limited and the current geographic

[1] James K. Boyce and Robert E. Evenson, *Agricultural Research and Extension Systems*, Agricultural Development Council, New York, 1975.

Table 1. Summary of international data on agricultural research

	Annual expenditures (million 1971 US $)			Ratio of expenditures on research to agricultural product (%)	
	1951	1959	1974	1951	1974
Western Europe	130	172	733	0·63	2·19
Eastern Europe and USSR	132	365	861	0·63	1·83
North America and Oceania	366	540	1289	1·23	2·70
Latin America	30	39	170	0·37	1·21
Africa	41	58	141	0·61	1·40
Asia (excluding mainland China)	70	131	646	0·37	1·85
World	769	1305	3840		

Source: James K. Boyce and Robert E. Evenson, Agricultural Research and Extension Systems, Agricultural Development Council, New York, 1975, Tables 1·1 and 1·5.
Note: Data are for public and private sector research, the latter is estimated to range from 25% in the USA, to 2% in Asia, of total research expenditures.

distribution of research efforts as revealed in Table 1 is unbalanced.

The proportion of agricultural research to the value of farm product, a measure of the intensity of research, is 2·7% in North America and about half this ratio in Latin America and Africa. The poor countries of the world invest proportionally less than the rich in research. Two effects operate here:

- To a certain extent, research, particularly public, is viewed by politicians and administrators as a luxury good, part of the educational-cultural complex, and the rich countries can afford to have higher research budgets;
- The supply of high quality research personnel is limited in most poor countries and they simply cannot develop large experiment stations, even if they recognised fully the importance of domestic research to their agriculture.

The International Agricultural Research Centres are an institutional innovation attempting to overcome the shortcomings of manpower and facilities in the developing world. The pioneer was the Rockefeller Project in Mexico where Norman Borlaug developed the first high-yielding wheat varieties. The Project involved international cooperation in an effort to increase farm productivity through a comprehensive approach. The new dwarf wheat varieties, released by the Mexican Centre and spread to many other countries, are particularly responsive to fertilisers, while traditional farm varieties suffer from lodging and loss of yield under heavy fertiliser application. A similar approach, institutionally and scientifically, was later adopted by the International Rice Research Institute (IRRI), the birth-place of the 'miracle-rice' varieties. Following in their steps, 10 regional institutes are today in operation or in advanced planning stages. Their work is coordinated through the Consultative Group on International Agricultural Research, a consortium of the World Bank, 18 donor countries, four foundations and three international agencies, who together pledged a contribution of $64M for fiscal year, 1976.[2]

The major contribution of the International Centres should come through their coordinated effort to create widely-based technology adaptable to the economic structures and climatic requirements of a large number of developing countries. The achievements of the work

[2] RF Illustrated, The Rockefeller Foundation, Vol 2 No 4, March 1976.

done in Mexico on wheat and in the Philippines on rice are impressive. High yielding wheat and rice varieties have been planted in 19 and 22Mha respectively in 1974/75[3] and a conservative estimate of the value of the additional output in Asia alone is above $1000M. The other International Centres of more recent origin have not had a significant effect on agricultural production to date.

The established Centres have recently been shifting part of the development and selection work to national research systems and a pattern of cooperation emerges where the International Centres introduce the major innovations and improvements and the national systems test them and adapt the new varieties and technologies to their specific conditions. IRRI has even ceased to name new varieties and turned over this right to the national systems. This international division of labour resembles in character the mode of the inter-regional work of the Japanese Assigned Experiment System, established in the 1920s, in which the Ministry of Agriculture and Forestry assigned experiments to regional stations. The Norin 10 wheat variety released by this system formed the genetic basis for the Mexican dwarf varieties which heralded the green revolution. In the USA, to give a different example, agricultural research has been based chiefly on the state experiment system with little central coordination. The question of the optimal institutional structure of a research system is of crucial importance but has hitherto not received enough attention in economics.

Economic analysis

Research creates knowledge which enters the production process. Viewed as a factor of production, knowledge has very peculiar attributes – it is difficult to produce but often, particularly in agriculture, comparatively easily reproduced. Moreover, unlike other productive assets, knowledge is not subject to wear and tear (though it may become obsolete), and its use by one farmer does not preclude another farmer from using the same piece of information. As a result of these attributes knowledge is of limited appropriability – the producer of knowledge is seldom the sole beneficiary of the product. Technologies that can be copied or seeds that can be easily propagated will not fetch on the market a price that will cover the cost of research and development necessary to generate new technologies or to breed improved varieties.

