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A Review of Innovation and Diffusion Theories: Implications for the Potential Adoption of Clean Coal Technologies

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A REVIEW OF INNOVATION AND DIFFUSION THEORIES: IMPLICATIONS FOR THE POTENTIAL ADOPTION OF CLEAN COAL TECHNOLOGIES

by

S.J. Flaim, P. Seretakis, and D.W. South

ABSTRACT

This report presents a historical review of the innovation and diffusion theories and models that are discussed in the economics literature. Many of the studies cited here focus on "optimal" levels of research and development (R&D) spending, timing of innovations, etc. The focus of this review, however, is to determine applicable innovation and diffusion patterns and identify relevant experiences in other industries to help researchers in the clean coal technology (CCT) program better understand how new technologies are developed and adopted. The process of technical change includes the discovery, development, and adoption of technological changes in production processes. For analytical purposes, this review divides the process into four steps: R&D, invention, innovation, and diffusion. It then identifies four principal economic determinants of technical change: a firm's size, industry concentration or market power, profitability, and behavior. This review contrasts the major elements in demand-pull and supply-push innovation theories and examines alternative functional forms of diffusion models. It also discusses results of selected case studies that are potential analogs for projecting how quickly CCTs will be adopted by utilities and industry. Potential barriers to adoption are identified, and recommendations for the CCT program are made.

1 INTRODUCTION

Research and development (R&D), invention, innovation, and diffusion are separate steps in the same continuum sometimes described as the process of technical change (Fig. 1). The literature on this topic is extensive; more than 500 citations have appeared in refereed journals alone. This literature has received wide attention in recent years because the increased productivity and improved standard of living in evidence today have been attributed chiefly to the invention and adoption of new technology. Although this review mentions many notable contributions, it represents only a small part of the total literature on this subject. Consequently, the findings discussed here are illustrative; revisions to these findings may arise as more current research is published. Many of the studies cited focus on "optimal" levels of R&D spending, the timing of innovations, and other subjects. The focus of this review is quite different, however. It

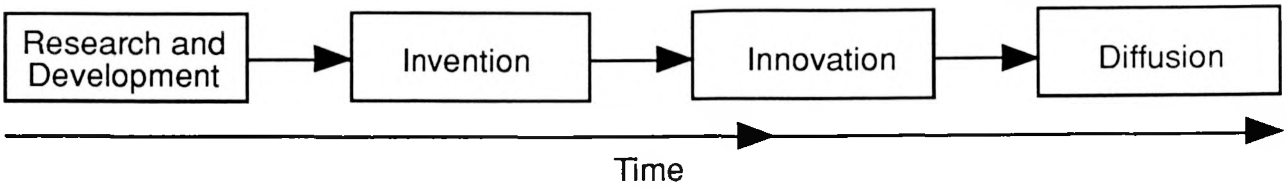

FIGURE 1 Four Discrete Steps in the Process of Technical Change

was undertaken to determine applicable innovation and diffusion patterns and identify relevant experiences in other industries to help researchers in the clean coal technology (CCT) program better understand how new technology is developed and adopted.

In economic terms, the end result of technical change is technological progress, which is usually represented by an inward shift of the unit isoquant; i.e., more output at the same level of input intensity (Jones 1965). This is represented as a shift from isoquant T_0 to T_1 in Fig. 2. In aggregate terms, technological change or the rate of growth of total factor productivity can be measured as the "difference between the rate of growth of real product and the rate of growth of real factor input" (Jorgenson and Griliches 1967).

The results of technical change are easier to describe than the process that leads to it. For the purpose of this report, the process that leads to change follows these steps. First, R&D activities take place. These are assumed to lead to new inventions. Inventions that are applied in industrial processes are called "innovations" until these applications are used by 5-10% of the potential market.* From this perspective, many CCTs are in the innovative stage of development. According to the literature, after the 5% saturation point has been reached, diffusion typically starts. The adoption of a technology is quite predictable and closely follows the logistic curve. The logistic curve (Fig. 3) has proven to best describe the pattern of technology adoption in more than two dozen industries described in the articles included in this review.

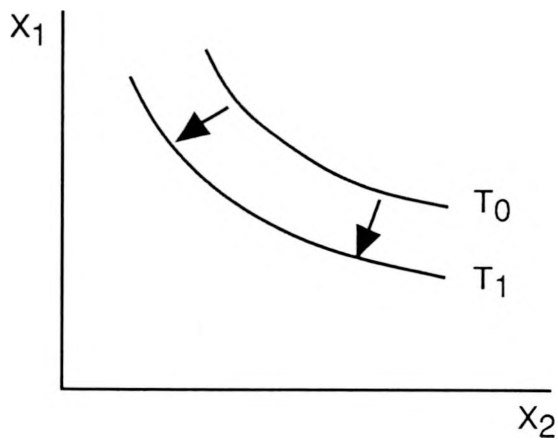

FIGURE 2 Graphical Representation of Technical Change

*The potential market is defined in terms of either all the potential applications for the innovation or all the potential adopters of the innovation, where an individual adopter could have more than one application (e.g., an electric utility company is likely to have several plants and units capable of using an innovation).

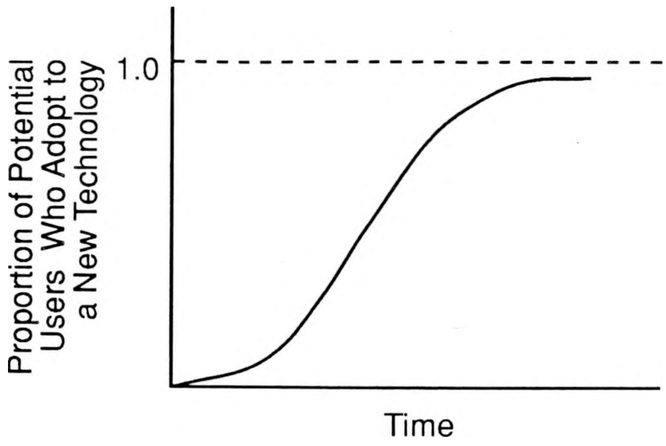

FIGURE 3 Graphical Representation of the Logistic Function

This review of the innovation and diffusion literature indicates that there is some disagreement about the relative influence of a firm's size, market power, profitability, and behavior on the rate at which R&D, invention, innovation, and diffusion of a new technology occurs. This discussion focuses on these four determinants at each step in the process of technical change. Each step is treated sequentially.

Despite the many theoretical and empirical differences that were found in the articles reviewed here, two findings were found to have a broad base of support. One is that diffusion follows a well-known pattern called the logistic curve. The second is that there may be certain barriers to the adoption of a new technology, even when strong economic incentives to adopt are present. These findings are discussed in detail in Sec. 4, and their implications for CCTs are identified.

2 RESEARCH AND DEVELOPMENT

2.1 DEFINITION

For the purpose of this report, R&D is defined as those activities that lead to new inventions. In practical terms, R&D may include the theoretical specification of a new process or product, model development, model verification, testing, and bench-scale demonstrations. However, R&D is more than what occurs in a laboratory. Any activity that might lead to a new patent or a new application for an existing patent is R&D. The Internal Revenue Service permits deductions for a wide range of activities and administrative overhead that support R&D activities.

Federal and state governments play a major role in sponsoring R&D, since many projects and ideas are too expensive to be tested and developed by one company. Furthermore, some inventions are highly appropriable and thus would not warrant a major R&D investment by a company, since it would have few prospects of protecting its investment. These characterizations certainly describe the technologies being developed in the CCT program. Thus, a key question related to CCT R&D is, "When should government sponsorship taper off and industry activity begin?"

