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Does a New Technology's Profitability Affect Its Diffusion?

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Abstract:

The economics literature is surveyed to examine its treatment of profitability as a factor affecting differential rates of diffusion. The emphasis is placed on domestic diffusion of U.S. agricultural innovations, including case studies of hybrid corn, mechanical cotton pickers, double cropping, high fructose corn syrup, soybeans, vegetable row covers, drip irrigation, gibberellic acid in malting, and bovine somatotrophin. The economics literature contrasts with the sociological literature in attempting to deal explicitly with profitability as opposed to interaction and other less quantitative concepts. However, the treatment of innovation diffusion by economists is not wholly satisfying to noneconomists, particularly futurists. An appeal for broadening the economics treatment of diffusion and introducing more generality in the results is made.

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Introduction

Mansfield asks "Once an innovation is introduced by one firm, how soon do others in the industry come to use it? What factors determine how rapidly they follow?" (p. 741) Rosegger states "The theory of diffusion attempts to answer the question why new, and presumably superior, products and processes are not adopted immediately by all firms who might benefit from them. In doing so, the theory has to deal with both factors that influence the demand of potential adopters for innovations and elements of the supply of innovations that might influence patterns of spread." (p. 117) An innovation's profitability is recognized widely as a major factor on the demand side, but how it is defined and measured is subject to various treatments. Brase and LaDue state "The fundamental economic basis for investment is that it be profitable...[but]...Because of the difficulty of accurately measuring the economic benefits of investments for individual businesses, empirical investment behavior research has generally not looked at the relationship between profitability and investment." (p. 57)

Innovation, which generally requires investment of some kind, could be expected to have a literature treating profitability explicitly, if only through the use of proxies such as yield advantage. This paper reviews the literature on innovation diffusion with emphasis on the role of profitability in affecting the difference in rates of diffusion. The objective is to compare previous research on innovation diffusion, concentrating on profitability as a variable explaining differences in diffusion among innovations or innovation adoptors. Ideally, diffusion studies are useful in providing the knowledge sufficient to forecast diffusion and the impact of technological change.

The literature on diffusion of innovation is vast. Two recent surveys without a large overlap of source material list 487 references (Rogers) and 581 references (Thirtle and Ruttan). These two works are important as roughly representative of two different schools of thought: the sociology and the economics schools, respectively. A third school, based on historiographical techniques, follows the work of Rosenberg, though this school concentrates more on innovation than on diffusion. To gather a literature as diverse as technology innovation and diffusion under a few headings may be misleading. Rogers lists 20 groups in his "Diffusion Research Tradition"--from anthropology, agricultural economics, and communication to rural sociology and statistics. However, several viewpoints of the diffusion process can be merged.

This paper surveys the economics school of thought on innovation diffusion with emphasis primarily on the role of profitability, an emphasis tracing back to the work of Griliches and Mansfield in the 1950s. A second emphasis is placed on agricultural innovations; thus, for example, Griliches's research on hybrid corn is more appropriate for this discussion than Mansfield's research on industrial processes. Further emphasis is placed on the diffusion of innovations in U.S. agriculture, excluding the considerable literature on diffusion of agricultural innovations in developing countries.

The paper begins with an introductory set of definitions, followed by an overview of textbook treatments of profitability in innovation diffusion. Next, case studies of innovation diffusion are examined; they are hybrid corn, mechanical cotton pickers, double cropping, high fructose corn syrup, soybeans, vegetable row covers, drip irrigation, gibberellic acid in malting, and bovine somatotrophin. Not all case studies treat profitability explicitly; but where a diffusion curve is used, at least, and profitability is mentioned, that study is included. Finally, the results are summarized and suggestions are made for possible future research.

Definitions

Thirtle and Ruttan "...use the term innovation to designate any 'new thing' in the area of science or technology..." (p. 2) An example of product innovations, though difficult to separate completely from process innovations, is a new crop, such as the perennial jojoba, which produces a lubricating substitute for whale oil. Just since 1982, nearly 20,000 acres of jojoba have been established in the southwest United States (U.S. Department of Commerce). A process innovation is contour plowing which reduces soil erosion. A more complex example is mechanical harvesting of tomatoes, a process innovation introduced in the 1970s and rapidly adopted on nearly 100 percent of U.S. processing tomato acreage. The mechanical tomato harvestor is also a product: a new machine substituting for labor and contributing to the migration of the industry from Ohio to California.

