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TECHNOLOGY ASSESSMENT OF THE U.S.  
CORN PRODUCTION SYSTEM (A CASE STUDY)\*

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I would like to think that my comments are a rather logical extension of the talk which Will Peterson gave here earlier today. I am strongly supportive of Will's work and although no methodology is ever perfect, I believe his work and that of Bob Evenson and others on "Rates-of-Return to Research" are solid and well done. One can argue about functional forms, the adequacy of data and the accuracy with which benefits are measured, but the general results are, I believe, very robust and very convincing.

However, as a number of people have suggested, there are other questions relative to research evaluation. And my inclination is to be an eclectic and a pragmatist when it comes to evaluation of research and technology. No single procedure or analysis will answer all the questions. Let me try to explain why very briefly.

Agricultural research doesn't get accomplished in big, broad aggregates. It gets done in a decentralized system of research projects. It is split up along both commodity (dairy, wheat, etc.) and functional lines (plant and animal breeding, mechanization, nutrition, etc.). And decisions about research priorities and funding allocations get made at a variety of

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project, program and institution levels. Moreover, the decision makers involved have a variety of variables to consider in addition to rates-of-return. Some are political and others deal with a range of "technology impact" considerations which include but are not limited to the following: human (labor displacement, health and nutrition), environmental (e.g., soil erosion), structural (e.g., size and number of production units - much technology is not scale neutral) and social (the latter including impacts on families, communities, etc.).

In addition to the research of Peterson, Evenson and others, we do have an interregional research project, IR-6, in which several Experiment Station researchers are attempting to apply a rather broad range of techniques to research evaluation. Some of the initial effective analysis of the benefits to research on "post harvest" technology has come recently from participants in that project. My past personal efforts have been in two directions:

- 1) Trying to measure rates-of-return for individual commodities (like wheat, corn and soybeans). Putting together input data is the big problem here. But we have some analysis for corn, wheat, soybeans and cotton which is now in manuscript form.
- 2) Also, I have been involved in some broader evaluation of research and technology under the general methodology of "technology assessment." And it is the example of corn technology assessment that I want to discuss with you today. First, though, I would like to talk briefly about technology assessment in general.

Technology Assessment in General

- 1) What is technology assessment? Figure 1 gives one definition of technology assessment (TA). It comes from a USDA workshop on technology assessment held several years ago.
- 2) Back in 1980, the Science and Education and Economic Research Units in the USDA were interested in a pilot project on technology assessment. Vern Ruttan was active on an Advisory Committee which encouraged the initiation of some analysis along these lines. There are, of course, a wide range of important commodity sectors and technological functions which could be assessed. And the Committee developed a matrix of options which are shown in Figure 2. We decided to do such an analysis for the commercial corn sector in the U.S.
- 3) The general framework for assessment is the one shown on Figure 3. It is an ambitious framework and one that we realized imperfectly at best.
- 4) After some extensive discussions with university, USDA and industry people involved with corn production technology, we agreed on a research program to try to fill in the outline shown in Figure 4.

One way of looking at our analysis, although an oversimplified one, is to say we were trying to explain the per acre yield increases shown on Figure 5 and cost them out both in terms of their direct costs and in their indirect costs or impacts (externalities).

FIGURE 1  
TECHNOLOGY ASSESSMENT

"TECHNOLOGY ASSESSMENT IS THE FORMAL, SYSTEMATIC, INTERDISCIPLINARY EXAMINATION OF AN EXISTING, NEWLY EMERGING OR PROSPECTIVE TECHNOLOGY WITH THE OBJECTIVE OF IDENTIFYING AND ESTIMATING FIRST AND SECOND ORDER COSTS AND CONSEQUENCES, OVER TIME, IN TERMS OF THE ECONOMIC, SOCIAL, DEMOGRAPHIC, ENVIRONMENTAL, LEGAL, POLITICAL, INSTITUTIONAL AND OTHER POSSIBLE IMPACTS OF THE TECHNOLOGY, INCLUDING THOSE CONSEQUENCES WHICH MAY NOT HAVE BEEN ANTICIPATED, INTENDED OR DESIRED BY THE INVENTORS, AND OF SPECIFYING THE FULL RANGE OF ALTERNATIVE COURSES OF ACTION FOR MANAGING, MODIFYING, OR MONITORING THE EFFECTS OF THE TECHNOLOGY."