Although hundreds of articles address R&D, invention, innovation, and diffusion, none deal specifically with an R&D program manager's decisions: i.e., how does one maximize the likelihood of achieving R&D objectives while adhering to budgetary constraints? For private companies, such decisions are readily addressable in an economic framework, since most projects have relatively short time frames and a specific commercial product objective. For federally sponsored research, however, especially in the basic sciences, programs are so diverse and long term that their effective management requires subjective assessments of technology trends. The program manager has the very difficult task of maximizing the benefits or returns to R&D investments, which requires an extensive knowledge of alternative research projects, the probabilities of success of each, and the impacts of any technological advances that might arise in related sciences. This subject area appears to be unusually well-suited for further investigation, since the practical application of R&D involves billions of dollars each year; Battelle estimates that R&D expenditures in the United States for calendar year 1990 will be $138.7 billion (Battelle 1989). Figure 4 identifies the sources of funds and performance of R&D.

Federal R&D must cover a wide spectrum of technological options simply to stay abreast of new developments and to avoid "putting all its eggs in one basket." The CCT program has a wide array of technological options under development for just such purposes (DOE 1989b).

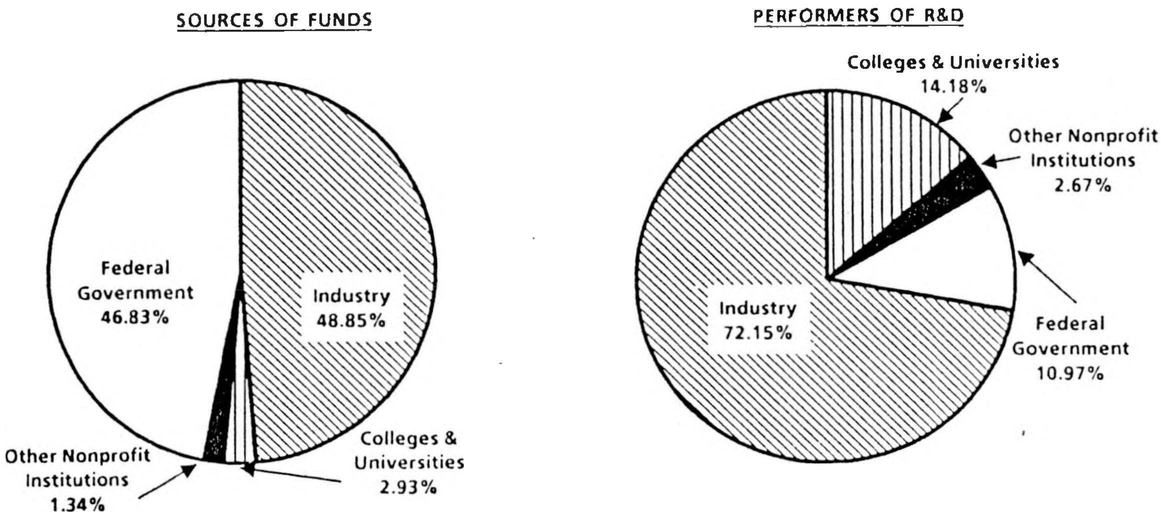

FIGURE 4 Expenditures for Research and Development in the United States, Calendar Year 1990 (Source: Battelle 1989)

2.2 ECONOMIC DETERMINANTS

2.2.1 Firm Size

The relationship between a firm's size and the amount it spends on R&D has not been a principal focus of innovation and diffusion research, because R&D spending by a firm is proprietary information, difficult to measure, and may be conducted on a cost-reimbursable basis (i.e., at no real expense to the firm conducting it). However, it is believed that larger firms have higher profits and more funding available for R&D investments. R&D spending appears to be associated more with certain industries that consist of many small players (chemicals and drugs, for example) than with industries (like steel) that consist of a few, very large companies with cash flows of hundreds of millions of dollars each year.

2.2.2 Concentration

Concentration is defined in different ways but generally describes the degree of market power held by one firm or a small group of firms. The literature addressing R&D spending and the market power of firms shows some conflicting results, although many of the differences may be attributable to the specific industries examined. Shrieves (1978) found that the degree of concentration in an industry is ambiguously related to R&D spending, although a high degree of concentration may have a detrimental effect. He states that ". . . contrary to Comanor's evidence, high concentration levels may have an adverse effect on innovative effort in some industries." The effects of low to moderate levels of concentration were not mentioned.

From a societal perspective, Loury (1979) found that some degree of concentration is best in terms of R&D performance. "More competition is not necessarily socially desirable. . . . In any market structure, competing firms invest more in R&D than would be optimal because they do not take account of the parallel nature of their efforts." Dasgupta and Stiglitz (1980a) found that when the degree of concentration in industries is small, industry-wide R&D effort is positively correlated with concentration. High degrees of concentration are not, by themselves, evidence of a lack of effective competition in R&D spending. They state, "Both optimal R&D expenditure and R&D expenditure per firm in a market economy increase with the size of the market. They [optimal R&D expenditure and R&D expenditure per firm] decrease with increasing costs associated with R&D technology if demand is elastic and increase with increasing costs if demand is inelastic." Hence, barriers to entry and inelastic demand may contribute to R&D spending that is higher per firm than the spending that would result from a competitive market with elastic demand.

A monograph prepared by the National Science Foundation (NSF 1978) identified four ways that regulation affects innovation. First, profits for regulated firms are calculated as a function of capital investment. If R&D investments are not capitalized in the rate base, firms have few incentives to innovate, since costs are not recoverable. Second, the cross-subsidization of rates permits inefficiencies in one area to be subsidized by revenues from other sources. A direct correspondence of rewards to investments in R&D would create a clear set of signals to innovative firms. Third, because costs are passed through to consumers, the monograph states that ". . . regulated firms permit a higher degree of managerial sloppiness than do competitive firms and that cost-cutting and new-service innovations are discouraged because they are not includable in the rate base." Total revenues (not necessarily profits) to the firm would fall with cost-cutting or new-service innovations. Fourth, the regulatory lag inherent in all approvals for spending slows the rate of R&D, invention, and innovation.

Despite these limitations, regulations can be structured to accelerate R&D spending if the costs for R&D are passed through to consumers or capitalized in the rate base.* Since consumers are the primary beneficiaries of new technology, some level of R&D spending would appear to offer long-run reductions in consumer prices even though short-run prices would increase. Regulated utilities, primary targets for CCTs, would have a greater incentive to try innovative or experimental systems if the risks of adoption could be shared with consumers. Risk sharing by consumers could lead to lower utility bills in the long term, since many of these innovative systems have lower levelized costs and perform better than conventional generating technologies. However, the ability to recover R&D costs is determined by regulators -- political officials who often focus more narrowly on shorter-term management issues than on the development

*In addition, such regulatory instruments as incentive rate of return on equity (to compensate for higher levels of risk associated with new technologies), accelerated amortization, and 100% construction work in process (CWIP) could be implemented to foster technology adoption. See McDermott and South (1989) for a discussion of these instruments and their potential application to innovative technologies, including CCTs.

of new technology, an activity that could require decades to complete.* Potential adopters of CCT include electric utilities, which are currently a regulated industry but are becoming more competitive. With a new group of market players, the effect of competition on technological adoption may be beneficial. However, the short-term outlook of many regulators (designed to keep consumers' costs as low as possible) might reduce the rate at which utilities will be allowed to experiment with and embrace new technologies such as those under development in the CCT program.

2.2.3 Profitability

The effect of profitability on R&D decisions is implied in each R&D investment. Firms must generate profits to have surplus funds available for R&D investment. In addition, R&D, like any other investment, must offer the promise of future returns large enough to offset expenses. Since the results of R&D cannot be projected with any certainty, future returns must be risk weighted and discounted to account for the time value of money.