"Diffusion studies do not consider the *innovation process*, but begin at a point in time when the innovation is already in use...Adoption studies consider the reasons for adoption at one point in time, or the reasons for time of adoption for individual users...In contrast, most diffusion models are dynamic and study the behavior of the diffusion process over time..." (Thirtle and Ruttan, p. 78, italics added) "Mansfield...conceives of a three way definition: imitation or inter-firm diffusion...; intra-firm diffusion... and overall diffusion..." (Davies, p. 6) Davies, more interested in the initial decision of whether or not to adopt an innovative process, discusses the inter-firm version.

The widely accepted model for diffusion is the S-shaped curve--typified by the logistic function, whose axis is usually time and whose ordinate is the proportion of adoptors. After adoption begins slowly, the rate increases, and finally slows as the cumulative distibution of users approaches 100 percent. Meanwhile the corresponding density function takes on a unimodal shape over time. The behavioral explanation behind the S-shaped curve varies according to the general approach of the research; in the economics school, it is generally labeled the "epidemic" model of behavior. In the sociology school, the unimodal distribution of adoptors may correspond to a range of types from early adoptors up to laggards.

A discussion of the behavior and implications of different functional forms of the S-shaped curve can be found in many sources, but particularly relevant papers include Griliches, Lekvall and Wahlbin, and Sharif M.N. and M.N. Islam. In a notable departure from reliance on the S-shaped curve, Sahal writes "While the descriptive power of these technological forecasting models [based on an S-shaped curve] is, in some ways, often good, their explanatory power is close to zero. These models provide neither any justification of the functional form employed nor any information on the determinants of technological change--let alone on the relative importance of various determinants [including profitability]. Very often such models have been justified on the grounds of empirical necessity." (p. 54)

Profitability can be broadly defined as net benefit. Profitability is simplified in a 'partial' analysis by considering, for example, price differences, yield enhancement, cost differences, or risk reduction, while holding other factors constant. Agricultural economists, assuming profit maximization motivates individuals to substitute more profitable for less profitable technologies, often use measures such as yield difference to approximate profitability. Linstone and Sahal prefers technological substitution in the economic sense as the operative notion in diffusion. Higher profitability merely motivates substitution behavior. (See also Ayres, 1985.)

Another problem with the definition of profitability, previously mentioned by Brase and LaDue, is its measurement. During the stage at which potential adoptors decide to adopt an innovation, expected profitability is the appropriate variable--a difficult one to measure empirically and objectively. In "a note of dissonance", Davies is pessimistic about the confidence placed in empirical measures of profitability (p. 19).

A related set of questions point to the difficulty of using profitability in the analysis of diffusion. If the innovation is profitable, how much more profitable must it be, relative to a substitute, for one firm to adopt it and an identical other firm not to adopt? Does profitability have a strength of stimulus: that is, does variation in profitability affect a firm's incentive to adopt, or does ten dollars profit cause the same stimulus to adopt as 100 dollars profit? What are the limiting factors causing firms to adopt one technology and not another? Simply put, what is being studied:

adopters' various perceptions of an innovation's profitability, or an adopter's perception of competing innovations' various profitabilities?

In the beginning

Perhaps the most notable discussion between the economist and sociologist schools centered on "profitability" versus "interaction" in the explanation of hybrid corn diffusion (Griliches and Havens and Rogers). The debate started in 1957 with Griliches saying "On the whole,...farmers [adopting hybrid corn] have behaved in a fashion consistent with the idea of profit maximization." (p. 522) In a following footnote, Griliches provoked the opposition by stating "...that in the longrun,...sociological... variables tend to cancel themselves out, leaving the economic variables as the major determinants of the pattern of technological change...With a little ingenuity,...I can redefine 90 percent of the 'sociological' variables as economic variables." The confounding problem is "...it is very difficult to discriminate between the assertion that hybrids were accepted slowly because it was a 'poor corn area' and the assertion that the slow acceptance was due to 'poor people.' Poor people and poor corn are very closely correlated in the U.S." (ibid.)