FIGURE 3  
FRAMEWORK FOR ASSESSMENT

1. DEFINITION AND DESCRIPTION OF TECHNOLOGY
2. DIRECTION AND MAGNITUDE OF TECHNOLOGY
3. DIRECT EFFECTS OF TECHNOLOGY ON:
  - A. YIELDS, COSTS, PROFITS, PRODUCTION CAPACITY
  - B. PRODUCTIVITY
  - C. INPUT DEMAND
  - D. ECONOMIC, ENVIRONMENTAL, LEGAL, SOCIAL, INSTITUTIONAL, ETC., CONSIDERATIONS
4. INDIRECT EFFECTS
  - A. GAINERS - LOSERS
  - B. LONG TERM EFFECTS
  - C. RISK AND UNCERTAINTY
5. FEASIBILITY OF TECHNOLOGY
6. ALTERNATIVE TECHNOLOGY OPTIONS
7. MANAGEMENT STRATEGIES FOR TECHNOLOGIES

FIGURE 4  
TECHNOLOGY ASSESSMENT OF COMMERCIAL  
CORN PRODUCTION IN THE U.S.

PROCEDURES AND BACKGROUND

- I. STUDY OBJECTIVE AND ASSESSMENT FRAMEWORK
- II. CHANGES IN CORN PRODUCTION AND UTILIZATION

ASSESSMENT OF INDIVIDUAL TECHNOLOGIES

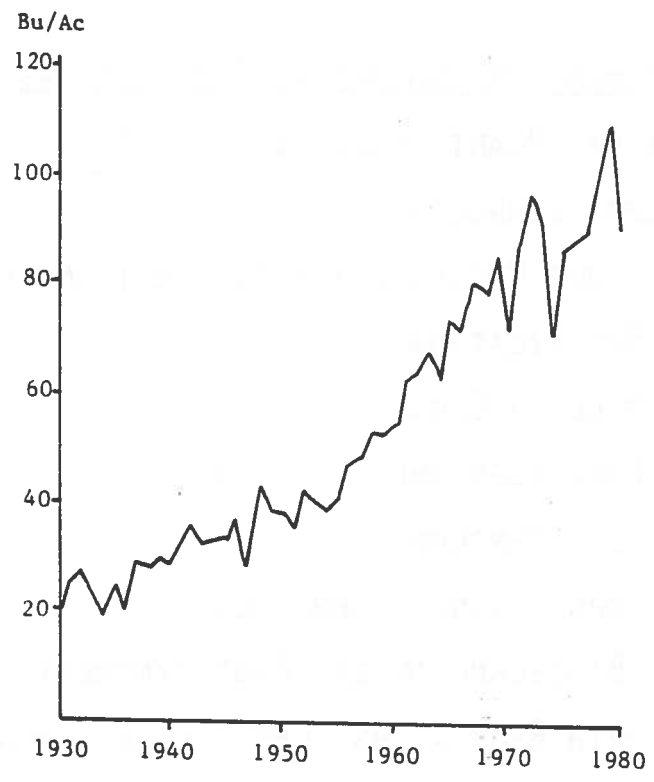
- III. CONVENTIONAL PLANT BREEDING
- IV. FERTILIZER TECHNOLOGY
- V. SOIL MOISTURE MODIFICATION (IRRIGATION, DRAINAGE,  
WEATHER MODIFICATION)
- VI. PEST CONTROL IN CORN
- VII. TILLAGE PRACTICES AND CROP ROTATIONS
- VIII. MECHANICAL TECHNOLOGY
- IX. ON-FARM CORN DRYING TECHNOLOGY
- X. EMERGING BIOTECHNOLOGIES (PHOTOSYNTHETIC ENHANCEMENT;  
PLANT GROWTH REGULATORS; GENETIC MODIFICATIONS AT THE  
CELLULAR LEVEL; BIOLOGICAL NITROGEN FIXATION)
- XI. MANAGEMENT OF CORN TECHNOLOGIES BY THE PRODUCER