Lee and Wilde (1980) examined R&D investments broken into fixed and variable components and analyzed their effects on firm behavior. They found that in general, equilibrium levels of R&D investment increase with a higher ratio of variable to fixed costs. Thus, because CCTs require high levels of fixed costs for innovative combustors and flue-gas cleaning equipment, equilibrium levels of R&D would probably decrease. In other words, in cases where R&D requires large nonreversible investments, the risk of failure is higher than it is in smaller-investment research projects with larger variable-cost components.

2.2.4 Firm Behavior

The impact of firm behavior on R&D decisions has not been a topic of wide investigation, although Salant (1984) examined preemptive R&D and competition. Firms that maintain active R&D programs have the potential ability to exclude competitors by maintaining lower cost structures through the development of new processes or entirely new products that are protected by patents.

Lee and Wilde (1980) examined the role of fixed and variable costs on R&D investments in rival firms. They found that ". . . if fixed costs are more important than variable costs in the R&D technology (in some appropriate sense), then an increase in rivalry [competition] should lead to a decrease in the equilibrium level of firm

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*The Innovative Control Technology Advisory Panel (ICTAP) report (DOE 1989a) examined actions that states could take to provide incentives for demonstrating and deploying CCTs. One of the stated reasons for the report is that ". . . despite the best efforts of regulators to properly balance the interests of electric ratepayers and shareholders, institutional problems inherent in rate regulation today cause utilities to be reluctant to spend large amounts of money for new generating projects of any kind, including CCTs."

investment in R&D. Similarly, if variable costs are more important than fixed, then an increase in rivalry should lead to an increase in equilibrium level of firm investment in R&D."

Since utilities, a principal market for CCTs, are regulated to certain rates of return and market areas, the potential role of rival behavior seems limited, except in those cases where independent power producers (IPPs) compete with regulated utilities. IPPs are currently exploiting technological advances available in the marketplace and are typically not conducting R&D. Apart from the prestige associated with R&D, few potential benefits are available to innovative utilities that are not available to other utilities.

2.2.5 Other Economic Determinants: Incentives

Wright (1983) examined the role of incentives in R&D decisions and the relative effects of prizes versus direct contracting for research services. He found that ". . . contracts, the centralized alternative [to R&D management and rewards] are more likely to be the best choice if researchers are highly responsive to incentives." The CCT program is managed under direct contractual arrangements and, from Wright's perspective, has chosen the most efficient method to encourage R&D.

3 INVENTIONS

3.1 DEFINITION

Many successful R&D activities lead to inventions. In many of the studies reviewed here, patents are used as a proxy for inventions. Most economists agree that an invention is a new or different way to produce more from the same level of input. Jones (1965) states, "Technological progress is represented by an inward shift of the unit isoquant." Nordhaus (1969) defines invention as follows: "An invention is viewed as a new process of production, or as a new vector of input-output coefficients." At the firm, industrial, or economic level, Jorgenson and Griliches (1967) note, "The rate of growth of total factor productivity is the difference between the rate of growth of real product and the rate of growth of real factor input."

3.2 ECONOMIC DETERMINANTS

The economic determinants of invention have been subjects of controversy for more than 25 years. Nordhaus (1969) notes that there is ". . . no compelling empirical evidence pointing toward technological change rather than associating increases in productivity with economies of scale, learning by doing, errors of measurement, or even sunspots." He goes on to state why this is so. "Recent work integrating invention into conventional economic analysis has given us a deeper understanding of the important problems in the economics of invention. These studies have highlighted (1) the high degree of uncertainty residing in the outcome of inventive activity; (2) the public good character -- or inappropriability -- of inventions, except under extreme legal arrangements like a patent system; and (3) the indivisibility of invention, meaning that once a new process has been discovered it can be spread to all firms at (virtually) zero marginal cost." Scherer (1965) stated that technical change is not systematically related to market power, prior profits, liquidity, or diversification.

Part of the problem in forecasting technical change is the stochastic nature of inventions. Technological breakthroughs may arise from sources apparently unrelated to R&D activity in a given industry. Studies in the basic sciences may provide applications across many industries. Another part of the problem in forecasting may be attributed to technological opportunity. As Rosenberg (1974) notes, "It is unlikely that any amount of money devoted to inventive activity in 1800 could have produced modern, wide-spectrum antibiotics, any more than vast sums of money at that time could have produced a satellite capable of orbiting the moon." Gort and Wall (1986) found that declining technological opportunities over the industry life cycle contribute to a decline in investment in innovative activity.

3.2.1 Firm Size

The effect of firm size on inventive activity, usually measured by the number of patents in an industry, has been widely disputed. Since Schumpeter, many economists claimed that larger firms are better candidates for inventive activity: Their size generates the profits necessary to fund inventive activities, they are more likely to have the number of scientists and engineers needed to discover and implement new technology, and they are better able to risk the chance of failure.* However, in the 1960s, these assertions became more ambiguous. Scherer (1965) found that invention increases with firm sales, but it does not increase proportionately. "These findings among other things raise doubts whether the big monopolistic, conglomerate corporation is as efficient an engine of technological change as disciples of Schumpeter (including myself) have supposed it to be" (Scherer 1965).

3.2.2 Concentration

The effect of market power on inventive activity is another area of research that has resulted in substantial disagreement. Fethke and Birch (1982), in a study of the timing of inventions, found that inventive activity increased with the number of competitors. "This means that the intensity of rivalry increases with both time and the number of competitors." Kamien and Schwartz (1970) reached a different conclusion: "In comparing a competitive industry with a monopoly, we found that the monopoly will have the greater invention incentive provided that the industry demand curves are equally elastic." Romano (1987) agrees: "A monopolized market can be more conducive to invention than a competitive market in contrast to Arrow's assertion of the opposite."

Many large companies encourage their research staffs to safeguard new discoveries with several and diverse patents to protect proprietary processes and products and maintain a competitive advantage. The Gilbert-Newbery model suggests that one ought to be very worried about the development of entrenched monopolies via preemptive patenting (Gilbert and Newberg 1982; 1984). However, Reinganum's studies suggest that one can reasonably worry far less on this score when the inventive process is stochastic (Reinganum 1983; 1984).

3.2.3 Profitability

Although profits are required to sustain R&D efforts and to develop new inventions, many small companies and individuals are developing and patenting new inventions every day. Large profits do not guarantee technological breakthroughs, but some technological innovations like those in the CCT program can be very expensive to build and test. No authors found a correspondence between the profit potential of some new invention and patent activity.

Kamien and Schwartz (1970) examined the effects of demand elasticity on incentives to invest: "In comparing industries of like structure, we found that the industry with the greater demand elasticity has the greater invention incentive since the resultant output expansion will be greater."

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*For a discussion and survey of these alternative perspectives, see, for example, Dasgupta and Stiglitz (1980a; 1980b), Fisher and Temin (1973), Kamien and Schwartz (1975), and Mansfield (1981).

4 INNOVATIONS

4.1 DEFINITION

The term innovation is often used interchangeably with invention, but the two are distinguished in this review. Inventions are technological advances or breakthroughs (usually patentable) that arise from R&D activity. Innovations are the practical applications of inventions in productive economic processes. Innovations represent the early stage of diffusion.

4.2 ECONOMIC DETERMINANTS

Historically, economists have argued about whether inventions arise from a demand-pull or supply-push process. Schmookler (1962) found strong evidence that patents are a function of output in an industry. He states that ". . . the decline in the industry's rate of growth apparently induced the decline in invention and technical progress . . . inventions usually increase after rises in output." Schmookler and Brownlee (1962) reported similar findings. They found that ". . . taking one industry at a time, inventive activity pertaining to an industry's capital goods appears to follow rather than lead investment." One year later, Griliches and Schmookler (1963) found that ". . . at least for those inventive efforts pursued to the point of securing a patentable result, economic influences operating via the demand side are usually strong and perhaps paramount."

