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Assessing Impacts of Agricultural Science and Technology

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Assessing Impacts of Agricultural Science and Technology*

George W. Norton, Julian M. Alston, and Philip G. Pardey**

Over the last half century, U.S. agriculture has undergone a transition from a labor-intensive, resource-based industry to a more capital- and information-intensive, science-based industry. Agricultural production (and total factor productivity) has roughly doubled while labor usage has declined by two-thirds, and capital and purchased inputs have increased about two and a half times. Many factors have caused these changes including structural changes in the U.S. economy, expansion in world trade, low-cost energy and fertilizer, improved transportation, and perhaps most important, the discovery and adoption of improved technologies brought about by science and education. This agricultural transformation has had a myriad of impacts including effects on food prices and nutrition, the structure of farms, agribusiness, and rural communities, global competitiveness of U.S. agriculture, farm income, and environmental quality.

Because science and technology (S&T) has played a vital role in this transformation, because almost half of the funds for agricultural S&T are supplied by the public sector (and these funds are increasingly scarce), and because questions are often asked about the nature (positive and negative) of social, environmental, and other effects of S&T, the demand for assessment of agricultural S&T has blossomed in recent years. Accountability has become a major theme, not just after the fact, but before decisions about public funding of agricultural research are made. Who will benefit, when, by how much, at what cost, and with what environmental and social benefits and costs? Answering these questions is not simple. It requires an understanding of the determinants of the costs and benefits of science and technology and of the factors that influence the distribution of those costs and benefits among different groups. My task today is to identify some of these determinants and to suggest "an economic way of thinking" about science and technology assessment.

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My comments are divided into three parts:

1. Basic economic model of research benefits.

2. "Nonmarket" research impacts.

3. Popular myths about impacts of agricultural science and technology.

I conclude with implications for ex ante technology assessment.

Basic Economic Model of Research Benefits

Agricultural research is an investment that affects future productivity, income growth, environmental quality, food and farmer safety and the quality of rural life. Research dollars spent on scientific personnel, experimental plots and animals, laboratory facilities, libraries, computers, etc. produce new knowledge. That knowledge, often embedded in new or improved technologies, may take several years to produce but then pays off over a long time. Eventually, the knowledge depreciates and requires maintenance. In some cases, the knowledge is utilized by farm supply industries in conjunction with their own R&D to create new, more productive inputs.

The increased productivity that results from agricultural research means that more output can be produced with the same amount of total inputs or the same amount of output can be produced with a smaller quantity of inputs. Society benefits from the more abundant supply of agricultural products which often result in a lower real cost of food and fiber for consumers. Lower food prices particularly help lower-income people, who spend a larger fraction of their income on food than do higher-income people. Other benefits of agricultural R&D stem from a safer food supply, the reduced need to farm highly-erodible lands, the freeing up of resources, particularly labor, for use by other sectors of the economy, the increased ability of those who remain full-time in agriculture to earn incomes similar to those outside of agriculture, and multiplier effects on income and employment elsewhere in the economy as a result of expanded agricultural output.

Freeing up of resources in agriculture also means that labor bears adjustment costs, as do rural communities. In many cases, even when there are great benefits to society as a whole, some people are made worse off by changes in science and technology. Some technologies may improve the natural resource environment and food safety while others may harm them. Hence, science and technology assessment is placed squarely in the middle of evaluating tradeoffs among the contributions of alternative research investments to economic efficiency, distributional, and other social objectives. A framework is needed for making these assessments. The basic economic model presented below may provide a useful component of such a framework. It is true that economic analysis cannot answer the question of whether one particular research program is better or worse off than another without information about the relative value to be placed on different societal objectives.

And, some effects are difficult to incorporate into an economic analysis. However, in many cases application on an economic way of thinking can shed considerable light on the nature of S&T impacts and the tradeoffs involved.

The Basic Model

The basic model of research benefits is represented in Figure 1. In this model, S_0 represents the supply curve before a research-induced technical change, and D represents the demand curve. The initial price and quantity are P_0 and Q_0. Suppose research leads to a savings of R per unit in the average and marginal cost of production, reflected as a shift down in the supply curve to S_1. This research-induced supply shift leads to an increase in production and consumption to Q_1 (by $\Delta Q = Q_1 - Q_0$) and the market price falls to P_1 (by $\Delta P = P_0 - P_1$). Consumers are better off because the R&D enables them to consume more of the commodity at a lower price. Consumers benefit from the lower price by an amount equal to their cost-saving on the original quantity $(Q_0 \times \Delta P)$ plus their net benefits from the increment to consumption. Although they receive a lower price per unit, producers are better off too, because their costs have fallen by R per unit, an amount greater than the fall in price. Producers gain the increase in profits on the original quantity -- i.e., $Q_0 \times (R - \Delta P)$ -- plus the profits earned on the additional output. Total benefits are obtained as the sum of producer and consumer benefits.

