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Ex-ante Economic Assessment of Agriculture Biotechnology

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In an evaluation of Futures Research, which includes technology forecasting and assessment, Linestone gives those efforts an A for quantity, a C for quality and a F for impact. In discussing methodologies for assessing the social impacts of biotechnology, Fishel and Kenney state that there is little we can do because our knowledge base on new technologies is severely limited. These acknowledge the challenges and limitations to ex-ante assessment of technology. Yet, a number of researchers are doing work in this area, and the public is demanding answers to questions concerning impacts of agricultural biotechnologies.

In this paper I discuss methodology that can be used in the ex-ante assessment of biotechnology in agriculture. Some of these approaches may appear to be non-rigorous and ad hoc. As applied economists, we often sacrifice rigor for procedures and methods that work. Yet, in evaluating these methods, we need to determine whether the results of the research provide information that is useful and not misleading. Many times useful research can be performed even when incomplete information is available on the technology involved. I also discuss methodology development that I think would be useful for those performing ex-ante assessment. I also argue that more resources need to be dedicated to technology forecasting and monitoring.

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Farm versus Aggregate Impacts

Completed economic research can be separated broadly into one of two types; farm management or farm structure, which Hardaker et al., refer to as farm-level and aggregate-level, respectively. Farm management research entails making economic recommendations to farmers concerning new technologies available to them. Farm structure research entails estimating adoption profiles, impact on prices and quantities, sector and regional impacts and total benefits and costs to society. Farm management research is important in guiding farmers in the best use of their resources and thus benefiting society. Farm structure research is important in planning and accommodating any changes that may occur from new technology and in guiding future public research funding. The availability of completed farm management research is not normally critical until the technology becomes available for adoption, except that management or adoption of future technology may influence decisions concerning current technology. However, alleviating any undesirable impact on farm structure of future or emerging technology may require economic evaluation and policy adjustment well before availability of that technology.

My emphasis in this paper will be aggregate impacts. Yet, since aggregate impacts will depend upon farm level impacts and adoption, it is critical that these farm level components be discussed and utilized in addressing aggregate impact. Utilization may be through formal modeling or in guiding the selection, modeling and estimation of coefficients.

Forecasting Techniques in Futures Research.

Economic research on technology consists of technology forecasting and measuring the economic impact of technological change. Technology forecasting typically entails estimating when a product will be developed, commercialized, or adopted. Techniques include the familiar Delphi survey and estimating adoption curves, although other techniques such as cross impact analysis and morphological research exist. Many of these methods are ad hoc or subjective in nature and require the information input of experts in the specific technologies. Some, such as morphological research, were originally designed for the engineer to catalogue and sort through the technological feasibility of systems, but could also be used by those forecasting what may technologically occur.

These technology forecasting assessments fall within the endeavor of futures research, a large and growing field of study. Although futures research encompasses much more than technology assessment, it is well recognized in the futures field that technology is a major driving force in determining the character of the future.

van Doorn and van Uught have summarized the popularity of the forecasting techniques in futures research. The fifteen unique approaches are grouped into four types.[1] As shown in Table 1, most researchers have a preference for exploratative and speculative forecasting techniques. Explicative forecasting techniques are not favored, and integrative forecasting techniques have medium preference.

Agricultural economists are most familiar with time series analysis and causal methods (econometrics) with exposure to delphi, bayesian statistics, and input-output analysis. Many of the other procedures, such as historical analogy, expert opinion, brainstorming, panel consensus, and subjective

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[1]There would obviously not be unanimous agreement in the groupings. For instance, Oliver, Loveridge, and Holroyd state that there are five methods that fall into the cross impact analysis category: probabilistic cross-impact; deterministic cross-impact; game theory in all of its forms; trend-impact analysis; and systems dynamics.

