Alternative sources of technology: An analysis of induced innovations

By: Albert N. Link

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Abstract:

This paper considers why firms differ in the degree to which they rely on their internal R&D organization for generating new technologies (induced innovations) rather than on existing external technology markets (purchased innovations). An empirical model is suggested to explan inter-firm differences in the percentage of new technology induced through R&D efforts. The analysis suggests that such differences are systematically related to the firm's size, its competative environment, and its degree of diversification.

Keywords: R and D | induced innovations | econometric studies

Article:

INTRODUCTION

Microeconomic analyses of innovative activity have generally focused on R&D spending as an easily quantifiable input into the innovation process. These inquiries fall broadly into two areas. The first, and the one more intensively researched (as measured by the total amount of published literature), is concerned with explaining inter-firm (interindustry) differences in R&D spending.[1] Work in the second area is directed toward measuring the impact of direct R&D spending on

[1] Such studies have appeared in the literature for about two decades. Their general purpose is to define the 'environment' (i.e. a set of firm and industry characteristics) most conducive for innovation. Kamien and Schwartz (1975, 1982), Scherer (1980) and Link (1981a) provide extensive reviews of this literature.

productivity growth.[2] These studies have been useful, but are somewhat limited in scope; for the technological basis of a firm is broader than the activities of its own R&D program. Technologies can enter a firm not only as the result of its own R&D – we call these induced innovations – but also through such channels as the licensing of others' technology or the purchasing of capital equipment that embodies new technology (perhaps the results of a capital supplier's R&D) — we call these purchased innovations. Surprisingly, this inter-firm flow of technology has been ignored in most previous econometric studies.[3] This paper is an attempt to fill that void by quantifying the economic importance of these alternative sources for the firm.

There appears to be a significant degree of interfirm and inter-industry variability in the proportion of new technological advances that are induced. To illustrate this, the mean percentages (averaged across firms) of induced technologies for eleven separate industry groupings are reported in Table 1 (data sources to be discussed below). These percentages range from a low of 25% in the textile and apparel industry to a high of 68% in the chemicals industry.

Table 1. Selected Industry Means of Percentage of New Technological Advances Induced through R&D

Industry	Mean percentage	R&D coverage ratio (%)
Food and kindred products (SIC 20)	46	87
Textiles and apparel (SIC 22, 23)	25	79
Paper and allied products (SIC 26)	57	51
Chemicals (SIC 28)	68	83
Petroleum refining (SIC 29)	49	96
Primary metals (SIC 33)	36	77
Fabricated metal products (SIC 34)	56	52
Machinery (SIC 35)	34	84
Electrical equipment (SIC 36)	43	39
Transportation equipment (SIC 37)	43	81
Professional and scientific instruments (SIC 38)	38	54

Source: Survey data for 1976.

The purpose of this study is to consider why firms differ in the degree to which they rely on their internal R&D organization for generating technologies rather than on existing external technology markets. Specifically, a model of inter-firm differences in the percentages of technologies induced through R&D activities is posited and tested empirically.

THE INDUCE VERSUS PURCHASE STRATEGY

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[2] These investigations are an outgrowth of literature seeking to isolate determinants of the slowdown in productivity growth in nearly all sectors of the economy during the past decade. Griliches (1979) gives an excellent discussion of these studies.

[3] There are several exceptions: Terleckyj (1974, 1980a,b, 1982) and Scherer (1981) consider the issues of technology flows at the industry level of aggregation. Terleckyj, for example, dichotomizes R&D into the categories of 'performed' and 'purchased'. His purchased category only includes capital-embodied technologies. Link (forthcoming) has extended these studies using firm data and has dichotomized each firm's expenditures on innovations into those associated with direct R&D activities and those purchased or licensed from other firms. Finally, Link *et al.* (forthcoming) have considered the induce versus purchase decision in the context of an empirical test of the Utterback–Abernathy production process lifecycle.

In a broad sense, one may view the decision to invest in R&D – that is, to induce technology – as a conscious plan to replace a market mechanism with an internal organisation.[4] Therefore we may hypothesise that the induce versus purchase decision is a rational aspect of the firm's overall innovation strategy. Accordingly, inter-firm differences in the percentage of new technology induced through the firm's own R&D reflect inter-firm differences in the perceived net benefits from internalising the innovation search.