In 1961, Griliches attempted to ameliorate the lashback from the sociologists by reducing the matter to semantics (to no avail). Babcock, in an attempt to referee the controversy, suggested that the misunderstanding stemmed from differences in the way the question was being asked. Havens and Rogers concentrated on why the diffusion curve was S-shaped; Griliches concentrated on why the S-shaped diffusion curves differed among adopting areas. Twenty years later Griliches stated "If I were to rewrite [the original hybrid corn article] today, I would still take the same position but add 'and vice versa' at the end of that footnote." (p. 1464) The debate is not merely a matter for semantics and thus surprisingly vigorous, since the policy implications are likely to be different for profit-maximizing individuals than for "poor people."

Textbook treatments

The treatment of innovation diffusion in textbooks or other books is expected to reflect the assimilation of research results and to integrate the new knowledge into a larger disciplinary matrix. The number of books treating innovation diffusion is not large. The choices for this review are Rosegger, Rogers, Thirtle and Ruttan, Davies, Clark, and Binswanger and Ruttan. The reader is reminded of the difference between innovation and diffusion, simply because the latter has received far less attention. My emphasis is placed on the Thirtle and Ruttan treatment.

Rosegger "suggests that, on the whole, economists as well as other social scientists have been more successful in explaining the demand side of diffusion than in dealing with supply factors" and refers the reader to Rogers for "...a comprehensive survey of diffusion as a social phenomenon". Rosegger distills the literature's "...bewildering array of hypotheses, clues, and suggestions...into four major categories: (1) factors related to the characteristics of the innovation; (2) factors attributable to the structural characteristics of adoptors and non-adoptors; (3) factors having to do with the mechanism whereby diffusion takes place in a particular setting; and (4) those originating from firms' and industries' institutional environment. Rosegger's categories and his subsequent treatment of diffusion do not treat profitability explicitly (for example, no entry in the book's index under diffusion). However, the discussion of the four major categories indicates an appreciation of profitability in the broad sense. Another, similar statement of Rosegger's views can be found in Gold. Rosegger could be considered to have a foot in both the sociologist and economist camps.

Rogers, under the section-heading Economic Factors and Rate of Adoption, writes "...farmers are not 100 percent economic men" in reference to Griliches's hybrid corn study. (p. 215) Rogers cites Dixon's 1980 "...conclusion that profitability and compatibility are complements, not substitues, in explaining the rate of adoption. So the original controversy seems to have died now to a close approximation of consensus." Rogers's Generalization 6-1 states "*The relative advantage of an innovation, as perceived by members of a social system, is positively related to its rate of adoption.*" Rogers subsumes profitability under the broader "relative advantage", thus effectively emphasizing factors other than profitability in the majority of his book.

Thirtle and Ruttan, under the chapter-heading, "The Adoption and Diffusion of Innovations", appears to agree with others that the epidemic model of diffusion contains little of economic significance and that "'universal' models" require more degrees of freedom than have been used in past studies. (pp. 85-86) They point out that as with Griliches's method in the study of hybrid corn diffusion, followers of Mansfield's work use time-series estimates of a new technology's rate of adoption followed by subsequent cross-sectional analysis of factors affecting differences in the time series estimates. Under "Alternatives to the epidemic model" Thirtle and Ruttan say "...the epidemic model has been infused with economic content but remains unsatisfactory since only the demand side of the problem is included." (p. 91)

In treating the supply side, Thirtle and Ruttan extend their analysis into the marketing and forecasting literature with the result that profitability gets lost in a broad array of factors such as "*internal*" and "*external*" influences. The generalized model shown in equation 32 of Thirtle and Ruttan retains the coefficient on the number of adoptors without specification with respect to profitability. "To summarize, the 'general static diffusion model' incorporates diffusion both by word of mouth and diffusion from a central source. It has been expanded to include explicitly the effect of economic variables such as product prices, advertising expenditures, and demonstration efforts." (p. 96) Thirtle and Ruttan also review dynamic models and "vintage and stock adjustment models" before turning to the literature on differential adoption.

Under "Adoption studies" Thirtle and Ruttan claim that "Mansfield's pioneering diffusion and adoption studies defined the conventional wisdom on the subject until recently...However, the variables chosen by Mansfield do not seem to reflect adequately the determinants of diffusion suggested by dynamic considerations." (p. 103) A subsection on agricultural adoption studies is mostly about "common methodologies" and does not treat profitability extensively. Also, with agricultural innovations studies of adoption in developing countries is pervasive.