Table 1. Preferences for Various Forecasting Techniques (from van Doorn and van Uught, Table 5)

	1973 (USA)[a]	1980 (USA)[b]
Explorative forecasting:		
1. Time series analysis	H	H
2. Historical analogy	M	-
3. Causal methods	H	H
4. Projective scenarios	H	M
5. Morphological analysis	L	L
Speculative forecasting:		
6. Individual expert opinion	H	H
7. Brainstorming	H	H
8. Panel consensus	M	H
9. Delphi	M	M
Explicative forecasting:		
10. Subjective probabilistic forecasting	L	L
11. Bayesian statistics	L	L
12. PATTERN (relevance trees)	L	L
13. Prospective scenarios	L	L
Integrative forecasting:		
14. Input-output and dynamic systems models	M	M
15. Cross-impact analysis	M	M

H - high preference for techniques
M - medium preference for technique
L - low preference for technique
- - not ascertainable

[a]from McHale

[b]from Balachandra

probabilistic forecasting, are descriptive in their titles. Others such as cross-impact analysis are less so. An excellent discussion of the techniques is in Makridakis et al.

Although economists have used quantitative forecasting techniques quite extensively, they have not used the technological or qualitative techniques to any extent. When technological methods are used it is often the expert who becomes the processor of facts, knowledge, and information rather than some set of mathematical rules or mathematical model (Makridakis et al.). Since that expertise typically lies outside the experience of the individual completing the forecast, the reliability of the forecast is often questioned by the researcher and others. With a mathematical procedure the bias and efficiency of a forecast can often be ascertained. That assessment is much more difficult using qualitative procedures.

The common technology forecasting technique used in agriculture has been the Delphi survey. Applications include the work by The Office of Technology Assessment in U.S. Agriculture (U.S. Congress) and by Farrell and Funk with plant biotechnology in Canada. The process entails surveying a group of experts concerning a future event, summarizing the results, and providing that information to the experts again to see if that alters their initial response or projection. Response outliers are often asked to provide justification to the group. A number of iterations can be performed until responses stabilize to some norm. Initial information or presentations may also be provided.

Although the Delphi method has become very popular, maybe due to its ease of execution, it is plagued with problems. The major concerns deal with asking questions outside the domain of the experts and poorly formulated and worded questions. It would seem obvious not to ask biological scientists questions on the economic implications of a technological change, as it would be to not ask economists questions concerning the yield impact, but both types of questions have been asked. Even the question of a projected yield increase is ambiguous if it is not cast in terms of its setting; experiment station or average farm; other inputs held constant or optimally adjusted. Biases are often not obvious. Most scientists view their work as important and are optimistic concerning its impact. This have been observed by Hutton. In some cases researchers are ignorant concerning field yields when their work has been strictly laboratory based.

A critique of a Delphi on medicine completed 10 years earlier found that many major medical achievements were missed and much of the expected scenario did not occur (Turner). Turner suggests two major reasons for the failure. The first is lack of sufficient attention to basic research since future developments occur there. The second concerns the time required to evaluate developments before they can be widely used. His conclusions suggest the need for experts familiar with basic research as well as applied research and development. This criticism may also now be valid for agriculture where increasingly the basic research is being completed outside the traditional agricultural research institutions.

Cross impact analysis is an attempt to decouple a technological change into it components in a systematic manner. It was originally devised by Gordon and Hayward to supersede the Delphi technique. It is based upon the observance that significant developments in one area often depends upon breakthroughs in another area, so uses a multivariable method of analysis that allows interaction between technical, social and economic trends and developments to be formalized. Like Delphi it requires using expert opinion in obtaining marginal and conditional probability measures on various developments. Cross impacts are also obtained. The collection of additional information allows testing and verifying the consistency in responses. Extensive efforts have gone into refining and modifying cross impact analysis during the last decade (Kirkwood and Pollock; Ducos). Cross impact analysis might be a technique worth trying in a sub-sector of production agriculture, such as crop production. The results would allow updating predictions on technology as basic scientific results become available, a process not allowed with the Delphi method with it's transient projections.