Distribution of Benefits

The distribution of benefits between producers and consumers depend on the size of the fall in price (ΔP) relative to the fall in costs (R).[1] This relative size difference depends on slopes or price responsiveness (elasticities) of supply and demand. The more elastic (flatter) supply is relative to demand, the greater the consumer share of total research benefits (and the smaller the producer share) and vice versa. In the extreme case of perfectly elastic (horizontal) supply with downward sloping demand, all of the research benefits go to consumers because the research-induced change in price is equal to the research-induced cost savings and there is no producer surplus. When demand is perfectly elastic, all benefits go to producers because there is no research-induced reduction in price.

The assumption that price is unaffected by research, so that all of the research benefits go to producers, is likely to be a reasonable approximation for several commodities for which U.S. production is too small to appreciably influence the world price (e.g. sugar) or for which there is a binding support price set by the government (e.g. dairy). On the other hand, when consumption is very unresponsive to lower prices (i.e. demand is inelastic), most of the cost savings will be passed on to consumers as lower prices, and there will be little, if any, benefit to producers. This situation is likely to occur for commodities that are not traded

[1] It also depends on the nature of the supply curve shift (e.g. parallel as shown in Figure 1 versus a more pivotal shift which would reduce producer benefits but which is also less likely).

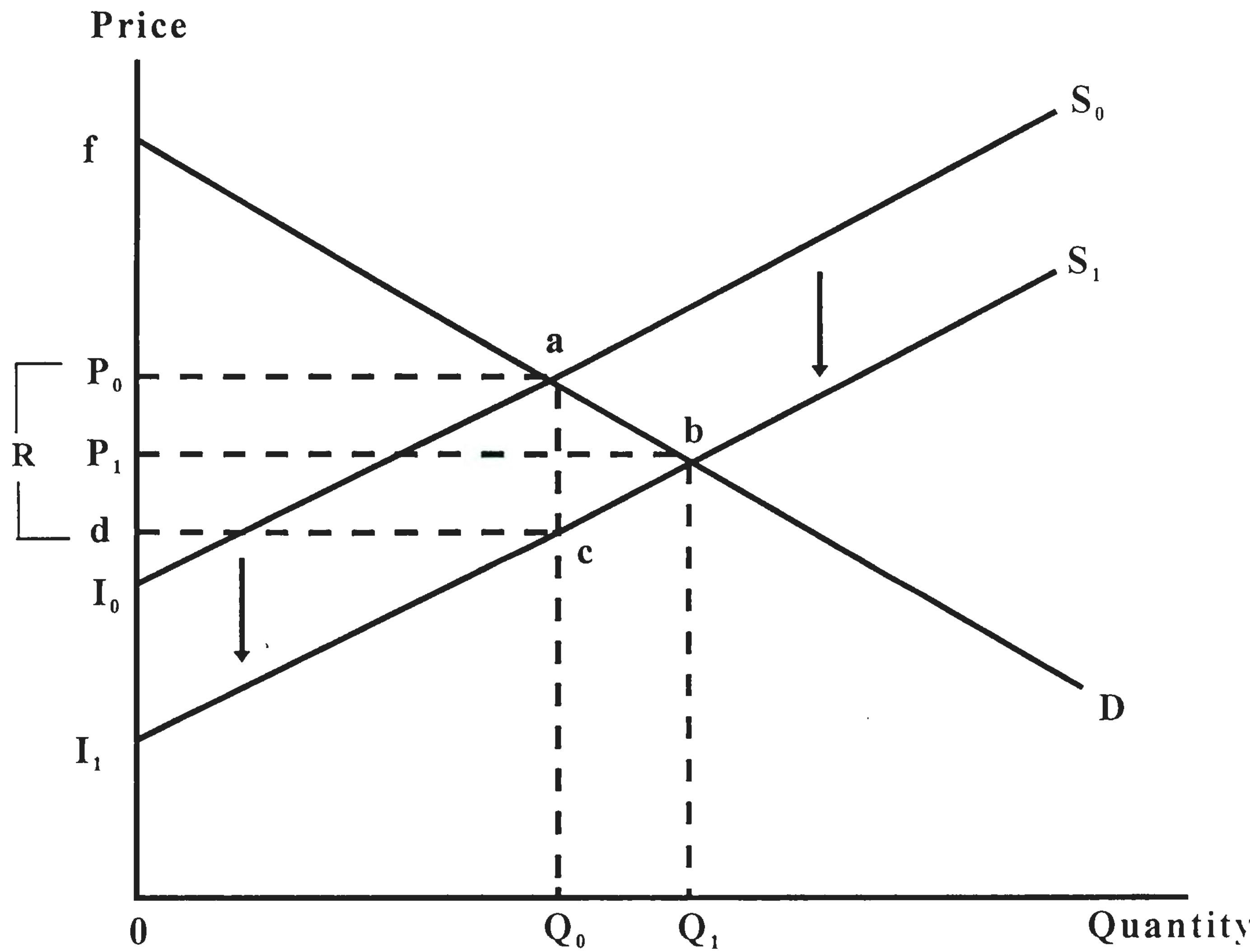

Figure 1. Research induces a shift down in the supply curve from S_0 to S_1 resulting in a cost saving per unit of output of R.

internationally and for perishables for which the United States produces a big share of relevant total supply.

For U.S. agriculture as a whole, total demand is a combination of domestic and foreign demand. Although domestic demand is not very price responsive, export demand is very much so, with the result that the aggregate demand for U.S. agricultural products is price responsive (elastic). This implies that on average, producers as well as consumers gain from science and technology.