Demand-pull theories are based on the premise that the profit potential of new technologies induces innovative activity; i.e., the bigger the market, the greater the level of activity. Supply-push theories, on the other hand, are based on the premise that technological change arises from specialized expertise in an industry, which determines the profitability of making a technological breakthrough and the cost of achieving it.

Scherer (1982) weakly confirmed Schmookler's finding that inventive activity is responsive to the pull of demand. This theory is based on two premises: (1) the ability to make inventions is widespread, flexible, and responsive to profit-making opportunities and (2) the larger an actual or potential market is, the more that inventive activity will be directed toward it, partly because the profitability of an invention increases with market size. Gort and Wall (1986) stated that the demand-pull hypothesis of innovation is also substantiated across the same sample of products (industries).

According to Balcer and Lippman (1982), supply-push models of inventions and innovations generally represent the process as a racing game. Potential suppliers invest in research whose outcome -- either the time until discovery or the size of the discovery -- is random. Supply-push models are divided into two approaches. Models by Dasgupta and Stiglitz (1980a), Lee and Wilde (1980), and Loury (1979) assume that the first to reach a discovery or the one with the largest discovery reaps all the benefits. The second approach relates market structure (competition, monopoly, oligopoly) to the level of research effort. Such studies include works by Dasgupta and Stiglitz (1980b) and Kamien and Schwartz (1975).

Barzel (1968) sums it up this way: "Technical change is now almost universally considered the major cause of growth in per capita income experienced in the Western world over the last few centuries. Yet, with few exceptions such as Arrow's 'learning by doing' argument [Arrow 1962], technical change is treated as exogenous to the economic system, a trend imposed on the production function making it shift outward systematically over time. Technical change, however, does not descend on us like manna. Resources have to be employed to generate such change, and it is not obvious that these invariably are better occupied by innovation than by other activities. In this paper it is shown that innovations are induced, since they become more profitable with the expansion of output."

Rosenberg (1974) argues that Schmookler's approach ignores the whole thrust of modern science and the manner in which the growth of specialized knowledge has shaped and enlarged man's technological capacities. Such growing sophistication suggests that at least some of the initiative in the changing patterns of innovations lies in the supply side. Therefore, allocation of inventive resources should be determined jointly by demand-side forces, which have broadly shaped the shifting payoffs to successful invention, and supply-side forces, which have determined both the probability of success within any particular time frame as well as the prospective cost of producing a successful innovation. Rosenberg states, "Therefore any analytical or empirical study which does not explicitly focus upon both demand and supply side variables is seriously deficient."

4.2.1 Firm Size

Benvignati (1982) cites Mansfield (1966) as stating that large firms are more likely to adopt new capital-goods innovations than small firms because they are more likely to (1) have old equipment that needs replacement, (2) be able to accommodate a new piece of equipment, (3) have the financial capability to afford the latest equipment, and (4) have access to more extensive outside information networks to learn about new advances.

Mansfield (1963b) says that ". . . when the profitability of the innovation is held constant, one can predict with considerable confidence that a large firm will be quicker than a small one to begin using a new technique. . . . The results indicate that the length of time a firm waits before using a new technique tends to be inversely related to its size and the profitability of its investment in the innovation."

Adams and Dirlam (1966) conducted a thorough case study of the U.S. steel industry's adoption of the basic oxygen furnace (BOF) and reached quite different conclusions. They state, "The view attributed to Schumpeter, that large firms with substantial market power have both greater incentives and more ample resources for research and innovation, has become part of popular mythology and an article of faith among many economists as well." To demonstrate this point, Adams and Dirlam (1966) note that the three major revolutions in steelmaking -- the Bessemer, Siemens-Martin (open-hearth), and basic oxygen processes -- were not the products of American inventive genius nor the output of giant corporate research laboratories. Instead, they state, "The oxygen process was developed in continental Europe and perfected by the employees of a nationalized enterprise, in a war-ravaged country, with a total steel ingot capacity of about 1 million tons -- by a *firm* that was less than one-third the size of a single *plant* of the United States Steel Corporation." Adams and Dirlam (1966) computed that the return on net worth in 1960 would have been 11.6% with a basic oxygen furnace, instead of the 7.6% realized by firms -- an increase of 65%. From Schumpeter's point of view, large electric utilities would seem to be ideal candidates for adopting innovative technology under development in the CCT program; the results from Adams and Dirlam's studies strongly challenge this view. Although utilities are large companies by most standards, the fact that they are regulated limits the inferences that can be drawn from these previous studies. Regulators' attitudes about innovative activity and their willingness to allow utilities to capture the benefits of individual activity are important, and from the point of view of this report, they outweigh the effects of a firm's size.

4.2.2 Concentration

The impact of concentration on a company's willingness to innovate is not well understood. In 1965, Williamson reported his findings about the impact of market power on innovations. He states that ". . . the relative share of innovations contributed by the largest firms in an industry decreases as monopoly power, as measured by the concentration ratio, increases. Indeed, according to the linear model, the four largest firms in an industry appear to contribute less than their proportionate share of innovations when the concentration ratio exceeds 50% . . . and more than their proportionate share when the concentration ratio is less than 50%."

Under conditions of low research costs, low uncertainty, and strong barriers against imitation, Angelmar (1985) notes, "High concentration appears to be detrimental to the vigorous exploitation of technological opportunities under these circumstances." At the other extreme, under conditions of high R&D costs, relatively larger uncertainty, and no barriers to entry, ". . . an increase in concentration is accompanied by a significant increase in research investment. In these industries, existing technological opportunities may not be exploited as long as industry structure remains atomistic. Here, high concentration appears to be essential to provide adequate incentives for innovation" (Angelmar 1985). Gort and Wall (1986) study was inconclusive. They state, "The net effect of the number of producers on innovative activity cannot be specified a priori."

Gander (1985) says, "In terms of direct involvement, greater government resources will certainly not decrease the speed of innovation but the extent to which more of such resources are effective in increasing the speed of innovation depends significantly on the degree of cooperation existing in the innovation production process between the firm and the government."

4.2.3 Profitability

Microeconomic theory suggests that potential profitability should have a large impact on a firm's decision to innovate. However, there is no direct correspondence between the cost savings of new technology and increases in profitability (Mansfield

1963b). The potential savings relate to impacts on the total operation in which the innovation is placed. Lynn (1981) observes, "It is useful to think of a choice of a technology as occurring in three conceptually distinct situations: (1) where a completely new plant is being built, (2) where worn-out facilities are replaced, and (3) where currently functioning facilities become technologically dated."

Adams and Dirlam (1966) found that the U.S. steel industry could have reduced its annual capital cost per ton from $39.61 to $20.22 if it switched from an open-hearth furnace to a basic oxygen furnace. In addition, operating costs (excluding metallics) would have been reduced from $14.33 to $9.37 yet resulted in the production of a higher-quality steel in a foundry with superior quality control and lower plant space requirements. Nevertheless, domestic steel producers continued to build open-hearth furnaces for more than 10 years after the basic oxygen furnace was perfected. (The reasons for this phenomenon are discussed in more detail in Section 5.)

4.2.4 Behavior

Kamien and Schwartz (1972) examined a firm's timing of an innovation in a setting of rivalrous competition. They note, "In selecting the optimal development schedule and introduction date, the cost saving from postponement of the introduction date must be balanced against the sacrifice of benefits during that period of delay. . . . Factors which must be taken into account by the firm in making its timing decision are the increasing cost with compression of the development period, the reduction of profit opportunities with prolongation of the development period, and the probability of rival innovation and imitation which affects the potential rewards available to the firm." They conclude, "Intensive rivalry will cause the firm to postpone development indefinitely, or equivalently to drop the project."