Economic Assessment

Economists often estimate economic impacts by econometrically estimating demand and supply functions or associated functions, and then shifting those curves to determine the economic impact of technological change (Osteen and Kuchler, 1986). A severe limitation of econometrically estimated functions is that they pertain to historical technologies and thus are not relevant under new technology, even if the institutional structure and resources do not change. Most technological change will shift the supply curve of a commodity. The difficulty is determining the character of the shift. Not only is it difficult to ascertain the magnitude of the shift, there is often no reason to expect the shift to be parallel. The size and type of shift will affect any estimate of consumer and producer surplus (Lindner and Jarrett). In addition, the interesting questions to be answered include more than price, quantity and economic surplus changes. With the potential technological change magnitudes that are being discussed, the impact on the structure of agriculture and resource usage could be tremendous. This necessitates extending the research methods to answer those questions. It appears those requirements have stymied research on the economics of technology in agriculture. Yet, although limited in the information it generates and in its accuracy, supply curve shifting can be a useful approximation in technological assessment because of its straight forward and simple approach (Love and Tauer). With a partial or general equilibrium model this initial approach permits ascertaining any impact outside of the primary market, providing information to determine the linkages that would be necessary in a more detailed sector model.

More elaborate research techniques beyond supply curve shifting are necessary to measure or estimate the detailed economic impacts of technology. It appears those requirements have stymied research on the economics of technology in agriculture since it requires building a total system of the production and economic relationships involved. The two procedures that are typically suggested are optimization and simulation. Both have been used extensively in economic research evaluating new technology. In the next sections the advantages and disadvantages of both will be discussed.

Mathematical Programming

Many believe that linear programming is the preferred option when analyzing technological change. The activities in linear programming represent technology, which can be defined to represent current and new technology. The challenge is in constructing the activities representing the new technology. This endeavor requires the input of those scientists familiar with the new technology. The standard approach then is to generate a long-run supply curve and input demand curves, with and without the new technology available. The objective function employed is typically cost minimization.

The activities in a programming model may be defined using two different approaches. Most models divide a country into regions with each region containing aggregate activities and constraints, typically on an acre or animal unit basis. Since this procedure does not model individual farm behavior, results may not represent true aggregate behavior. Even if aggregate behavior is reasonable approximated by this approach, the farm distributional impacts are not measured, which is often the policy question. Duloy and Norton suggest as an alternative a linear programming model where farm activities are represented, along with a set of national market clearing relationships. Because the size of the model becomes hopelessly large, they suggest a decomposition algorithm such as the Dantzig-Wolfe algorithm for solutions, but that was before super computers. As McCarl has observed, however, another approach that this procedure suggests is to utilize activities representing whole farm plans in the linear program rather than attempt to generate entire representative farms in the linear model. I have experimented with this procedure (Tauer, 1985). Without incorporating dynamics the procedure simply shows the farm structure before and after the new technology. It is still not known how these resources are reallocated as farm structure is altered.[2]

A problem that plagues aggregate sector programming models is the non-diversification that often occurs. A typical result could be corn only grown in Iowa while only soybeans are grown in Illinois. These types of results imply mis-specification or a model not very representative of the true situation. The remedy is to build more detail into the model (after verifying that an incorrect coefficient was not the culprit). A commonly used correction procedure has been to specify a risk model. That would be logical since agriculture is a risky business and farmers are probably not risk

[2]Even when representative farms do approximate well the response of the groups of farms that they represent, there is frequently a bias in the aggregation of the results. Agricultural economists have spent considerable efforts addressing this issue (Day; Buckwell and Hazell). The conclusions have been that aggregation error is unavoidable but careful model design can minimize the problem.

averse. It is also the least cost correction procedure, requiring only a quadratic model, an estimate of farmers' risk preferences and a variance-covariance matrix of returns. In contrast, another corrective method would be to define additional types of resources, such as various land qualities, and alternative current production technologies. Unfortunately, this approach requires much more extensive data.