AGGREGATIVE IMPLICATIONS OF TECHNOLOGIES

- XII. AGGREGATIVE ASSESSMENT OF THE CORN PRODUCTION SYSTEM  
(ASSESSMENT OF OVERALL CORN PRODUCTION SYSTEM; PRODUCTION  
IMPACTS OF TECHNOLOGIES BY THE YEAR 2000)
- XIII. EVALUATION OF PAST R & D ON CORN AND A RESEARCH AGENDA  
FOR THE FUTURE



FIGURE 5  
U.S. CORN YIELDS  
1930-80



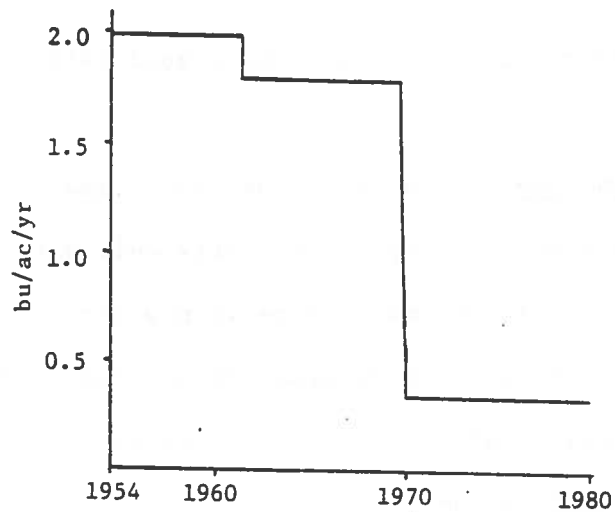
Source: USDA, Agricultural Statistics, 1930-79; Field Crops: Estimates by States 1974-78; and Crop Production, Annual Summary, 1980.

### Assessment Results

Let me rather briefly discuss each of these several technology areas and then try to aggregate the results briefly and comment on my perspective relative to the general advantages and disadvantages of technology assessment as an evaluative tool.

- 1) Conventional plant breeding (together with related technologies - plant population, etc.) adds about 1 bu/ac/yr to yields on a continuing basis. It is pretty clear that we are getting a good return on a very modest investment here.
- 2) Fertilizer technology - this technology had dramatic impacts in the 1950's and 1960's but its impact is pretty well worked out (especially for N) because almost 100% of acreage is now fertilized and most at a high level (135# of N). The Marginal Value Product from an additional pound of N is only about 1/5 of what it was in the 1950's (Figure 6).
- 3) Soil Moisture Modification
  - (a) Drainage - has added about 1.2 billion bu/year to corn production capacity over a lengthy time period. Small diameter plastic tubing, trenchless installation and laser leveling is now available at about \$300/acre.
  - (b) Irrigation - adds about 700 million bu/year to production capacity. And it probably reduces annual production variance by about half that amount. The labor efficient center-pivot system was a big factor in irrigation of corn - about 11.5 million acres of corn, or about 1 acre in every 6 or 7, is now irrigated.

FIGURE 6  
FERTILIZER NITROGEN'S CONTRIBUTION TO  
U.S. CORN YIELD INCREASES DURING  
THE PERIODS 1954-60, 1961-70 AND 1971-80