Thirtle and Ruttan have a heading called "Theoretical developments", under which they repeat "Although the disequilibrium 'epidemic' model has frequently produced good empirical results and may adequately describe the spread of diseases, fashions, and gossip..., critics...stress its lack of economic content and doubt its general relevance." (p. 108) Probit models are discussed, praised, and criticized under this heading. However, the second stage of analysis is common to earlier epidemic model studies, in that the "parameters are interpreted to suggest that diffusion will be faster: (i) the greater the growth rate of the industry; (ii) the greater the profitability of the innovation; [etc.]." Learning models are discussed, including a Bayesian framework; but the results are important apparently because they generate a sigmoid adoption curve incorportating risky behavior. Also, a game theoretic approach is shown to generate a diffusion curve in a duopoly or an oligopoly game.

Thirtle and Ruttan treat product versus process innovations under the heading "The supply of new products". (p. 118) Also, applications of the Cambridge growth models are discussed in relation to Schumpeterian firm's decision rules. Generally, though, the application is to industry-level growth, as opposed to diffusion of a single technology.

The final heading under "The Adoption and Diffusion of Innovations" concerns international diffusion of technology in economic history and agricultural development. The discussion concludes "...that aspects of technical change such as induced innovation, the effect of market structure, appropriate technology, diffusion, and technology transfer interact in a complex manner, especially in the context of international diffusion." (p. 126) The discussion on agricultural development focuses on institutional elements and "centralized and decentralized systems," avoiding the direct treatment of profitability.

Thirtle and Ruttan conclude "The analysis of technical change involves problems such as market failure, interdependencies, historically contingent events, and the dynamics of change, which do not fit easily into the neoclassical framework...[W]e share...the view that it will not be possible to endogenize fully either technical or institutional change. Both the rate and direction of technical and institutional change will be influenced by forces that are exogenous to the economic system. However,...the power of the analytical methods and the advances in knowledge [from the neoclassical approach in their view] provided too much insight into the process of technical change to accept [the critics' pessimism about possible future advances]". (p. 131)

Davies, following the lead of Mansfield and Griliches, treats profitability in the main as an economic variable in the diffusion of process innovations; but his treatment is updated in Thirtle and Ruttan, so only brief mention is made here. In Davies, the discussion is lucid and less directed toward Ruttan's induced innovation hypothesis. However, Davies's emphasis on process innovations includes fewer agricultural examples. Chapter 2 is "A Survey of past research on diffusion" in which alternative specifications of the S-shaped curve are discussed. Davies, under "The inter-industry/innovation approach" specifies the diffusion function with profitability as a variable, "the profitability of installing this innovation relative to that of alternative investments" (p. 14). For supporting evidence, Davies identifies Mansfield's specification of profitability as the average pay-out period required divided by the average pay-out period actually achieved for the innovation. Finally, "Even though Mansfield's and Griliches's studies were published more than a decade ago [from Davies's writing], there has been very little critical analysis of their work." (p. 19) In one of the few follow-ups, "[The study claims] that there is such a diversity of variables which affect the diffusion of individual innovations, that it is almost pointless to build a general model of diffusion as did Mansfield...Indeed, [it] cites 'special circumstances' for all of the innovations [under] study." (ibid.) Davies, under "The inter-firm approach" again identifies Mansfield as the main source, but here profitability is "the firm's profitability..." (p. 20) And "Most other research in this area follows Mansfield's ad hoc theorizing and empirical methodology quite closely." (p. 21)

In The Political Economy of Science and Technology, Norman Clark of the Science Policy Research Unit at University of Sussex, England writes "...within the neo-classical tradition of economic analysis the treatment of diffusion has been much more robust [than the]...rather conservative view on the rate of diffusion of innovations given by followers of the Schumpeterian tradition." (p. 136) "The reaction of competing firms to an innovation of a rival is assumed to be a function entirely of expectations of its likely economic profitability, mediated by the uncertainty which always attaches to something new and which will have a differential impact on being taken up by other firms simply because of their different circumstances. Interaction between learning through experience and the "bandwagon" effect are supposed to explain the typical S-shaped diffusion curve. After pointing to criticisms of the "standard approach of neo-classical economic analysis", Clark suggests that the recommended improvements are "...probably not yet fully thought out..." (p. 137)