Reinganum (1983) developed a theoretical model that embodies Scherer's empirical observations: Entrants stimulate progress both through their own innovative behavior and through their provocation of incumbent firms. He found that in equilibrium, new entrants ". . . contribute a disproportionate share of important innovations."

4.2.5 Other Economic Determinants

4.2.5.1 Education and Experience

A human capital approach to innovation was pursued in two separate studies. Oster and Quigley (1977) examined the role of education and experience on innovation and came to significant conclusions. They state, "The permissibility of four particular innovations in a cross section of jurisdictions in 1970 and the timing of these innovations are explained by attributes of local firms, labor unions, building officials, and housing demand. Our results suggest that the educational level of the chief building official, the extent of unionization, and the relative size of housebuilding firms in an area affect the diffusion of innovations in residential construction." Wozniak's (1984) model incorporated similar variables: "Education, experience, and the availability of information are hypothesized to be measurable dimensions of innovative ability." Both studies found that innovation tends to increase with education.

4.2.5.2 Optimal Time Path of Innovations

Gort and Wall (1986) examined the effects of competition on the optimal time path of innovations. "In sum, the effect of competition on the optimal time path of investment cannot be solved analytically and, at least at present, can only be determined empirically."

4.2.5.3 Effects of Expectations on Innovation

Walker and Young (1986) found that although technological advances can reduce the damages caused by soil erosion, the expectations of farmers about future technological changes can lead to an underestimation of the damage of soil erosion. In other words, innovation may be impeded by a firm's expectations that improvements to the technology will be realized in the near term.

5 DIFFUSION

Diffusion is not as important a step for the purposes of this review, since most studies show that the process is self-actualizing -- an almost automatic response once the initial penetration in the market has been realized. Acknowledging the large size and long life of most utility investments, the fixity of these investments, and the "sunk" nature of previous plant and equipment expenditures, one would expect slower diffusion rates for a CCT than a technology with the opposite characteristics. However, the growth in electricity demand has required new generating capacity -- growth that could be satisfied with equipment and processes under development. Since most regulatory structures do not reward risk taking, it seems evident that many utilities will be slower to adopt a new technology than will unregulated industries with smaller, shorter-lived investments. Because of this fact, the ICTAP report (DOE 1989a) outlined a series of economic incentives (tax incentives, loans, and grants) and regulatory incentives that could be implemented to reduce the risk associated with the adoption of new technologies.

5.1 DEFINITION

Diffusion is the process by which firms accept innovative production processes and adopt them as their own. Only when a technological breakthrough is adopted by most producers (diffused throughout the industry) are the benefits of the invention realized. The rate of adoption determines the rate of productivity growth.

Gort and Klepper (1982) define five stages of diffusion: (1) commercial introduction, (2) a sharp increase in the number of producers, (3) a period when net entry is relatively balanced, (4) negative net entry, and a (5) second period of relatively balanced net entry. This definition may be useful for competitive industries but its application to regulated industries is not clear. It may make more sense when examined from the perspective of suppliers providing the new technology to regulated buyers (utilities).

5.2 ECONOMIC DETERMINANTS

According to Byerlee and de Polanco (1986), adoption is a stepwise process, with five determinants driving the adoption decisions: (1) profitability, (2) riskiness, (3) divisibility or initial capital requirements, (4) complexity, and (5) availability. Mansfield (1966) says that diffusion is a function of the proportion of firms already using the innovation, profitability of the innovation, size of initial investment, and other unspecified variables. However, for the sake of consistency, this report examines the same set of determinants as before (firm size, concentration, profitability, and behavior). Each of the case studies reported on below shows that conventional economic reasoning has substantial limitations when applied to adoption decisions.

From a modeling perspective, Jensen (1982) argues that the diffusion curve sheds no light on the adoption decision and that most authors proceed with estimating diffusion as if it were driven by its own engine. He argues that the diffusion should reflect decision making under uncertainty with learning, which seems like a potential analog to technologies under development by the CCT program. He states, "Firms may delay adoption of an innovation if they do not known whether it is good (profitable) or not in order to gather information and reduce this uncertainty."

Balcer and Lippman (1982) argue, "The timing decision is largely influenced by expectations about the time path of future technological changes. . . . To flesh out the desired realism we will need to introduce other salient factors such as uncertainty about the profitability of new discoveries; temporizing measures such as minor adjustments, alterations, and additions to existing equipment; learning by doing, flexibility of technique; and compatibility of the various innovations."

5.2.1 Firm Size

Sutherland (1959) found that uncertainty about an industry can impede diffusion and that a major source of uncertainty is the technical complementarity of new technology with the existing configuration of equipment. On the basis of interviews with managers, he decided that smaller firms take a short-run view, adopt more slowly, and have a more pessimistic view of the long term.

Adams and Dirlam's (1966) study of adoption of the basic oxygen furnace in the steel industry challenges the view that large firms adopt faster than small firms. However, McAdams (1967) refutes the findings of Adams and Dirlam, saying that their study ignores important factors such as (1) high domestic scrap utilization rates (which favor open-hearth designs), (2) batch sizes, (3) interrelated technology (both factor 2 and factor 3 are technological complementarity issues), (4) low-cost ores (which reduce the importance of cost-saving capital investments), and (5) a decline in shipping rates (essentially allowing new competitors entry into now markets). McAdams (1967) states, "VOEST (the developer and innovator of the BOF), is dismissed as 'tiny' in absolute terms; yet, it is a virtual monopolist in its home market and has state financial backing." Adams and Dirlam (1967) acknowledge McAdams's criticisms but do not find his arguments convincing. Gold, Pierce, and Rosegger (1970) agree with Adams and Dirlam, stating that the ". . . largest firms in the U.S. steel industry trailed their smaller counterparts in the rate of adoption of the BOF, contrary to what one might deduce from the Schumpeterian hypothesis."

This issue has never been resolved. Romeo (1975) states, "Firm size may be important. Larger firms would seem more likely to be using the innovation for three reasons: (1) more equipment needing replacement, (2) wider range of operations, and (3) more resources (than their smaller counterparts)." However, Benvignati's (1982) study of the textile industry shows that smaller firms are quicker to adopt. "We have discovered that large firms play a more limited role in the textile industry than might be anticipated on the basis of previous diffusion studies. While large firms seem to have a higher probability of being adopters than non-adopters of innovations, they seem to have no particular advantage in being pioneers among adopting firms. Moreover, the speed of adoption appears more strongly associated with labor-cost conditions facing the firm and the competitive circumstances it confronts than does the decision to adopt (or not to adopt)."

5.2.2 Concentration

The effects of concentration on diffusion are ambiguous. According to Scherer (1982), the extreme conditions of perfect competition and pure monopoly are often viewed as less conducive to pioneering efforts than are intermediate degrees of market power. One reason is that very competitive markets lead the innovator to anticipate rapid imitation by competitors and hence rapid dissipation of monopoly profits. Another is that too little competition leads the firm to expect the maintenance of status quo profits with only uncertain rewards to be gained from innovation (Benvignati 1982).

A firm's perception of its position within a market can have an important influence on its decision to introduce new technologies. According to Dietz and Hawley (1983), a firm that dominates a market may be in a better position to take the risk of introducing a new technology, but it may have less incentive to do so. For example, if a firm has a large share of a competitive market, it will bear the risk that a competitor involved in obtaining a new technology will cut into existing sales of current technologies. This situation may be an incentive to implement a new technology or to at least develop it to the point where it can be controlled even if it is not implemented. Therefore, dominance in a competitive market offers both incentives and disincentives to innovate. Innovation is retarded in the absence of competition and market diversity. For the intermediate cases, oligopolic, profitable firms have little to gain from replacing existing technology, since they can effectively block new entrants and avoid the risks of technology adoption.