In the model in Figure 1, "consumer" benefits include all of the benefits due to reduced price and greater availability of the farm product beyond the farm gate (i.e. to people involved in the industries that transport, process, distribute, and sell the product up to retail and to final consumers). Similarly, "producer" benefits include all of the benefits due to cost savings and increased production accruing up to the farm gate (i.e. to people who supply inputs used by farmers, including land, labor, machinery, and material inputs, as well as to farmers). In addition, the benefits include those to all "consumers" of the product and all "producers" of the product, including foreigners. The model, however, can be "disaggregated" to assess benefits to producers and consumers at different levels in the marketing chain and in domestic and foreign markets.

Non-Market Benefits and Costs of Science and Technology

Several impacts of agricultural research are "non-market" in the sense that they are not priced in the marketplace. For example, many types of research on environmental and natural resource issues result in non-market impacts, e.g., research that affects wildlife habitat and diversity, farm worker health, and water quality. Research related to rural services and social amenities that are not subject to user fees are other examples. Further, research benefits related to environmental or resource issues or to social services and amenities may be difficult to assess even when such research affects agricultural markets.

Many types of environmental and resource effects of research can be conceptualized in a market model even if quantification is difficult. For example, when a negative production externality exists such as water pollution or soil erosion, the cost to society as a whole is greater than the cost to private producers. This difference can be reflected in our model by considering the marginal social cost curve (MSC) to be above the standard supply (marginal private cost) curve (S_0) (See Figure 2). The existence of the environmental externality means that the true cost of the production to society is greater than that reflected in the private supply curve and that too much of the product is being produced. The effect of a specific technology might be to reduce the external cost (shift down MSC), increase the external cost (shift MSC up or shift it down less than S_0 shifts down), or have no effect. Production scientists and economists can work together in attempting to quantify these effects.