Although not a textbook, Binswanger and Ruttan's Induced Innovation: Technology, Institutions, and Development deserves mention because of its use of profitability in two of the contributed chapters. Binswanger criticizes the Nelson-Winter treatment of profitability in the search process of their evolutionary model of economic development. (p. 29) "The early Nelson-Winter model...states that firms start to do research only when profits fall below a certain level...[but, in fact]...An increase in demand leads to more innovation, not less." (page 32) Later, Ben-Zion and Ruttan, assuming "...that the marginal productivity of investment diminishes (in a manner similar to Keynes' marginal efficiency of capital),...predict a direct relationship between the level of investment in technical progress and the expected savings from the investment." This treatment of technical progress and profitability is designed to account more for countries' development than for firms' decisions to adopt innovations and the resulting impact of diffusion in the aggregate.

Of the books reviewed, Thirtle and Ruttan is the most explicit on the issue of profitability as a variable explaining diffusion. To Thirtle and Ruttan criticisms of the epidemic model remain problematic for the Griliches-Mansfield disequilibrium approach. Praise for recent developments using probit analysis is based on the movement toward equilibrium models. Thirtle and Ruttan continue to support second-stage analyses of diffusion coefficients using cross-sectional variables to compare the contribution of profitability to the contributions of other variables such as sociological ones. However, Thirtle and Ruttan give little more than a mention to ex ante methods, apparently because the state of knowledge in this area is still undeveloped.

Before beginning the discussion of case studies of innovation diffusion, mention will be made of perhaps the most rigorous economic treatments of adoption to be found in the literature. Jensen (1982, 1983, 1988) proves several results, including the existence of an optimal adoption rule and the expected relationship between probability of adoption and profitability using a Bayesian learning behavior model. "The main conclusion...[is]...firms may delay adoption of an innovation if they do not know whether it is good (profitable) or not in order to gather information and reduce this uncertainty." (1982, p. 193) Also, "...[a] major finding...does, however imply that the frequently-observed ogive shape of diffusion curves need not be the result of any type of external demonstration effect or differences among firms, other than prior beliefs." (1984, p. 170) And "[a] theoretical model of innovation adoption under uncertainty is developed to show that greater information capacity implies not only faster learning, which tends to reduce the expected delay [in adoption], but also a more stringent adoption criterion, which tends to increase the expected delay." (1988, p. 336) Jensen's research is focused more on adoption than on diffusion, but "...one can use the optimal behavior for an individual firm in this model to derive an expected diffusion curve for an industry which has the commonly observed S-shape." (ibid., p. 346) Jensen's approach includes the information gathering and processing costs of adoption decisions in the firms profitability calculations. Dosi provides a recent, related review of this research.

Hybrid Corn

Griliches's original paper, published in 1957, spurred the controversy between the economists and the sociologists debating the role of profitability in explaining regional differences in diffusion rates. The results were preliminary in that hybrid corn had not completely diffused in all the regions where it had begun to be adopted. Nevertheless, Griliches "eyeballed" the ceiling rates in each state and counted the date of first commercial adoption at 10 percent of the acreage. The remaining parameter in the logistic curve was estimated from the data and its variation across states was "explained" using regression with "economic" variables: yield and acreage. Not surprisingly, several of Griliches conclusions were later shown to be inaccurate; but, overall the results stand mostly intact, as demonstrated by Dixon. Dixon's treatment is thorough apparently balanced between supporting Griliches where he was right and showing where time proved him wrong. Therefore, Dixon's treatment of the case of hybrid corn diffusion is chosen for review.

Dixon found (contrary to Griliches's original conclusions) no interstate variation in the ceiling proportions--all states adopting hybrid corn eventually adopted 100 percent. Also, "It would appear...that for two thirds of the states the logistic is an inappropriate summary device." (p. 1457) However, "In conclusion we must note that our results...are (surprisingly) supportive of Griliches's finding of a close association between the variability in the rates of diffusion across states on the one hand, and yield per acre and acres per farm on the other." (p. 1460)

Dixon compares several estimators of the S-shaped curve's "rate of acceptance" of hybrid corn, taking account of heteroscedasticity in the disturbance term using weighted least squares, asymmetry across time using the Gompertz functional form, and nonlinearity using a nonlinear iterative procedure for estimation. The estimates for the slope of the Gompertz curve obtained by nonlinear least squares is lowest (0.13-0.16) for southern states (LA, MS, TN) and highest (0.45-0.62) for the corn belt states (IN, IL, IA, MI, MN, WI). (Dixon's Table II) In summary, Dixon's Table IV treats separately symmetrical and asymmetrical states. Dixon estimates the coefficient for yield to be 0.016 (logistic) or 0.010 (Gompertz lnB) and the coefficient for acreage to be 0.007 (logistic) or 0.009 (Gompertz lnB).