A unique approach that has been proposed is positive quadratic programming (Howitt and Mean). Technical and economic information that are not being represented by the linear structure of the model is picked up by a quadratic cost function in the resource rows, transforming the problem into a non-linear model with smooth curvature solutions unlike the basis solutions under linear models. A major limitation of positive quadratic programming in ex-ante technology assessment is that the cost adjustments are estimated under current technology (and economics). These adjustments cannot be expected to be valid when new technology activities are inserted.

Dynamics have been incorporated into programming models in various ways depending upon the need. The simplest procedure is to restrict the adoption of technology via an external adoption curve, and generate a temporally shifting supply curve. This provides little useful information. Alternatives involve explicitly modeling the adjustment process. This can be done within the linear programming model via a multi-period framework, or by sequentially solving the programming models with adjustments being made in the linear programming model coefficients. The multi-period approach has been used successfully for farm models to help farmers optimally plan for temporal changes in their business. It also implies perfect foresight. As a sector model perfect foresight would not be appropriate. It would be necessary to add stochastic elements. The complexity of the model may become overbearing.

The sequential approach might be more useful. This might even entail an iterative process to arrive at equilibrium conditions within the period (Walker and Dillon). Thus, by using exogenous annual input supply and output demand functions, it would be possible to arrive at annual equilibrium conditions. A long-run disequilibrium can be modeled by solving the short-run equilibrium over time with exogenous adjustment factors. This endeavor would quickly move into the area of simulation with an optimizing sub-model, the subject of the next section.

In all modeling efforts a decision is made whether to construct the model for the specific task at hand, or to build a more general model useable for a broad range of assessments. Only a few have constructed successful general purpose linear or non-linear programming models. The challenge in working with these models is the vast resources necessary to construct and maintain them when more satisfactory results appear obtainable from smaller simulation models, especially when the analysis does not entail new technology. Fortunately, new software has reduced the burdens of designing and altering mathematical programming models, while electronic data transfer has reduced the cost of updating. For new technology that may dramatically alter resource usage and broadly substitute or complement current technology, a well constructed mathematical programming model produces quality results other procedures cannot produce.

Simulation.

Given the enormous effort required to construct representative programming models, the behavior of a market is often simulated using econometrically estimated relationships. The difficulty is incorporating technological change into simulation models. Supply functions are typically estimated as a function of prices and other variables, conditional upon the requirements of the maintained hypothesis (i.e., profit maximization). The result is a supply function that has current technology embedded in the estimated coefficients. Since the new technology is currently not available, no empirical data exists to estimate a supply function under the new technology. It is necessary to alter the current supply curve. A parallel or non-paralled shift in the supply may be useful for some initial analysis but has severe limitations since the character of the shift is typically ad hoc. What is needed is to add precision to this shift.

An approach is to use time as a proxy for technological change. The estimated coefficient then represents the impact on supply of the historical rate of technological change. It is then necessary to determine if the new technology is a component of this historical rate projected into the future, or if it is an augmentation. An augmentation can be incorporated by adjustments in the time variable in simulation (Weersink and Tauer). The implicit assumption is that the new technology will alter the supply curve in the same manner as the historical composite of technological change, only at a different rate. A major limitation is that time also serves as a proxy for changes in the sector other than technology not modeled structurally.