- 4) Pest Control - almost all corn acreage now receives herbicide treatment and slightly over 50 percent, insecticide treatment. Herbicides have opened up some new opportunities for reduced tillage and these are still evolving. Moreover, this reduced tillage opens up some new options relative to control of soil erosion but poor stands have been a continuing problem with no till as is retardation of soil warm-up in the Northernmost part of the Corn Production Region.
- 5) Tillage Practices and Crop Rotations
  - (a) Corn and soybean production and production technology have become more specialized.
  - (b) A large acreage is now grown in a rather intensive row crop rotation (cash crop system) and without accompanying livestock enterprises (particularly forage consuming livestock).
  - (c) A side effect has been increased soil erosion vulnerability and some increased impacts from insects which thrive on the corn after corn rotation.
  - (d) We need a new generation of no till technology (including machines) which is now evolving.
- 6) Mechanical technology - mechanization has pushed down labor requirements dramatically via:
  - (a) 6-8 row planters and combines
  - (b) Synchronization of planting, harvesting and artificial drying utilizing hybrids of different maturities - calendarization.Actual farm operating unit size for this technology is not captured

by ag census numbers. A high proportion of this technology is probably used on operating units of the following sizes:

	<u>Total Cropland</u>	<u>Corn</u>
Dryland	500-1,000	250-400
Irrigated	750-2,500	500-1,000

These systems are generally operated with two full-time workers and some part-time help.

7) On Farm Drying:

(a) Function of rapid harvest technology, off-farm movement of most corn and longer maturity, higher yielding hybrids. As recently as 1949 less than 25% of corn was sold off of the farm where it was produced. By 1978 this was 65%. Corn drying technology uses a lot of liquid fuel but some shift to using waste products (particularly corn cobs) is probably imminent.

8) Emerging biotechnologies: We looked at

(a) Photosynthetic enhancement

(b) Plant growth regulators

(c) Gene modification at the cellular level:

1. Gene transfer and

2. Cell and tissue culture

(d) BNF

Prior to our analysis of the expected impacts of the emerging biotechnologies we made a heuristic sample of scientists working on biotechnologies as they relate to corn.

Though highly speculative, we project contributions from the emerging biotechnologies of over 1.5 bu/ac/yr by 2000 but little, if anything, before 1990. And in any event, we are not talking about the doubling and tripling yields as some have speculated.

9) Management of corn technologies by the producer:

(a) Electronic and human monitoring devices and programs

(b) Use of computers both as decision aids and in order to make information out of data

(c) Private consulting services - scouting, etc., are now available on a broad basis. This will impact mostly to reduce some of the gap between current experimental and on-farm yields.

10) Figure 7 shows on our yield projections to 2000 - based on our assessment of existing and expected new technologies and with the assumption of constant real rates of public research expenditures. Figure 8 depicts these projections in diagrammatic form.

11) Critical issues relative to current technology:

(a) Corn is an energy intensive crop relative to others, particularly soybeans, but hasn't changed much on a per bu/basis since World War II (irrigation, fertilizer N and grain drying are big energy users).

(b) High capital requirements for current technology (investment costs can run up to \$3,000-3,500 per acre of upwards of \$30/bu for investments in land, machinery and equipment, drying for irrigation equipment, drainage, etc.). This has shifted up the whole cost and cash flow structure for corn production. The typical investment

FIGURE 7  
PROJECTED MARGINAL IMPACTS ON CORN YIELDS  
OF VARIOUS TECHNOLOGIES, 1981-2000  
 (BU/AC/YR)