Three hypotheses underlie the formulation of this model. First, larger firms are expected to induce a greater percentage of their new technological improvements than smaller firms. A frequent interpretation of Schumpeter (1947) is that larger firms can more easily provide the physical and financial economies of scale in production and innovation requisite for success in the R&D process. Therefore some of the technical uncertainties surrounding technological advancements are reduced as size increases. There are, of course, technical uncertainties associated with purchasing technology as regards the adaptability of a particular technology to the firm's production process or to its requirement set. Assuming these uncertainties remain for all purchasers, then as firm size increases the relative benefits of their own R&D increase, *ceteris paribus*.[5]

A second hypothesis is that the market structure of the industry in which a firm produces is likely to affect its induce versus purchase strategy. Innovation is a form of nonprice competition, and nonprice competition occurs to a greater extent in markets where there is at least some degree of seller concentration. A firm in a concentrated industry, then, will have the incentive not only to innovate but also to appropriate as much of the technical knowledge associated with that innovation as possible. Therefore, one might expect that the incentive to induce is greater in industries rich in nonprice competition, that is, in industries with some degree of seller concentration, *ceteris paribus.*

Finally, a third hypothesis is that more diversified firms may induce to a greater degree, *ceteris paribus,* because they are better able to utilise the unexpected spillovers of technical knowledge. This hypothesis is an extension of Nelson's (1959) proposition that diversification is a prerequisite for basic research owing to the inherent uncertainty associated with basic research efforts; simply, 'firms that have their fingers in many pies' (p. 302) are better able to profit from whatever inventions or discoveries may result.[6] Along these same lines a more diversified firm may be better able to appropriate the R&D-related knowledge from induced efforts.

The following regression model is posited in order to test these three hypotheses:

$$\text{INDUCE} = \beta + \beta_1\text{SIZE} + \beta_2\text{CR} + \beta_3\text{DIV} + \Sigma\beta_i \cdot D_i + \varepsilon \qquad (1)$$

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[4] Coase's (1937) pioneering article provides the first theoretical insights into the nature of the firm's nonmarket activities. His concepts have been extended by Alchian and Demsetz (1972), Teece (1980, 1981) and Williamson (1975, 1979), among others, but very little empirical work has been done to test the applicability of the theoretical issues. One exception is Mowery's (1981) historical case study of in-house R&D versus contracted work.

[5] Somewhat related to this proposition is Mowery's (1981) finding that in-house R&D, as opposed to contracted R&D, increases as firms become larger. Also, Link (1980, 1981b) suggests that firm size is important for efficiency within the firm's overall R&D program.

[6] The National Science Foundation (1979) defines basic research as original investigation for the advancement of scientific knowledge that does not have a specific commercial objective.

The independent variable, INDUCE, represents the percentage of a firm's technological advances that come from its own (self-financed) R&D activities. This variable reflects the firm's 1976 subjective evaluation (as reported by the R&D vice-president) of the role of its R&D program within its overall strategy for acquiring new technologies. A total of 329 major R&D firms within the manufacturing sector were surveyed and interviewed in an attempt to quantify the dichotomy between the use of the firm's own R&D resources relative to the use of existing external technology markets.[7]

Firm size, SIZE, is measured (in millions of 1976 dollars) as gross sales and other operating revenues less discounts, returns and allowances as reported by Compustat. Seller concentration, CR, is measured as the four-firm concentration ratio corresponding to the four-digit SIC industry in which Standard and Poor's *Register of Corporations* classifies each firm. These data came from the 1972 *Census of Manufactures*.[8] The extent of each firm's product differentiation, DIV, is represented by the number of four-digit SIC industries in which the firm and its subsidiaries operate. These data came from Standard and Poor's *Register of Corporations*.[9] Finally, eleven dummy variables, corresponding to the industries in Table 1, are included in Eqn (1) to control for industry specific factors that may influence the firm's innovation strategy. Such factors may be the extent to which a market has matured for providing new technologies, or the extent to which there are other aspects of competitive strategies not captured by the concentration terms. The sample of 329 firms contains 32 firms in various manufacturing industries other than those listed in Table 1: their impact is subsumed in the intercept term. The error term, ε, is assumed to obey the classical assumptions.

The least-squares results, with *t*-statistics in parentheses, are

$$\begin{aligned} \text{INDUCE} = {} & \underset{(6.09)}{0.57} + \underset{(3.03)}{0.00012}\,\text{Size} + \underset{(2.19)}{0.041}\,\text{CR} + \underset{(2.04)}{0.003}\,\text{DIV} - \underset{(-1.16)}{0.073}\,\text{D}_{20} - \underset{(-2.36)}{0.192}\,\text{D}_{22/23} \\ & + \underset{(1.02)}{0.015}\,\text{D}_{26} + \underset{(3.27)}{0.195}\,\text{D}_{28} - \underset{(-0.52)}{0.049}\,\text{D}_{29} - \underset{(-1.40)}{0.121}\text{D}_{33} + \underset{(0.82)}{0.072}\,\text{D}_{34} - \underset{(-1.76)}{0.107}\text{D}_{35} \\ & - \underset{(-0.36)}{0.029}\text{D}_{36} - \underset{(-1.47)}{0.104}\text{D}_{37} - \underset{(-0.55)}{0.054}\text{D}_{38} \end{aligned}$$