Private firms restrict their research efforts to areas in which new knowledge is embodied in products whose price can be set to cover the development cost. Such products are, for example, hybrid seeds which have to be procured from the developer, patented mechanical equipment and chemicals, eg fertilisers, herbicides and pesticides. A private firm cannot be expected to invest in an intensive wheat improvement programme as wheat is self-pollinating and the new seeds can be produced on the farm and distributed among the producers by any grower without loss in yield potential.

Thus the market mechanism cannot be expected to induce optimal levels of investment in agricultural research. This is the economic rationale for the concentration of this activity in the public domain. The fact that agricultural research is mainly publicly financed, adds to the dimensions of the economic issues involved.

The pioneering study in the economics of agricultural research has

[3] Dana G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in Less Developed Nations*, Economic Research Service, USDA in Cooperation with US Agency for International Development, Foreign Agricultural Economic Report No 95, Washington DC, 1976.

been the, by now classic, work of Griliches on hybrid corn in the USA.[4] This is a case of complementary public and private research efforts. The public sector studied the biology, developed the hybridisation techniques and supplied parental material to seed companies which propogated and distributed competitively seeds of hybrids tailored to local conditions. Griliches studied the diffusion of the new technique throughout the maize growing area. He explained the earlier availability and the faster rates of adoption by farmers in the corn-belt states by recognition of the experiment stations and seed companies of higher economic payoffs in these intensive maize growing areas and by postulating that farmers react to absolute advantages in considering the adoption of new techniques. As hybrids increased yields proportionally in all fields, their absolute contribution was higher in the high yielding corn-belt than in the peripheral and southern regions.

Griliches also developed a framework for the cost-benefit analysis of publicly financed agricultural research in which past outlays are viewed as stages in a long-term investment programme and compared to present and future benefits (from higher production) of the research project. By his estimates, the development of hybrid corn was an extremely profitable investment to society with the benefits to producers and consumers of corn exceeding by far the accumulated cost of research. High rates of return to research have since been reported for many crops and in many countries.[5]

A major contribution has been that of Hayami and Ruttan[6] who attempted to outline an economic theory of agricultural research. By their postulates a research system faces a spectrum of potential technologies; the choice of the appropriate technology to develop and the direction research takes is affected by cost and returns considerations. Thus, in the land-scarce Japanese agriculture technical change was 'land augmenting' – the innovations were mainly biological, the new varieties created were suitable for intensive cultivation and for comparatively heavy application of fertilisers. In the USA, on the other hand, the scarce factor was labour, innovations were mechanical, resulting in an increased output-to-labour ratio, yields per hectare were stagnant until the Second World War, while the mechanical innovations facilitated outmigration from agriculture in response to rising urban wages and income opportunities.

This theory of the economically induced direction of agricultural research raises an important institutional issue, namely, what is the mechanism which transmits to the non-profit, bureaucratically structured, research systems the relevant economic signals? Hayami and Ruttan concentrated on the demonstration of the existence of institutional economic response. Further work on the theory of induced institutional change is now in progress.[7]

Transfer of technology

The comparative analysis of international data brings up the problem of the transfer of knowledge and technologies. Such transfer may be restricted by the climatic and economic applicability of research findings in one country to the circumstances of the other. To study these issues, Evenson and Kislev[8] developed a system of geo-climate classifications and showed, for wheat and maize, that the transfer of knowledge across international boundaries has been regional-specific, and estimated that more than two-thirds of the economic contribution

[4] Zvi Griliches, 'Research costs and social returns: hybrid corn and related innovations', *Journal of Political Economy*, Vol 66, 1958, pp 419-31, and Zvi Griliches, 'Hybrid corn and the economics of innovation', *Science*, Vol 29, 1960, pp 275-80.

[5] Boyce and Evenson, *op cit*, Ch 6, review these findings but W.S. Wise in 'The role of cost-benefit analysis in planning agricultural R&D programs', *Research Policy*, Vol 4, pp 246-261, criticises the approach and its use in research planning.

[6] Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development, An International Perspective*, Johns Hopkins University Press, Baltimore and London, 1971.

[7] Hans P. Binswanger and Vernon W. Ruttan (forthcoming), *Induced Innovation. Technology, Institutions and Development*, The Johns Hopkins University Press, Baltimore.