Along with Dixon, Fishelson reestimated Griliches's logistic diffusion curves and concludes "The adoption parameter of the log logistic is best explained by economic variables among which the total area of corn in the state, which stands for both the importance in the economy and economies of scale of extension services is outstanding." (p. 299) Fishelson's contribution is mainly in remedying the serial correlation remaining in the residuals of his econometric models.

Mechanical Cotton Pickers

In a similar study to that of Griliches, Maier found profitability to be the most important factor in adoption of mechanical cotton picking. "The years when adoption is estimated to have become hypothetically profitable for early adopters correspond closely with when adoption actually began in each state, even though 15 years separate when the first and the last state began." (p. 8) Subsequent diffusion was found to be strongly affected by "diffusion of information." (p. 15) In Maier's view, "...what happened with mechanical cotton pickers and strippers may be the basis for inferences as to what may be expected elsewhere." (p. 15) Maier's study, a dissertation under the direction of T.W. Schultz, D.G. Johnson, and Z.

Griliches at the University of Chicago, is clearly in the economics tradition. Maier planned to fit a logistic curve to the states' proportion of acreage, but "It was recognized...that this would be [in]valid..." because the longrun ceiling rates were not uniformly stable. (p. 51) Therefore, estimates of "rates of acceptance" similar to Griliches's hybrid corn study are not available from Maier.

Double Cropping

Hexem and Boxley show that double cropping has gained more acceptance in some regions than in others (Hexem and Boxley, Table 2). The Appalachia, Southeast, and Delta regions of the United States had the highest percentage acreage double cropped in 1982 (about 10 percent), compared to 5 percent or less in 1974. Under "Factors Affecting Adoption of Double Cropping", Hexem and Boxley lists growing conditions, management requirements, and economic conditions. "Producers anticipate increased returns when they double crop. Additional risks and expenses are involved, price and production uncertainties are spread over two or more crops, which may stabilize returns and improve producers' creditworthiness. Even though second-crop yields may be lower than for a single crop, returns can be comparable or higher because of reduced production costs, especially if no-till cultivation is used. Spreading fixed costs of production over two or more crops reduces unit production costs for individual crops, and residual plant nutrients can be used for producing the second crop." (p. 6) Hexem and Boxley did not estimate diffusion curves and found that generally "returns to risk and management for corn, grain sorghum, and soybeans as second crops in double-cropping systems were nearly always negative based on several experiments..." (p. 8) When acres of winter wheat planted and acres of soybeans double cropped in the Appalachia, Southeast, and Delta regions were regressed on acreage and price variables, Hexem and Boxley did find statistically significant economic relationships. Hexem and Boxley conclude that "Provisions in the Food Security Act of 1985 will affect farmers' cropping decisions...[and] factors that limit expansion of double cropping [are likely to follow from improvements in the technology]." (pp. 11-12)

Marra and Carlson, using an application of the expected utility maximization approach, estimated that in eight southern and southeastern states the following variables explained the optimal proportion of soybean acreage double-cropped: prices and yields of soybeans and wheat, costs of production, opportunity costs, yield covariance, and total acreage. A logistic-type diffusion function was not estimated and profitability was not explicitly specified as a variable explaining actual diffusion of double cropping. The Marra and Carlson analysis may be viewed as an equilibrium approach, explaining a portion of the diffusion curve for double cropping wheat and soybeans without the constraints of the logistic function methodology.