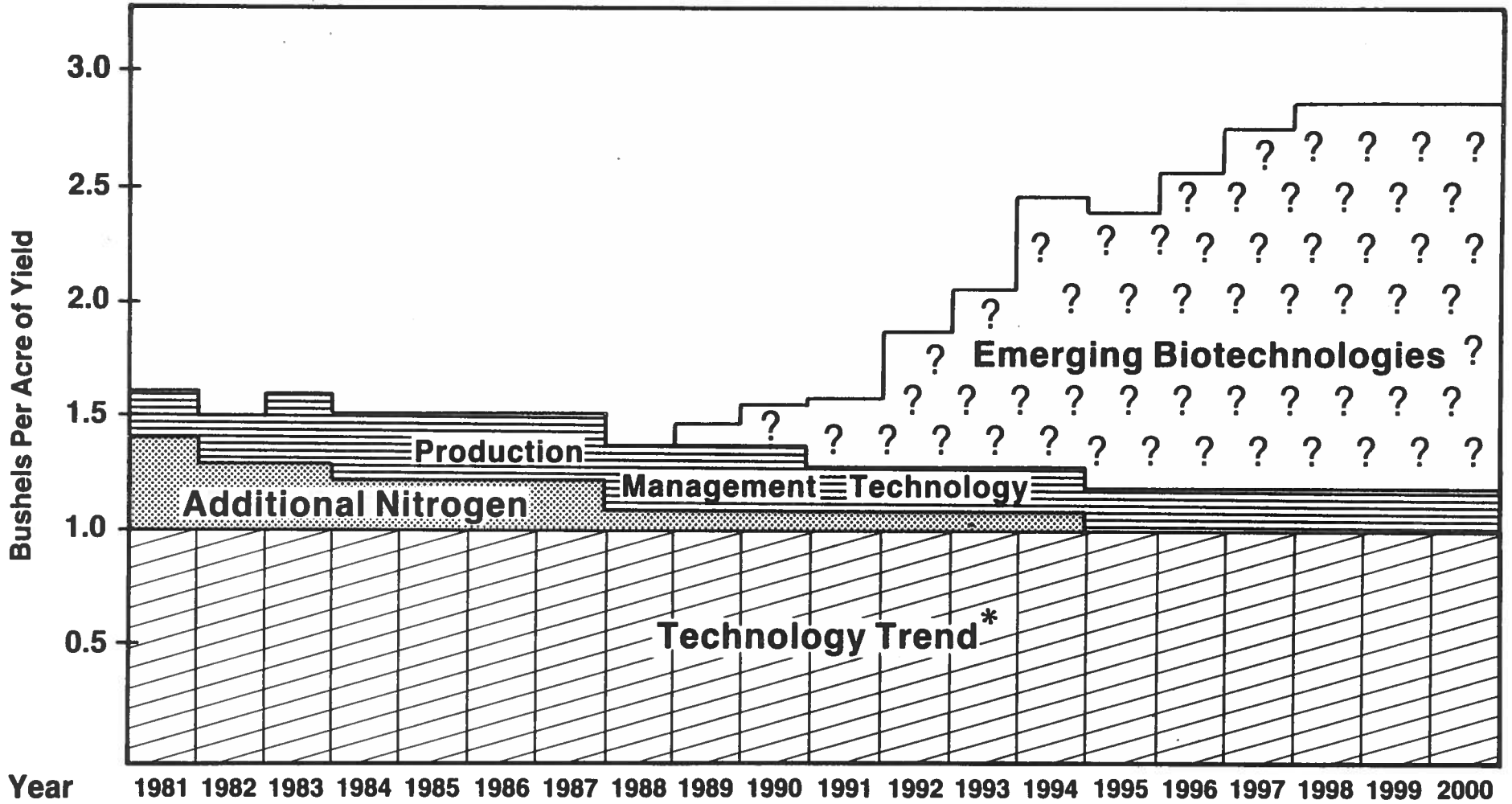
YEAR	TECHNOLOGY TREND A/	ADDITIONAL NITROGEN	PRODUCTION MANAGEMENT TECHNOLOGIES	EMERGING BIOTECHNOLOGIES	TOTAL B/
1981	1.0	.4	.2		1.5
1982	1.0	.3	.2		1.5
1983	1.0	.3	.3		1.5
1984	1.0	.2	.3		1.5
1985	1.0	.2	.3		1.5
1986	1.0	.2	.3		1.4
1987	1.0	.2	.3		1.4
1988	1.0	.1	.3		1.4
1989	1.0	.1	.3	.1	1.5
1990	1.0	.1	.3	.2	1.6
1991	1.0	.1	.2	.3	1.5
1992	1.0	.1	.2	.5	1.7
1993	1.0	.1	.2	.8	2.0
1994	1.0	.1	.2	.9	2.1
1995	1.0		.2	1.2	2.4
1996	1.0		.2	1.4	2.6
1997	1.0		.2	1.5	2.7
1998	1.0		.2	1.7	2.9
1999	1.0		.2	1.7	2.9
2000	1.0		.2	1.7	2.9

A/ INCLUDES CONVENTIONAL PLANT BREEDING AND OTHER HIGHLY CORRELATED TREND FACTORS SUCH AS PLANT POPULATION AND MOISTURE CONTROL.