[8] Ch 4 in Robert E. Evenson and Yoav Kislev, *Agricultural Research and Productivity*, Yale University Press, New Haven, 1975.

of research in these crops in a country come through its augmentation of knowledge transferred from other countries in similar geo-climatic conditions. Furthermore, domestic research is a necessary condition for the transfer of knowledge as no transfer takes place in its absence. The emphasis in the International Centres on 'outreach' programmes in cooperation with national research systems indicates the recognition by these institutions of the natural barriers to direct transplantation of technologies.

Of course, natural differences are not the only obstacles to the adoption of modern, scientifically developed, technologies. The human factor plays a crucial role. This point is stressed by sociologists who hotly debated Griliches' emphasis on the economic factors in the development and adoption of hybrid corn.[9] It is probably true, as Schultz has often stressed, that many modern western technologies failed in low income countries because of economic or climatic incompatitability and that even poor farmers recognise a good opportunity when presented with one. Still, even clearly superior technologies are not adopted by all farmers simultaneously and the better producers often benefit more from the findings of research. Welch[10] contributed to these issues an analysis of the interaction of schooling and technical change. He views the impact of new knowledge as throwing operators out of balance. In a traditional society of stagnant technology farmers converge, through experience and generations of learning by doing, to the optimal allocation of resources, ie optimal given their natural and economic environment. As new knowledge appears, farmers are no longer in optimal positions – they have to readjust their operations to the new opportunities. Here the role of schooling is crucial; the educated farmer can decode the information flowing from the research system, he can assess its value and make the needed modifications faster and better than his unschooled neighbour. The educated farmer will, therefore, benefit earlier and more from the new technologies. This explains both why research is more successful where levels of schooling are higher and why the returns to schooling are high in a technologically dynamic environment while schooling is of little importance in a stagnant environment.

Extension via the agricultural advisory service complements the role of schooling. The extension agent translates the new information to simple technical instructions and distributes the experience gained by the first adopters. If this view is correct, and Welch's and following studies supported it with statistical evidence, the contribution of extension also vanishes in a traditional setting. A test of this hypothesis in a developing country was conducted by Evenson[11] who analysed productivity growth in the states of India. His conclusion was that whatever little research took place was highly effective. The major experimental extension effort executed by the Indian government in collaboration with the Ford Foundation 'had a payoff of approximately the same order of magnitude as other development efforts, with the glaring exception of investment in research', which had a much higher payoff.

Adjustment problems

Agricultural research and the technical change it stimulates create adjustment problems which can sometimes be quite severe,

[9] A balanced account of this controversy is given by Everett M. Rogers, *Diffusion of Innovations*, The Free Press of Glencoe, New York, 1962.
[10] Finis Welch, 'Education in Production', *Journal of Political Economy*, Vol 78, 1970, pp 35-59.
[11] See Ch 6 in Evenson and Kislev, *op cit.*

particularly if the impact of technical change is as sudden and big as in the early stages of the green revolution. I shall not discuss in this review the enlarged marketing, transportation and institutional credit facilities – preconditions for expanded production[12] – but focus mainly on the distributional problems: the distribution of the benefits (sometimes even losses) between producers and consumers and between groups of farmers.

In a market economy, which does not trade internationally in food products, consumers benefit from technical change by getting larger quantities at lower prices. Depending on the conditions of demand, farmers may even lose if the reduction in price more than offsets the increased production. Since the demand for agricultural products and particularly for food is inelastic, technological change in agriculture will reduce farm income unless it is accompanied by outmigration and increased scale and efficiency for the remaining operators. This is, of course, the other side of the modernisation and urbanisation coin – at a higher technological level, a smaller number of farmers feed a larger urban population.

The situation is different if food is exported or imported, as then prices are unaffected by domestic supply changes. Thus Hayami *et al*[13] estimated that throughout the whole period of the Japanese rice breeding programme, from 1915 to 1961, producers' benefits would have been negative, ie their income would have declined, if the country were self-sufficient in rice. However, since Japan imported rice under a Government policy designed to stabilise the price of this major food item to the urban population, the programme did not affect consumers' welfare, and its benefits were mostly captured by the producers.

