CORNELL
AGRICULTURAL ECONOMICS
STAFF PAPER

Does a New Technology's Profitability Affect Its Diffusion?

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September 1989

A.E. Staff 89-32

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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