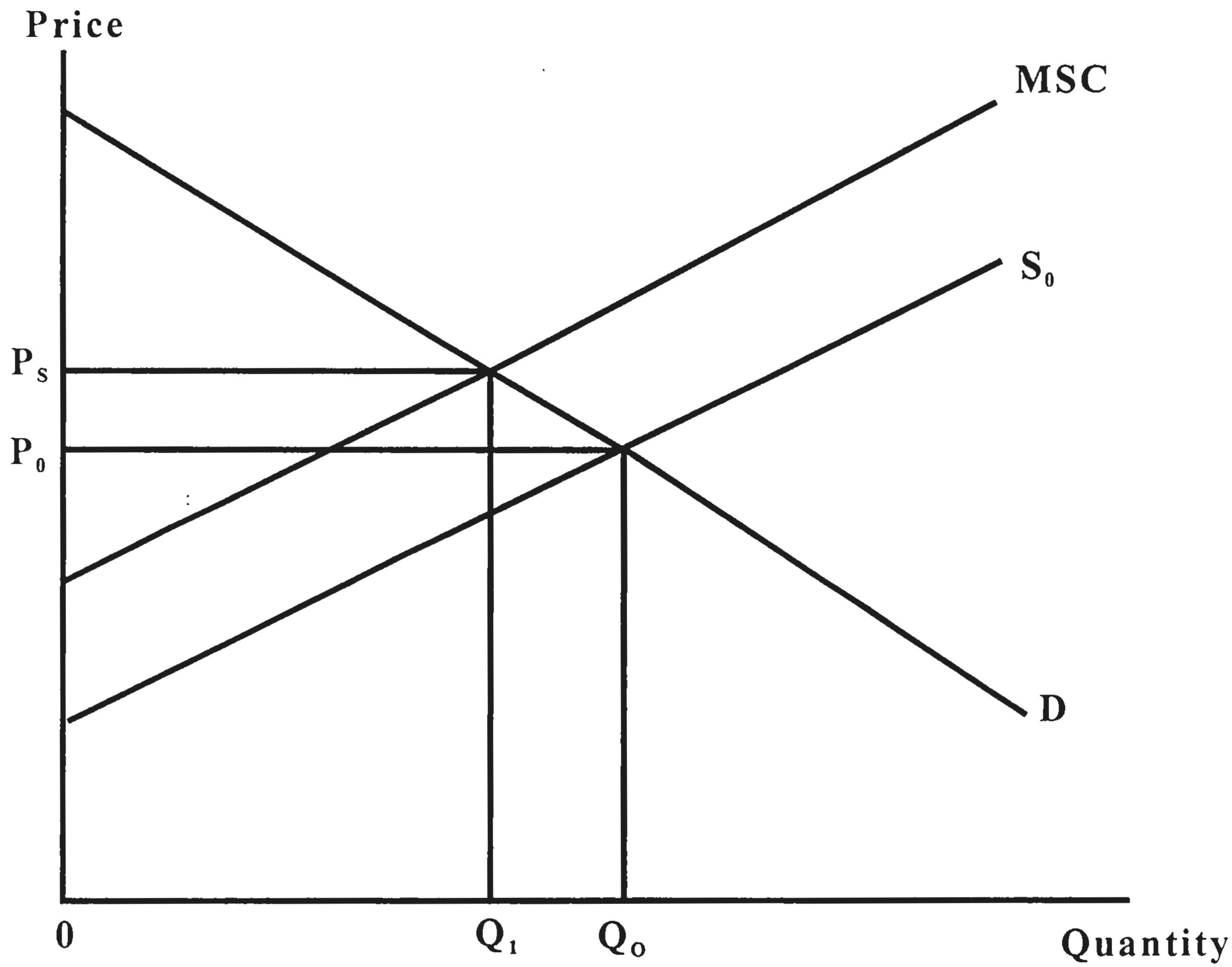

Figure 2. The marginal social cost curve (MSC) may lie above the marginal private cost (supply) curve S_0 due to an unpriced external cost.

Popular Myths

Science and technology assessment is confronted with several myths that are useful to dispel as we attempt to develop S&T assessment methods. The first myth is that science and technology is bad for agriculture (even if it is good for the economy as a whole). To the extent that research-induced technical change drives prices down, consumers gain and producer benefits are diminished, and those producers who are unable to exploit the new technology are liable to be losers. But losses to producers as a group are not possible unless, following the research, the percentage increase in quantity demanded is less than the percentage decrease in price; an unlikely prospect for most U.S. tradable products and for agriculture as a whole.[2]

Farmers and agricultural labor have both exited agriculture over time even as total income in agriculture has grown. The labor adjustment process has come at a cost, both to individuals and to rural communities. However, all societies experience this cost as per capita income levels grow with overall economic growth. Income growth and higher wages outside of agriculture raise the cost of farm labor, (both wage labor and the opportunity cost of operator and family labor). Farmers demand labor-saving technologies and grow in size in attempts to increase productivity and raise their incomes. Without growth in productivity, it is difficult to obtain and sustain an increase in per capita income in agriculture. Other policy instruments can be used to mitigate unacceptable income distribution effects or to facilitate adjustment. But in an increasingly open trading environment, it is simply not feasible for one county to choose to stop technological change in order to preserve a way of life or particular pattern of production, at least not for an extended period of time. If they do stop it, technological change in other countries will continue to reduce prices, causing farmers in the technological-laggard country to become less competitive.