In regulated markets, Magat (1976) found that ceiling-price regulation induces technical change at a faster rate than does a market without regulation. Competitive market disincentives are avoided, and regulated producers do not compete through price mechanisms, so that technologies that reduce costs lead to higher profits for adopting firms.

5.2.3 Profitability

The effects of profitability on diffusion were demonstrated by Griliches (1957) in his examination of adoption of hybrid corn. However, profit is not a significant explanatory variable at the innovative or saturation stages of adoption. "The observations below 5 and above 95 percent of the ceiling value were discarded because they are liable to have very large percentage errors and would have had very little weight anyway in any reasonable weighting scheme . . . the 10 percent data was chosen as an indicator that the development had passed the experimental stage and that superior hybrids were available to farmers in commercial quantities."

A lack of immediate profit opportunity may not be a substantial impediment to early adopters for a variety of reasons. Mansfield (1963a) notes some considerations in his intrafirm diffusion study of diesel locomotives: "However as time went on, several developments helped to make the advantages of complete dieselization more obvious. First, further refinements were made in diesel design, and the price per horsepower of the diesel locomotive continued to decline relative to steam. Second, it became obvious that large savings could be effected by completely eliminating the facilities needed to service repair steam locomotives." Maddala and Knight's study (1967) of international diffusion of steel technology notes, "In the case of steel production one could argue that raw material factors (types of ore and amount of scrap available) and quality of product produced would play an important role in the choice of a process."

Chow (1967) made several interesting observations in his study of digital computers. The rate of growth for digital computers (measured in rental equivalents) was 78% per year from 1954 to 1965. To determine how much growth was attributable to falling prices, he separated natural growth (with no technological change) and growth induced by technological change. Chow (1967) states that ". . . two elements account for the increase in the use of computers. First, it takes time for a new product to reach an equilibrium level even without quality change. Second, in the meantime, the quality of the product is improving, so that the equilibrium level is being continuously raised." Accounting for these two different equilibrium levels allowed Chow to calculate the amount of growth attributable to falling prices. "If the price elasticity of demand for equilibrium stock of computers is 1.3, say, price reduction alone would account for a 34% annual growth out of a total of 78% observed." Other factors are clearly affecting adopting decisions and not simply potential profitability.

The effects of potential profitability have been overstated by economists, according to Gold (1976). In general, Gold argues that economists have erroneous expectations about technical change because they (1) minimize concerns about the specific means whereby changes are affected, (2) ignore intraplant readjustments engendered by the innovation, (3) ignore extra-firm readjustments traceable to the innovation, and (4) expect managers to make evaluations within unduly short time horizons. "The assumption cannot be justified that even demonstrably superior technological innovations are, or should be, promptly adopted throughout an industry" (Gold 1976).

In the Gold (1976) study, ". . . only four of the 14 major innovations covered accounted for more than half of total output even 15 years after actual commercial use began, although each became dominant eventually." Gold argues that resource-saving innovations do not necessarily yield comparable reductions in their respective unit costs (e.g., chemical or size specifications of materials, or skill requirements of labor). Industrial managers ". . . are usually entirely amenable to adopting innovations involving increases in total unit costs whenever these promise to improve products sufficiently to yield more than proportionate increases in product prices or in capacity utilization rates. In short, although gains in profitability are always a powerful incentive to and a possible result of, technological innovations, they are not consistently achieved. . . . Technological innovations are not most effectively measured by reductions in real unit costs" (Gold 1976).

The Sumrall (1982) study of the steel industry reveals, "Very rapid diffusion took place in the case of four inventions, i.e., the Dessemer process, the continuous cold-rolling of sheets, electrolytic tinplating, and continuous flat hot-rolling (the wide-strip mill)." However, other "major" innovations were adopted less rapidly. "Direct displacement of functioning facilities and capacity is likely to be substantial only when forced by shortages of input factors for which older facilities have heavier requirements and by increasing demands for product qualities not obtainable via older facilities" (Sumrall 1982).

Carman's (1982) logistical model of diffusion of high-fructose corn syrup (HFCS) shows 22 years to adoption, with a market share ceiling limited below that for total sweetners. "Information on technical constraints for the use of HFCS help establish a probable market share ceiling. Even though HFCS prices have ranged from 55% to 70% of sugar prices on a dry basis, many firms have not switched to the cheaper input."

5.2.4 Firm Behavior

Reinganum (1981) examined the role of firm behavior on adoption decisions and concluded, "When a cost-reducing innovation is announced, each firm must determine when (if even) to adopt it, based in part upon the discounted cost of implementing the new technology, and in part upon the behavior of the rival firm." Reinganum quantified the role of behavior and rivalry but also acknowledges that diffusion must account for strategic behavior, costs and benefits of adoption, and competitive market shares.

5.3 DIFFUSION MODELS AND PROCESS FUNCTIONAL FORMS

New product acceptance is an adoption-imitation process: The new product is first adopted by a few people -- the innovators -- who in turn influence other people to adopt it (Teotia and Raju 1986). According to Reinganum's (1981) theoretical model, even with perfect information and identical firms, diffusion of innovation, rather than prompt adoptions, is evident. Gold (1976) gives the following explanations. First, various innovations differ in the specific patterns of their benefits and burdens. These patterns change as the innovations themselves undergo improvements and modifications. Second, even firms in the same industry often differ in their relative urgencies at any given time; hence, they differ in their evaluations of the attractiveness of particular innovations relative to the other alternative and pressures confronting them. Third, the net attractiveness of even unchanging innovations tends to vary with alterations in the firm's factor and product prices, profitability, need for expansion, and availability of capital.

The basic diffusion model given by Teotia and Raju (1986) follows:

$$\frac{dN(t)}{dt} = a\ [\bar{N}(t) - N(t)] + bN(t)\ [\bar{N}(t) - N(t)] \tag{1}$$

where:

$dN(t)/dt$ = rate of diffusion at time t,

$N(t)$ = cumulative number of adopters at time t,

$\bar{N}(t)$ = population of potential adopters at time t (ceiling level),

a = innovation coefficient, and

b = imitation coefficient.

According to Teotia and Raju (1986), there are various diffusion approaches. First, many diffusion studies have been done under the assumption that the diffusion process is based purely on the innovation effect with a constant market potential. In this case, the number of new adopters is proportional only to the potential number of new adopters still available. Second, some models assume the existence of both innovation and imitation effects. In this case, innovations are not influenced in their timings of the purchase by the number of persons who have already purchased the new product. However, imitators are influenced by the number of previous adopters. Imitations therefore increase relative to the number of innovations over time. Third, there are technological substitution models, which are pure imitation models. In these models, the extent of substitution is defined in terms of the market share captured by the new technology.

A common issue that arises in diffusion studies is the graphical representation of the diffusion process. A diffusion curve for an innovation is usually defined as the proportion of its potential users who have already adopted as a function of time (measured from the first adoption). Various functional forms are used. Three common ones are the modified exponential functions, the logistic function representing the sigmoid curve, and the Gompertz function representing the asymmetric sigmoid curve. Brief discussions of these models follows.

5.3.1 Modified Exponential Functions

Modified exponential function models are based on the assumption that the instantaneous diffusion rate depends solely on the remaining distance to the saturation level. Mathematically, it is given as: $dY/dt = a(N - Y)$, where Y = some measure of the diffusion level at time t, N = saturation level, and a = a constant of proportionality. Solving with respect to Y and prescribing that the process starts at the origin yields the following diffusion function, the graph of which is shown in Fig. 5 (Lekvall and Wahlbin 1973):

$$Y(t) = N(1 - e^{-at}) \qquad (2)$$

This model has been used successfully in a number of studies. For example, Fourt and Woodlock (1960) uses it to describe the market penetration of certain consumer goods, and Kelly (1967) uses it to predict the growth in patronage of a new retain outlet.