High Fructose Corn Syrup

Carman used the logistic function to project the demand for high fructose corn syrup (HFCS) in the sweetener market. Even though HFCS was known to be a less expensive substitute for other sweeteners, "[t]he adoption decision requires time for firms to learn about HFCS, time to determine its compatability with the manufacturing process, and time to formulate recipes and assess new product characteristics...The logistic function, used most often in empirical applications, is based on a solid theoretical model and is easy to estimate and interpret. [But] selection of a ceiling market share for projection of HFCS use is a matter of judgement...[This estimate of the projected ceiling market share is] about 25 percent." (p. 625) With about half the diffusion curve as actual data, Carmen used trial and error to find the ceiling proportion that resulted in the best fit and projection to 1990, following the procedures of Griliches. (As of 1989, actual HFCS use accounted for about 36 percent of U.S. per capita caloric sweetener use (USDA).) Profitability, although in the analysis implicitly as one of many "technical constraints" limiting the likely ceiling ratio, was not used directly to estimate the "rate of acceptance".

Soybeans

Powell and Roseman, examining the diffusion of soybeans in Illinois, extend Griliches three stages of diffusion--the origin stage influenced by the cost of innovating, the diffusion stage by profitability, and the equilibrium level by long run demand factors. Powell and Roseman collapsed 61 variables describing Illinois counties into 10 variables via principle component analysis. Among the 102 counties, "the readiness to adopt...seems best explained by mechanization, soil productivity, and the relative importance of the cash crop, soybeans, to hay and oats,..." (p. 226) Profitability, although obscured in its measure, is specified as part of the "commercialization" variable.

Vegetable Row Covers

Kislev and Shchori-Bachrach describe an innovation cycle as a function of learning on the part of potential adoptors. As more producers enter the market, supply of the new product increases, driving down price, and discouraging further adoption. Thus, the innovation cycle produces an S-shaped diffusion curve. Profitability is assumed to motivate adoptors as they learn of the new product. "Generally, producers will adopt the new product if it is profitable and will increase production if profits increase." (p. 30) Using data on plastic row covers in vegetable production (from communal or cooperative farming units), Kislev and Shchori-Bachrach estimated logistic functions. The number of observations for each estimation was small, and the large variability among coefficients was not explained by profitability.

Drip Irrigation

Fishelson and Rymon, similar to the Kislev and Shchori-Bachrach study, also used observations from "...the micro level--an individual kibbutz...[H]ow much land [was] to [be] convert[ed] each year from sprinklers to drip irrigation." (p. 377) "...[T]he estimated parameters of the adoption function are explained almost perfectly by the economic motive for adoption--profitability." (p. 380) The measure of profitability was the difference in yield, but the number of observations was only seven while the number of parameter estimates was two, leaving only five degrees of freedom for the statistical inference. Nevertheless, "...at the mean ["rate of acceptance"] and mean [difference in yield,...Fishelson and Rymon calculated an] elasticity of total adoption with respect to profitability of 1.5, i.e. well above unity." (p. 380)

Gibberellic Acid in Malting

Ray found among a "number of factors [which] have a significant influence on the diffusion of gibberellic acid in malting [and] are likely to be relevant to the diffusion of new techniques generally [is]...gibberellic acid profitability [which] increases the capacity of one important part of the malting plant..."(p. 225) Ray pointed out that the profitability measure should account for added costs elsewhere (with respect to bottlenecks in capacity); and when done so, resulted in questionable overall profitability of gibberellic acid.

Bovine Somatotropin

Kalter, et al. state "A factor key to determining whether the adjustment to a new equilibrium will be rapid and difficult or gradual and smooth is the rate of acceptance of bGH or bST [bovine somatotropin] by dairy farmers. (p. 71) [However,]...predicting the rates of adoption and diffusion for an entirely new product such as bGH is necessarily a speculative exercise." (p.75) Kalter, et al. used survey responses from a sample of New York dairy farmers who were given hypothetical information about bGH and asked to predict their time and extent of adoption. From the survey responses, logistic functions for the diffusion of two bGH technologies were estimated, but the difference in diffusion between bGH by injection and bGH by implant was not explained with the use of profitability. The different behavior of the two diffusion curves "...results from the fact that farmers who reported they would adopt bGH in injection form would do so aggressively and rapidly, leading to higher, early rates of diffusion,...[whereas] because implants...appealed to less innovative farmers, early rates [of adoption] will be slower but ultimate diffusion higher." (p. 87)