An alternative utilized by Taylor is to estimate supply as a function of profits, where profits are defined by unit budgets. The rationale is that if farmers are profit maximizers, then it is possible to estimate supply as a direct function of profits. Prices are determined within the model, but the impact of new technology is incorporated by altering the technical relationships within the model. Input/output relationships can be modified given information on the new technology. Profits will be altered given the output demand functions and input supply functions. I have used Taylor's

AGSIM model to measure the economic impact of herbicide resistance in corn (Tauer and Love) and biological nitrogen fixation (Tauer, 1989). Staff at the USDA has also used AGSIM or it's predecessor to analyze the impact of removing or restricting the use of a current pesticide technology (Osteen and Kuchler, 1987; Osteen and Suguiyama). Using profit as an explanatory variable has also been used by Halbrendt and Blase in their estimate of the potential impact of biological nitrogen fixation in corn. Kaiser and Tauer also used this approach in discussing the impact of bovine somatotropin.

A limitation to this method is that a strong statistical relationship between supply and profits may not exist. This could be due to lack of variability in profits. It may also be due to mis-specification. At least in a traditionally estimated supply curve a strong statistically relationship usually exists between output and prices even if the maintained hypothesis of profit maximizing behavior is not valid. That is not true when profit is the independent variable. Dynamic adjustment via a profit specification also does not have the theoretical underpinnings as the traditional supply function does via dynamic duality.

A logical extension with a profit variable is to endogenize the rate of adoption as a function of profitability rather than model adoption exogenously. Unfortunately, a survey of the literature has indicated little effort in specifying adoption as a function of its' profitability over current technology (Love).

As with sector programming models, aggregation error exists with aggregate simulation models. Thus, an interest has been shown in the linkage of firm and aggregate models. This approach not only may reduce aggregation error, but also allows analyzing the distributional impacts of technological change across different types of farms. These micro-macro relationships were discussed in an ERS conference held in 1981 (Baum and Schertz). A linkage approach was used in the USDA study on the economic impact of bovine somatotropin (Fallert et al.).

These firm-market interaction models are related to the Schumpeterian Competition models that are utilized in industrial organization (Nelson and Winter; Futia). In agriculture the market structure may be different (perfect competition), and the innovation may be developed by the public or private sector distinct from the adopting firm, but the dynamics and survival may be similar. In fact, the process is the agricultural treadmill described by Cochrane.

As economists we typically use econometrically estimated relationships in our simulation models. In system dynamics those relationships are often determined in an ad hoc manner, relying on experts, but testing robustness of the results to those relationships. But, since so much unacknowledged pre-testing occurs in econometric estimation, the validity of reported statistically significant results is suspect. Maybe more valid results are obtainable from the experts in the field if their knowledge is extracted without bias. Sommer discusses dynamics in modeling and concludes that attributes of both techniques may be useful in modeling approaches.

Concluding Comments

Conceptually, linear or mathematical programming models would be the preferred approach by most researchers analyzing the economic impact of new technology. That new technology can be inserted as additional activities in the model. Operationally, constructing programming models are time consuming and requires extensive data, and the results produced are often deemed unsatisfactory. As a substitute many utilize econometric simulation models.

However, a better job must be done to measure technological change in econometric models than merely using a time variable. Time can represent changes other than technology occurring in a sector. This is especially true when only a few inputs are specified and aggregate industry data are used to empirically estimate functions theoretically derived for the firm. Aggregate variables may change over time more from institutional or structural changes not modeled as from technological changes.

The primary limitation to technology assessment is data availability. If necessary data were available many of the elaborate theoretical models developed could be utilized. Given data limitations more work needs to be done to develop models that are less data extensive. As an example, it appears that little work has been accomplished in systematically using ex-post results in developing ex-ante impact models. Yet, a primary justification for ex-post technology assessment is that it provides the information necessary to determine the likely impact of future technology. Changing institutions and resources would complicate any attempt to systematically categorize the character and impact of previous technological change. Nonetheless, a potentially useful area to pursue may be historical analogies (Ayers).

Finally, a former ERS administrator has stated that no other factor has done more to shape the structure of agriculture or influence the outcome or performance of the system than technology has (ERS). I believe that technology forecasting and assessment should be considered as important as commodity forecasting in providing critical information to decision-makers.

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