$$R^2 = 0.406,\ \text{F} = 17.93 \qquad (2)$$

[7] The range of reported values is 0.12 to 0.83, with a standard deviation of 0.31. The mean is 0.48. Unfortunately, no data exist with which to compare my survey responses. The sample of 329 firms appears quite representative of the total R&D activity in the manufacturing sector. R&D coverage ratios are reported at the industry level in Table 1; also, more detailed descriptive statistics of the sample are in Link (1981a).

[8] Compustat classifies firms by an SIC industry code; however, these classifications are often at the three- and sometimes two-digit levels. In those instances the firm's four-digit classification was taken from Standard & Poor's *Register of Corporations.*

[9] No attempt was made to weight this index by the percentage of the firm's sales in each of the four-digit industries. Since, as hypothesized above, one incentive to induce is provided by the firm's potential to use whatever unexpected technical knowledge results, it is therefore the absolute number of markets served by each firm which is important in measuring inter-firm differences in potential sources of application. Grabowski (1968) and McEachern and Romeo (1978) measured diversification as the number of five-digit SIC production lines in which a firm produced. Those data, however, were last published in Fortune's 1966 *Plant and Product Directory.* Link (1982) and Link and Long (1981) have used the number of four-digit industries as a measure of diversification in an empirical test of Nelson's hypothesis.

The estimated coefficient on SIZE is positive, as hypothesised, and significant at the 0.01 level. The coefficient suggests that a $1 billion increase in sales is associated with a 0.12 percentage point increase in the proportion of technological advances related to the firm's R&D program, *ceteris paribus.* The estimated coefficient on CR is also positive, as hypothesised, and significant at the 0.05 level. A one percentage point increase in measured concentration is associated with a 0.041 percentage point increase in induced innovations, *ceteris paribus.* Also, more diversified firms appear to induce a larger portion of their innovations: the estimated coefficient on DIV is positive, as hypothesised, and significant at the 0.05 level. As the number of four-digit industries associated with a firm's production and sales increases by 10, the percentage of the firm's technological advances induced internally increases by 0.03 percentage points, *ceteris paribus.* Finally, the sign pattern on the two-digit industry dummy variables corresponds well to the distribution of means in Table 1.

Several alternative specifications of Eqn (1) were also considered but are not reported here. A nonlinear CR term was included to test for the possibility of an inverted-U relationship. Such a relationship has previously been found when analysing other aspects of non price competition (e.g. advertising and R&D spending) and seller concentration (Greer, 1971; Martin, 1979; Scherer, 1967; Scott, 1978, 1981; Strickland and Weiss, 1976). The coefficient on the nonlinear CR term was negative but was not significantly different from zero. This hypothesis of nonlinearity was therefore rejected. Also, a nonlinear SIZE and DIV term were included to test for the possibility of diminishing returns on the firm's incentive to induce. There was no evidence of diminishing returns with respect to firm size, but the positive statistical influence of DIV diminished after firms were diversified in more than seventeen four-digit SIC industries.[10]

In summary, these findings indicate that the extent to which firms induce new technologies is not random: it varies in a systematic manner that is related to their size, competitive environment and degree of diversification.

CONCLUSIONS

In this paper I have argued that firms have at least two avenues through which they can acquire new technologies: they can induce them through their own R&D efforts or they can purchase them through a market alternative. It is suggested that a firm's choice between these alternative sources reflects a rational aspect of its overall innovative strategy: this choice mechanism has not previously been considered in detail within the R&D literature.

It is very important to emphasise that the findings presented here are preliminary and perhaps not without error. The key variable in this study, INDUCE, reflects an individual's subjective evaluation about his firm's overall innovative activities, and is thus quite noisy. Also, it was not possible to control for any intangible characteristics of the firm that may influence the direction of its innovation strategy. Such factors may be related to the firm's or R&D division's organizational structure, or even to the tone (offensive or defensive) of its long-term R&D plan. Still, this paper indicates that a firm's self-financed R&D is not its sole source for new and

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[10] This result is not sensitive to whether the firm is diversified within a two-digit SIC industry or across several two-digit industries (McEachern and Romeo, 1978). The mean value of DIV is 8.31 and the range is 1 to 39.

relevant technologies. This conclusion is important if we are to fully understand the process of innovation and its ultimate relation to productivity and technological change.

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