Concluding remarks and suggestions for research

The literature on profitability as a factor affecting diffusion of innovations is not as well developed as one would expect, given the apparently vigorous controversy during the 1960s between economists and sociologists about hybrid corn diffusion. Two of the notable assimilations of research--Rogers, and Thirtle and Ruttan--do not treat the subject extensively. Instead Rogers's vision is broad and sociological in focus; while the economists, Thirtle and Ruttan, emphasize their economic interpretation of induced innovation. Also, the often mentioned rapid technical change in post-war U.S. agriculture has not received the detailed analysis that would allow extrapolation of previous estimates of "rates of acceptance" to future scenarios. Contrast this to the agricultural economics literature replete with estimates of demand and supply elasticities that are used widely in forecasting policy impacts. The diffusion literature lacks "hard" estimates of the relationship of a typical innovation's diffusion and its expected profitability.

A glaring characteristic of the diffusion literature is the case study method, which suggests that the research tradition is either in its infancy or faces methodological difficulties in making inferences about general diffusion behavior. Without confidence in ex post estimates of diffusion parameters, ex ante estimates will be more speculative still. But, a major problem for the studies which do attempt generalizations is the dearth of observations and the consequent lack of degrees of freedom.

What could account for this seeming lack of research progress? Ayres (1989), a leading technology forecasting analyst, writes "Better methods of forecasting and planning for the future are needed now as never before...Can the rate and direction of technological change be forecast accurately enough to provide useful guidance to decision makers...?" (p. 49) This, among other "broad, and perhaps too vague" questions are posed in his assessment of the future of technological forecasting. "Beyond them, however, lies another, more fundamental set of questions that economists and sociologists have been more successful at [treating]..., but not necessarily resolving. Some examples include (1) ascertaining the relative importance of 'push' versus 'pull' forces as determinants of historical technological change, 2) measurement of the return on R&D investment, 3) measuring the effect of changing relative prices of labor, capital, energy, etc. on innovation, and 4) determining the relative efficacy of small versus large firms as innovators. This [success] is partly [due to] the availability of relevant administrative or financial data, partly [due to]...easily definable [and]...suitable measures, and partly [due to]...the availability of computers...[and] modern statistical methods...Nevertheless, there are major and embarrassing gaps in our knowledge...[T]he point of these remarks is simply that economics by itself is too narrow a discipline for the problem of technological change." (p. 50) Ayres indicates a "target of opportunity" in the "era of better causal models, based on more sophisticated economic theories...[but]...it is necessary to develop better theoretical explanations of technological change at the micro-level." (p. 50) Ayres is more critical of futures research on innovation than on diffusion, but his suggested "bottleneck-breakthrough paradigm" may by applicable to diffusion research as well.

In his reply to Dixon's reexamination of the hybrid corn data, Griliches summarizes: "...time is brought in to proxy for at least three distinct sets of forces: (1) the decline over time in the real cost of the new technology...; (2) the dying-off of old durable equipment...; and, (3) the spread of information...as to [the innovation's] workability and profitability...I focused on the third 'disequilibrium' interpretation,...Alternatively,...one can focus on reasons (1) and (2)...[A]ll such approaches lay stress on the economic determinants of diffusion although they differ in the emphases that they put on them."

Whether the emphasis is placed on disequilibrium models (which are represented by the early "epidemic" paradigm) or the more recent developments with equilibrium models, theoretical developments must be accompanied by empirical applications before technology forecasts will be entirely convincing. In agriculture, the potential examples for testing theoretical developments is huge and untapped. For example, the many agricultural commodities have undergone substantial technological improvements--and under various conditions, suggesting the potential for robust estimation of diffusion parameters. Consider just the improvements in some horticultural products which are unexamined: orange juice processing, controlled atmosphere storage, day-neutral strawberry cultivars, kiwi fruits, truck transportation, to name a few.

Our own interpretation of the comparative lack of widely accepted diffusion parameter estimates involves the long-term nature of the subject matter versus the short-term nature of most policy analysis, as well as data limitations. Also, the original purpose of much early diffusion research appears to be motivated by the dispute over profitability and other sociological factors, and not on futuristic projections of innovation diffusion. Economists do not have a stellar tradition in the subject of futuristic research. But, since the 1970s, futures research has gained considerable attention (See Linstone and Simmonds). Thus we would conclude about diffusion within technology forecasting research generally, that Ayres (1989) is correct in his assessment about economics' narrow focus, and that economics should be broadened to include more diffusion research.

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