A second myth is that agricultural research should contribute to each societal goal in proportion to the weight society places on each goal. While it may be reasonable to assess the impacts of science and technology on societal goals (in retrospect or in prospect), it is not reasonable to use this assessment in setting research priorities without considering the effects of other policy instruments. Agricultural research is an effective instrument for achieving gains in economic efficiency, for transferring income to agriculture in the aggregate and to certain groups of farmers, and, in some cases, for reducing environmental externalities. However, other tax, subsidy, or regulatory policies are usually more cost effective than research at achieving other distributional, and certain environmental and health objectives. Policy instruments should be matched to policy targets or a high social opportunity cost is likely to be involved.

A third myth is that public research priorities can be established without considering private sector incentives for conducting particular types of research and development activities. The primary rationale for public support of agricultural science and technology is that the private sector will underinvest in certain types of

[2] See Alston, Norton, and Pardey for an extended discussion of this topic.

research because it cannot capture all the benefits--others can "free-ride" on an investment in research, using the results and sharing in the benefits without sharing in the costs. Hence, private benefits are less than social benefits and, as a result, the private sector underinvests in certain types of research even though that research might have a high social payoff. These are the types for which the research output cannot be patented and licensed or otherwise legally protected. The private sector may also underinvest in research that is long-term, large-scale, and risky (e.g. certain types of basic research), even if it appears to be high payoff. It may also underinvest in research to offset externalities (e.g. overuse of unpriced natural resources) and in research aimed at policies and institutions. The implication is that scarce public funds for research (and extension) should be concentrated in areas of underinvestment, not just anywhere the payoffs are high.

Implications for Ex Ante Technology Assessment

The identification of social objectives and listing of criteria for assessing contributions of proposed or emerging technologies to those objectives can provide a useful framework for discussing the nature of impacts expected with a new technology. However, if the purpose of the technology assessment is to rank technologies or consider appropriate levels of resource commitments to the technologies, additional analysis that includes the economic framework and consideration of issues discussed above will establish a more defensible link between the technology and its contribution to social objectives. The idea is not to suggest wholesale adoption of sophisticated and costly approaches to evaluation and priority setting. But we should recognize that it is all too easy to let science and technology assessment slip from the simple to the simplistic.

A second point is the need to involve a carefully structured set of participants in technology assessment. Some of the decisions involve value judgments about societal objectives and weights on objectives. Involvement of policymakers, clientele groups, and administrators is needed in making these decisions. Other types of decisions require careful analysis of likely impacts of the science or technology on various objectives and groups of people. These decisions should involve technical scientists, economists, sociologists, and others with the knowledge and tools to assess these impacts. For example, the size, probability, and timing of research-induced supply shifts must be assessed with the help of scientists in the field (as well as end-users). The level and distribution of economic benefits and costs are difficult to assess without an economist. Consideration of technology effects on the social structure of rural communities needs the input of sociologists. In other words, it is a mistake to ask policy makers to make judgments that require technical or scientific knowledge and scientists to make value judgments that public officials or other clientele groups should make.

A third point is that quantitative technology assessment should be reserved for strategic program decisions and for large projects. Not only is it costly to quantitatively assess smaller projects or experiments, but priorities at that level are influenced primarily by technical questions (as opposed to economic and social ones). Also, excessive use of formalized procedures for research evaluation and priority setting could even stifle ingenuity, serendipity, and scientific entreprenuership. Peer review procedures using technical committees and specific criteria are useful at this level. Producer or other clientele input on these committees can be very useful. However, for large projects, programs, or areas of work of the type being considered by ASTRB, formal and somewhat quantitative procedures can help insure consistency between major investments and societal objectives.

Concluding Comment

Developing cost-effective yet logically-structured and rigorous methods for science and technology assessment is essential, but the process through which the assessment is implemented is as important as the methods. Other speakers this afternoon and several of the subsequent workshop sessions will address that process. With the collective creativity represented by the group assembled at this workshop, a clearer view should emerge about the appropriate nature of the assessment process so that future participants in S&T assessments will gain a greater understanding of what may be achieved by particular technologies.