Many writers have pointed out that technological change is not scale-neutral – it improves the relative position of the large farm operators and increases rural income inequality. Several factors operate here. In the short term, the income distribution effect of technical change may be neutral: a new variety may increase yield proportionally on fields of all sizes, this will increase income of all farmers to the same proportional extent, every one will be better-off, and the degree of equality (or rather inequality) will remain the same as before the introduction of the new technology. Thus, technical change may possibly be income-distribution neutral. It is doubtful, however, whether it is likely to be such. Most modern technologies require the purchase of non-farm inputs, eg seeds, fertilisers, implements. The introduction of these is risky, or conceived to be risky by the traditional farmer. The small operator is often not in a position to finance the new inputs. Moreover, the larger farmers are better skilled and educated and, as pointed out earlier, benefit more from technological change.

With these factors considered, even the short term income-distribution effect of technical change is unlikely to be neutral. Dynamics seems to handicap even further the comparative position of the small operator. With time, the bigger farmer will accumulate more capital, will be able to acquire machinery, to dig wells, and his income will rise even faster. The introduction of the new technology may start him on a new growth path. At the same time, if machinery is spreading, the chances are that the demand for labour will decrease. The landless day-labourers or the owners of small plots who work partly for others will see their wages or, in some places, shares in

[12] See Walter P. Falcon, 'The green revolution: generations of problems', *American Journal of Agricultural Economics*, Vol 52, 1970, pp 698-710.
[13] Yujiro Hayami in association with Masakatsu Akino, Masahiko Shintani and Saburo Yamada, *A Century of Agricultural Growth in Japan*, University of Minnesota Press, Minneapolis, and University of Tokyo Press, Tokyo, 1975.

crops, decline while the bigger operators improve their position as new technologies flow in.

Data availability and methodological difficulties limit the possibility of getting reliable estimates of the distributional effect of the introduction of new technologies and improved varieties. Nevertheless, several writers have attempted to deal with the dynamic processes accompanying technological changes.[14] Two studies of special analytical interest will be discussed here.

Schmitz and Seckler[15] analysed the effect of the introduction of the tomato harvester on labour displacement in agriculture. Since we cannot compare the welfare loss of the unemployed labourers to the gains to consumers and producers of tomatoes, they attempted to estimate whether labour can be compensated by society so that, as the economic welfare criterion requires, 'everybody will be better off' after the introduction of the tomato harvester. The crucial issue here is the operation of the labour market. If the displaced labourers can easily find alternative employment, compensation will be only a small part of the benefits of mechanisation; otherwise it may wipe-out these benefits and mechanisation is socially undesirable.

Using Philippines data, Hayami and Herdt[16] show that technological change in rice production can improve the position of the small farmer, who consumes most of the rice he produces, relative to the larger farmer who markets his product at lower price. Also the relative position of the urban poor, in whose diet rice is the major component, improves with rising supply. Of course, a precondition for this distributional effect to occur is that small farmers can readily adopt the new technology and that markets are allowed to operate freely – conditions which do not always prevail.

A major source of inequality, as Evenson has pointed out, is the unequal geo-climatic distribution of research work. IRRI, for example, has estimated that the rice varieties developed to date can be used only by 25% of present rice farmers – three out of four rice farmers in the world cultivate deep-water, high mountains or dry areas for which no new 'miracle' varieties have yet been bred. It is questionable whether the research system can contribute much to the other distributional problems discussed in this section, but the redressing of the last imbalance is undoubtedly one of its major tasks.

Resource allocation

The discussion of the optimal allocation of the resources in agricultural research can be focussed around three major issues:

- Institutions – big or small stations, international centres or national systems, independent scientists or mission-oriented task-teams, and the role of farmers in directing research.
- Policy – research in socially desired areas or directed to maximise productivity (if a conflict exists).
- Techniques – planning and administrative methods to affect efficient resource allocation.

Since some of the institutional and policy issues have already been discussed, it will be useful to review as an example, one of the suggested planning techniques, the Minnesota Agricultural Research Resource Allocation Information System[17], which takes explicitly into account the uncertainties involved in planning research. The system incorporates a sampling procedure: scientists and knowledgeable

[14] Inderjit Singh and Richard H. Day, in 'Factor utilization and substitution in economic development: a green revolution case study', *The Journal of Development Studies*, Vol 11, 1975, pp 155-77, analyse the effect of the green revolution on mechanisation in the Punjab. Keith Griffin, in *The Green Revolution: An Economic Analysis*, UN Research Institute for Social Development, Geneva, 1972, stresses the monopoly position of the larger farmer as a cause of the unequal distribution of benefits from technological change. See also Ingrid Palmer, in *The New Rice in The Philippines*, Studies in the Green Revolution No 10, UN Research Institute for Social Development, Geneva, 1975, who discusses the position of the low-income farmer in the Philippines.