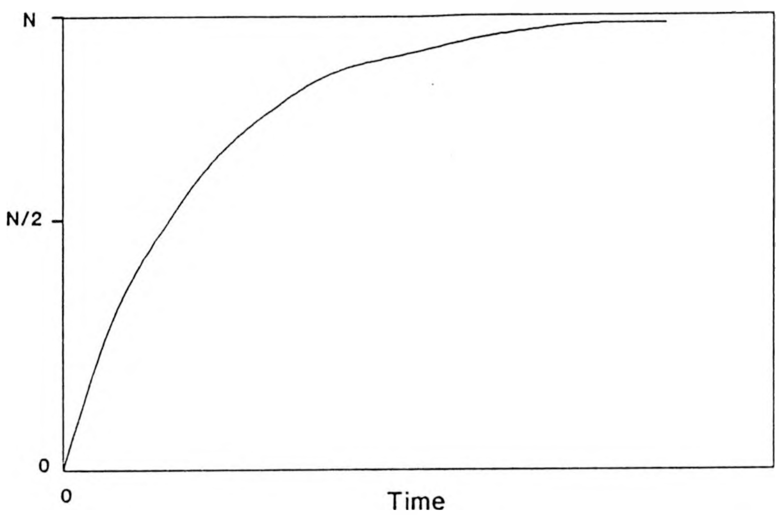

FIGURE 5 Modified Exponential Function (Source: Lekvall and Wahlbin 1973)

5.3.2 Sigmoid Curve and Logistic Function

The most commonly used diffusion curve is S-shaped and is one in which the proportion of the new technology adopted is an increasing function of time; the curve is initially convex but eventually becomes concave (see Fig. 6). A characteristic of the sigmoid curve is the fact that it is symmetrical around an inflection point at 0.5N. The S-shaped growth curve reflects not only the growth rate of diffusion of the new technology but also the growth rate of supply and demand. It represents the growth rate of the supply of the new product if a closed economy (no imports or exports of the product) and a stationary state (no changes in the inventions) are assumed. It also represents demand growth, since all that is produced is being consumed domestically. The growth curve might, in fact, be construed as the growth of demand or supply, whichever is smaller at the time in question (Hurter and Rubenstein 1978).

Initially, the rate of diffusion is slow because of a lack of information about the new product, supply bottlenecks, and uncertainties surrounding the product. Such factors delay adoption. At the next stage, growth results from the greater availability of information about the product and the increased interaction between adopters (innovators) and nonadopters (imitators). Finally, the growth rate slows and the market penetration approaches the saturation point (ceiling) as the number of potential adopters decreases (Teotia and Raju 1976).

Casetti's (1969) explanation of why diffusion follows an S-shaped path is based on the following three postulates. First, potential users of a technological innovation become adopters under the influence of previous adopters in the course of direct personal contacts ("messages"). Second, potential users have different degrees of resistance to change. Third, resistance to change may be overcome by a sufficiently large repetition of messages from adopters. This theory illustrates the sigmoid curve, with slow diffusion at first, then rapid diffusion, and then slow diffusion again until a saturation point is reached.

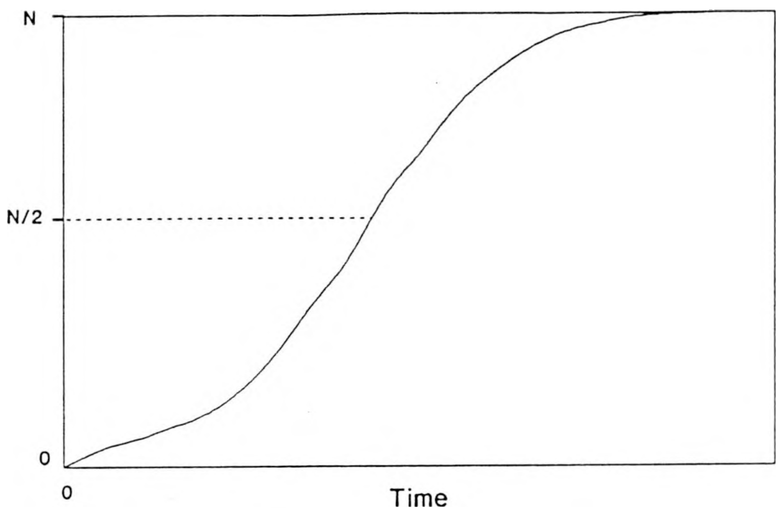

FIGURE 6 Logistic Function (Source: Lekvall and Wahlbin 1973)

Another point of view suggests that the S shape would be generated by the aging of the capital if the ages of the components of the capital stock follow a normal distribution. Operating costs are often assumed to vary in direct ratio to the age of the equipment. The relationship between the age of the capital equipment and the rate of diffusion seems to be supported by empirical evidence. It has sometimes been assumed that resistance to adoption of an innovation is normally distributed throughout an industry. Simulation studies based on this assumption have yielded S-shaped curves. Age of capital could then be considered a surrogate for resistance with respect to some kinds of innovation (Hurter and Rubenstein 1978).

David (1969) offers another explanation for the S shape. He bases his explanation on the distribution of firm size. Since the distribution of firm size in an industry is often found to be log-normal, the path of diffusion of an innovation, defined to be a labor-saving, fixed capital investment using new production techniques, will be the standard normal cumulative distribution, which is S-shaped when plotted against a positive linear transformation of the time dimension (Hurter and Rubenstein 1978).

The vertical axis of the sigmoid diffusion path uses alternative measures of penetration of the new technology. For example, the percentage of firms using the new technology and the percentage of output produced using the new technology are two options. On the other hand, two different labels can be used for the horizontal axis. The most widely used measure is time. In this case, the behavioral lag represented by the logistic curve results from a combination of several factors, including these: (1) the economic advantage of the new technology, (2) the initial uncertainty associated with the new technology, (3) the rate of reduction of this initial uncertainty, and (4) the extent of the commitment required to adopt the technology (Warren 1980; Mansfield 1961). In this case, less than 100% of the market may be captured by the innovation, which in Warren's case is solar technology, and thus the relevant definition of its potential market is the total market.

According to Warren (1980), the other measure that can be used to label the horizontal axis is economic competitiveness. In this case, the behavioral lag is based on changing economic competitiveness. First, when the new technology is only marginally better than the conventional technology, only a few imitators will adopt it. Second, as the new technology becomes more clearly economically superior, a "bandwagon" effect occurs, which gradually dissipates as the majority of the market is captured. The portion of this market captured by the new technology approaches 100%, so its potential market must be defined as that portion of the total market in which it can be competitive.

The function used to represent the sigmoid curve is the logistic function. This model is based on the assumption that the diffusion rate at a given point in time is proportional to the remaining distance to some predetermined saturation level as well as to the instantaneously attained diffusion level (Lekvall and Wahlbin 1973). The model has been used successfully to summarize empirically the time pattern of adoption for numerous innovations and new products, including hybrid corn (Griliches 1957), soybeans (Powell and Roseman 1972), machine tools (Romeo 1975), and high-fructose corn syrup (Carman 1982). The logistic function is a cumulative distribution function that indicates that the level of growth of a product comes from the following:

$$Y(t) = N\left(1 + be^{-aNt}\right)^{-1} \qquad (3)$$

where:

$Y(t)$ = consumption of the product at time period t,

N = equilibrium level of demand (ceiling) $a,b > 0$, and

b = constant depending on initial conditions.