B/ MAY NOT ADD DUE TO ROUNDING.

FIGURE 8

# Projected Marginal Impacts on Corn Yields by Various Technologies, 1981-2000



\* Includes conventional plant breeding and other highly correlated trend factors such as plant population and moisture control.



cost has, however, declined substantially with the drop in land prices since 1981. And it needed to. It was getting much too high to be competitive in the international marketplace.

(c) Some environmental issues:

1. soil erosion
2. local nitrate pollution problems (coarse soils, heavy irrigation)
3. other nutrient and toxic pollutants
4. declining water tables in Southern Plains (from mining underground reserves for irrigation)

(d) Real differential between revenues and costs has decline dramatically over time - but how one handles land costs is crucial. Even then, however, the cost-price differential is small and we need to work on cost reducing and yield increasing technologies (with new technology, corn production has taken on more of a "value added" form of business than a "natural resource" based one).

Research Needs

- (a) Plant breeding and biotechnologies to push up yields - when achieved, these come cheap on a per bu. basis
- (b) Energy efficiency and water efficiency
- (c) Improved nutrient uptake - a lot of N is being wasted
- (d) Soil erosion control
- (e) Improved management of technologies

- (f) Not mechanization solely for purposes of saving more labor, labor costs as such are already very low.

Technology Assessment as an Evaluative Tool

The following listing of advantages and disadvantages of the technology assessment framework is not a comprehensive one but probably includes most of the important considerations.

Advantages

- (i) the multiple-criterion framework permits the identification of economic, environmental, social and other trade-offs;
- (ii) flexibility of the technique - it utilizes a broad range of methods - from complex analytical tools to subjective determinations of potential impacts. There is no single "technology assessment methodology." Thus, if certain types of data are not available, the assessment framework does not "break down;"
- (iii) TA permits consideration of "non-market" as well as "market related" criteria (e.g., environmental impacts can be included even though they are not priced in the market);
- (iv) TA permits the evaluation of the "whole" production system and the "linkages" in the system as well as the "individual" components;
- (v) the use of the TA framework does not preclude the use of other specific analytical and/or evaluative techniques. It can, in fact, utilize information generated by a broad range of methods;

- (vi) each TA can be focused on the important dimensions of technology suggested by the objectives of the assessment.

Disadvantages

- (i) TA may not generate unique answers to the questions under consideration;
- (ii) the analytical procedures are necessarily somewhat ad hoc (e.g., particularly those used in evaluating the social and institutional impacts);
- (iii) the framework does not, in itself, provide a weighting procedure for each of the multiple assessment criteria;
- (iv) if the TA is a partial analysis of one agricultural commodity, changes in other segments of the system which influence the segment in question will have impacts which will not be accounted for (e.g., price changes in other crops due to technological advances in the production technology of these other crops);
- (v) the interaction of price and technology. Some technologies will cease to be feasible under certain price regimes. This is true since the price of a commodity is not independent of the production technology and at the same time technology employed is dependent on price. This interaction between prices/technologies may require an interactive framework. But such a framework is feasible in TA.

- (vi) there is a trade-off between the narrower "single criterion" evaluative frameworks and the broader TA framework. The scope of the single criterion evaluative framework is narrow, however; its strength (and appeal) is that numbers can be calculated - the results are tangible.

In Conclusion

Technology policies, including those related to public sector R & D, often require information from multiple criterion evaluation procedures. I conclude that a "technology assessment" framework can be effectively utilized to generate such multiple dimension evaluations. But for effective utilization, the objectives for a TA need to be well specified in advance of the analysis. And a systematic analytical framework should be developed. This is, of course, true for almost any other evaluative procedure as well.