[15] Andrew Schmitz and David Seckler, 'Mechanized agriculture and social welfare: the case of the tomato harvester', *American Journal of Agricultural Economics*, Vol 52, 1970, pp 569-577.

[16] Yujiro Hayami, and Robert W. Herdt, 'The impact of technological change in subsistence agriculture on income distribution', Mimeo, International Rice Research Institute, Los Banos, Philippines, 1974.

[17] Walter I. Fishel, *Resource Allocation in Agricultural Research*, University of Minnesota Press, Minneapolis, 1971.

persons in the industry are asked to estimate the degree of success of research projects and length of time to application (pure science projects are compared to applied research). The sample replies are processed to form subjective probability distributions of outcomes. At this stage formal, well-known, decision-theory techniques can be used to programme an optimal allocation (under specific assumptions). Even if not used as inputs into sophisticated decision calculations, the probability distributions of the research outcomes are an interesting information device, augmenting the research administrator's insight, and capable of improving his decisions. This approach was tried successfully but is not widely used – bureaucrats, even if scientists, prefer the freedom and power of discretion of informal processes to disciplined, demanding and somewhat costly procedures.

Concluding remarks

The major highlights of the recent developments in the economics of agricultural research can be viewed as a succession of empirical and theoretical contributions, each based on the previous stages and, at the same time, expanding their scope and applicability. Thus Griliches work in the USA was followed by a group of empirical estimates of the contribution of research in that country and others. Schultz, ever strong in his conviction that farmers – even in low-income countries – are, by necessity, sharp enterprenuers, made the lack of domestic research and hence of appropriate technologies one of the cornerstones of his theory of traditional agriculture.[18] In his view, the correction of the research imbalance and the biased price system, which was tilted in many countries against agriculture, will transform traditional agriculture into a modern growing sector.

Hayami's work on the Japanese agriculture and on international productivity differences was followed by the development, by Hayami and Ruttan, of the theory of induced institutional changes, which was supported by further empirical work. According to this theory, not only the direction of agricultural research is affected by economic signals; changes in economic environment entail modifications in social and economic institutions that are necessary to realise the economic potentials of the new environment. Premature institutional reforms, in land-tenure system, credit or extension, unaccompanied by technological changes, are doomed to fail. Again, the policy implication is a stronger reliance on the price system to translate the economic necessities and potentials to profit signals recognisable by farmers and administrators.

Hayami and Ruttan have demonstrated beyond reasonable doubt that research and technological changes follow economic guidelines. There is, however, a certain degree of inconsistency in their theory that views institutional development as indigenous to the economic system and, at the same time, prescribes policy changes from administrated pricing to free markets. Either the invisible hand can be relied upon to create optimal institutional constructs or, at least in certain societies, its efficient operation can legitimately be questioned. The work now in progress on the subject of induced development will probably clarify some of the issues involved.

Perhaps the writers that were impressed by the success of agricultural research neglected the adjustment problems involved. Falcon's is the most articulate statement of these issues and it has

[18] Theodore W. Schultz, *Transforming Traditional Agriculture*, Yale University Press, New Haven, 1964.

been followed by an array of empirical studies, particularly on the distributional effects of science created technical change. The evidence accumulating is far from giving unambiguous support to the claim that the adjustment problems and inequalities created by research outweigh its benefits. At the same time, as I have tried to stress in the course of this review, only seldom, if ever, can agriculture develop in isolation. Successful technical change, and smooth acceptance of technologies created by the research system with minimal social cost, can only be achieved in a growing economy. The difficult question of the optimal rate of growth is outside the scope of this review.

Viewed from a historical prespective, intensification of agricultural practices is not a new phenomenon. What is new is the recent pace of productivity changes that can be achieved only by a science-based agriculture. This pace is necessary to avoid malnutrition and starvation of the world's growing population. However, as Norman Borlaug has already stressed, even with the best achievements of science and the farming community, it will simply be impossible to feed the future world population if it continues for long at the present growth rates. This rate must simply be curtailed.