The rate of growth can then be written as:

$$\frac{dY}{dt} = aY(N - Y) \qquad (4)$$

Equation 4 shows that the growth rate of demand at time t depends in a multiplicative manner on the level of use (Y), the degree of market saturation (N - Y), and the parameter a. The economic rationale for this relationship is that a rise in actual use of the brand tends to stimulate its growth because of "demonstration effects" among consumers and also to dampen growth as the proportion of market demand left unfilled falls. The logistic function attains a maximum growth rate when actual use reaches 50% of the equilibrium and is symmetrical around this inflection point (Lakhani 1979).

Another characteristic of the logistic model is that it assumes only an aggregated effect on the adoption rate of a new product because of previous adoption in the population. The effect results simply from the decrease in the number of individuals still available to adopt the product because at a given time they have not yet done so. In addition, the model includes what might be called an aggregate experience factor, which reflects risk aversion through a lower probability of finding an individual who will be willing to adopt the product when only a few members of the population have already done so and through a higher probability as more and more do adopt it. The competition of the two factors results in a slow start for the rate of adoption until the new product "catches on," then a period of rapid growth in acceptance of the product, and finally, in another slowing of the rate as the available market approaches saturation (Philipson 1978).

5.3.3 Right-Hand Skewness and Gompertz Function

According to Lekvall and Wahlbin (1973), even though the modified exponential function and the popular logistic function have shown good fits to data in certain situations, from a purely empirical point of view, most real-world diffusion curves actually show a more or less distinct asymmetric S shape, usually with the upper shank of the S being more extended (see Fig. 7). The right-hand skewness stems from the fact that the curve has an inflection point below half the saturation point. Thus the function is concave over the greatest amount of time; in fact, this skewing is occasionally severe enough to make the diffusion curve appear concave everywhere (Jensen 1982).

One growth function that produces such a right-hand skewed diffusion is the Gompertz curve. Its cumulative distribution function, which represents the level of growth, is $Y(t) = Na^{(b^t)}$ where $0 < a,b < 1$, and b determines the rate of change of the growth rate. The rate of growth is:

$$\frac{dY}{dt} = -\log(b)Y\,(\log N - \log Y) \tag{5}$$

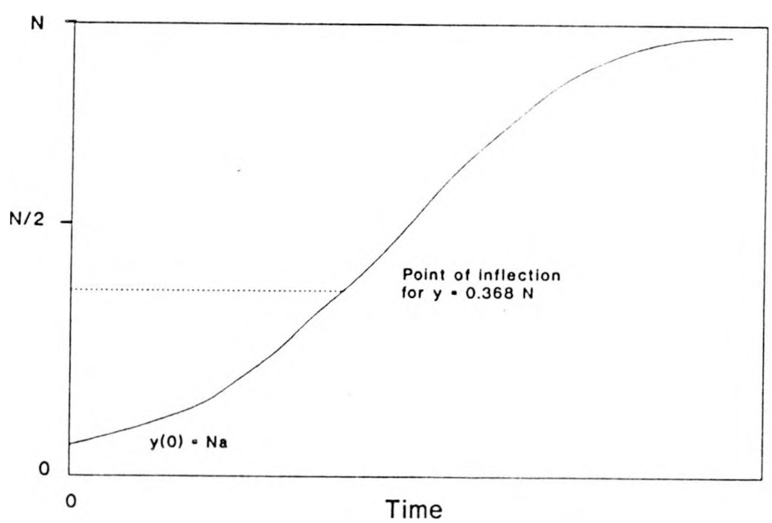

FIGURE 7 Gompertz Curve (Source: Lekvall and Wahlbin 1973)

Therefore, the smaller the b constant is, the greater the rate of diffusion is. The constant "a" can be used to determine the date that a brand was available on a commercial scale, in the sense that actual use reached 5-10% of the equilibrium level.

With the Gompertz curve, growth rises rapidly to its maximum rate, which occurs when actual demand is 37% of the equilibrium. Thereafter, growth tapers off gradually, so that the growth rate at any point around the maximum is greater than that of an equally distant point below the maximum (Lakhani 1979). The Gompertz curve was used by Chow (1967) in his analysis of growth in the use of electronic computers.

5.3.4 Cumulative Normal/PROBIT Model

This model is associated with the linear probability model of the following form: $Y_i = \alpha + \beta Y_i + e_i$, where X_i is the value of the attribute and where Y_i is equal to one if the first option is chosen and zero if the second option is chosen.

The main task is to transform the model in such a way that predictions will be in the (0,1) interval for all x by utilizing some notion of probability. The PROBIT probability model is used for that purpose, and its standardized function can be written as:

$$P_i = F(Z_i) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z_i} e^{-s^2/2}\, ds \qquad (6)$$

where:

P_i = probability of an event occurring; by construction, it lies in the (0,1) interval,

Z_i = theoretical (but not actually measured) index Z_i, which is determined by an explanatory variable X_i as in the linear probability model, and

s = random variable that is normally distributed with mean zero and unit variance.

The problem that the PROBIT analysis solves is how to obtain estimates for the parameters α and β while at the same time obtaining information about the underlying unmeasured scale index Z (Pindyck and Rubinfeld 1981).

6 IMPLICATIONS FOR CLEAN COAL TECHNOLOGIES

The authors of the studies cited in this review have widely divergent views about how much a firm's size, market power, and potential profitability affect its development and adoption of new technologies. Many of these differences may be attributable to the fact that the studies examined different industries, were conducted at different times, and employed different functional forms for estimation. However, two themes seem to have a broad base of support: (1) diffusion follows a well-known pattern called the logistic curve and (2) certain barriers to adoption of new technology may exist, even though strong economic incentives to adopt are present.

Research and development, invention, innovation, and diffusion are different parts of the same continuum, sometimes described as the process of technical change. R&D is the activity that generates new inventions; inventions applied in industrial processes are called innovations; and after innovative techniques approach 5-10% saturation of the potential market, the process of diffusion starts. Predicting adoption when the saturation point is below 5% or above 95% has been shown to be error prone and unreliable.

When 0-10% of the market has adopted a technology, it is widely considered to be in the experimental or innovative stage; most CCTs would fall within this category. After the 5% saturation point has been reached, the prediction of subsequent adoption becomes much more reliable and closely follows the logistic curve. The logistic curve has proven to best describe the pattern of technology adoption in more than two dozen industries, which are described in articles that were examined during the preparation of this report.

Most analysts agree, however, that certain barriers may impede adoption, even when many economic incentives to adopt are present. These barriers have been extensively described in the case of the steel industry and its adoption of the basic-oxygen furnace to replace open-hearth designs. One of the potential barriers is market structure. The literature on how market power influences the rate of technology adoption, however, is sparse. On this topic, Quirmbach (1986) found, "A joint venture adopts innovations more slowly than other market regimes . . . and the adoption rate is slower than socially optimal. . . . A monopoly supplier, on the other hand, adopts at a faster rate than is socially optimal. This is usually also the case when there is not market power. A monopoly supplier accelerates adoptions faster than when there is no market power, but retards later adoption."

The most serious limitation in applying these findings and the results cited in this report to the CCT program is that few of these studies account for the effect of regulation, and regulated utilities are a primary market for most CCTs. Nevertheless, the implications from this study for the CCT program are clear. Substantial cost reductions of the technology must be achieved before CCT adoption will occur, and compatibility with existing equipment, resources, and management must be reconciled. These conditions include obtaining the appropriate skills to operate innovative equipment.

Although CCTs are in the innovative stage of development, large increases in coal-based electricity generating capacity are projected. If invention and innovation follow demand -- as many economists believe and as theory prescribes -- there should be a rapid and substantial improvement in coal utilization technologies. Based on findings in other industries, if CCTs can achieve a 5% market penetration level by 1995, a 90% saturation level is possible by 2020.

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