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THE DYNAMIC INTERACTION BETWEEN INDUSTRY LEVEL PROFITS AND RESEARCH AND DEVELOPMENT

John Beggs

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by

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Introduction

A relationship between research and development expenditures (R&D) and profits has been posited, either explicitly or implicitly, in many studies of industrial R&D. Thus, Schumpeter (1950) maintained that monopoly power provides the firm with profits and security, which give it the opportunity to take the risks involved in R&D. Scherer (1965), Minasian (1962), Mansfield (1968), Smith and Creamer (1972), Branch (1974), Grilliches (1975), Grobowski and Mueller (1978) found evidence supporting the hypothesis that R&D exerts an influence on subsequent profits. Hamberg (1966), Grabowski (1968), Mueller (1967), Elliot (1971), Johannisson-Lindstrom (1972), and Branch (1974) have observed, with ambiguous results, various associations between profit rates and subsequent R&D.

The above literature suggest there are at least three possible relations between R&D and profit. First, profits may influence subsequent R&D. Second R&D may influence profits. And third, it is possible that R&D and profits are influenced simultaneously by some third group of factors, for example, exogenous surges in demand, etc. Although the first two of these relations involve influences of one variable on another over time, the problem of identifying the interacting relationship between the two series has not been tackled in previous work.

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The data bought to bear on the problem are industry level profits and research and development expenditure for the period 1953 through to 1978. The data are for fourteen industry classifications for which NSF survey data on R&D is available.

The model employed is a two-equation model of the time series relationship between industry profits and industry R&D. The econometric model is an error components model which attempts to account for the presence of contemporaneous economy-wide shocks to the system. In particular, time specific error components have been included in the disturbance structure of the model. The time domain representation of the resulting model is extremely complex so spectral techniques are employed to produce a remarkably computationally amenable representation of the model in the frequency domain. Maximum likelihood estimation techniques are then employed.

The final section of the paper reports on the empirical findings and relates then to the hypotheses to be introduced at the outset of the paper.

The Hypotheses

A firm undertaking R&D is assumed to be mindful of the relative benefits and costs associated with the project. Benefits, in the form of profits, accrue to the firm as a result of either reduced operating costs (a process innovation) or sales in a new market (a product innovation). In the case of product innovation, R&D can be considered as a demand-accruing asset. Phillips (1966, 1971) has argued that R&D and innovative behavior by existing firms tend to define, along with other factors, limits to entry by new firms. Entry deterring limit pricing and the greater the exploitation of opportunities presented by exogenous scientific and technical developments make entry of additional firms less likely. Phillips further argued that in the presence of substantial learning costs, the successful firm will be immediately placed in a dominant position, while other firms fall into inferior positions; successful innovation becomes easier for the former and increasingly difficult for the latter. Such arguments suggest that R&D should continue to contribute to a firm's profits many years into the future. Empirical evidence of Commanor (1964) and Branch (1975), however, suggests that firms compete vigorously in the area of new product development. New product developments by a firm are most usually soon matched by rivals who actively engage in producing 'me-too' products and 'inventing-around' patents. In this situation, the mean lag time between R&D and subsequent profits would be quite short. It remains to collect further empirical evidence on the length of these lags, and by inference upon the nature of the rivalry occurring in the market.

The other main postulated relation is between profits and subsequent R&D. Because of the well-known uncertainty associated with R&D, it has been argued that firms may be unwilling to borrow substantial funds to finance development of a new product or process, and that only firms generating a substantial cash flow can support a sizeable R&D effort. This suggests that high current profits as a source of liquidity are necessary for a sizeable R&D effort. The assertion that uncertainty should affect the willingness of firms to go to the capital market to finance a project needs to be supported by further argument. In the case of R&D projects, there may be asymmetry in the perception of the risk associated with a project. If, as an extreme example, the project in question was the development of some highly secretive product which could not reasonably be patented, then the borrowing firm may be unwilling to reveal any more than a small part of the technology to the capital market. In the general case, it will simply be difficult for the market to objectively evaluate the risk associated with a proposed new technology when the bulk of the expertise about the new technology is held by the personnel of the borrowing firm. For minor new product developments, the market may be able to use the past record of successes and failures of a firm to evaluate expected success rates, but in the cases of radically new technologies the problems of asymmetric information would seem to bias the firm towards using internal funds. A second argument as to why firms use internal funds for R&D is made along similar, but less convincing, lines. It can be argued that the market has relatively little information available to it for evaluating firms and must rely heavily on standard accounting devices such as leverage ratios, and that such statics take on an importance beyond that justified by their true information content. Small firms may consequently be unwilling to go to the capital market for a risky R&D project simply because, in the event of a project failure, the firm's debt-equity ratio may rise substantially, subsequently prejudicing the firm in the capital market because of its one failure. In the case of large firms, which are the ones of primary interest here, a firm can go to the market many times and establish some sort of track record as a product innovator without any one single failure seriously prejudicing its financial position.

Current profits can also be viewed as an indicator of future profits: a firm enjoying past success may be more inclined to take the risks of R&D in expectation of future success. Surges in profits may potentially come from all types of temporary exogenous influences which would not be expected to raise the long-run viability of most R&D projects. Indeed, high profit may coincide with heavy demand and operations at near capacity levels. In such cases, profits may be inversely associated with R&D. As managers attempt to adjust investment to booming demand, funds may be diverted to capital expansion with its almost immediate financial return and away from R&D with its longer pay-back period.

The level of R&D may be inversely related to sustained high profit rates. While Schumpeter saw the quest for extraordinary profits through innovation as the motivational force propelling his process of "creative destruction," such managerial and entrepreneurial vitality may not be the most useful characterization of market behavior. Indeed, satisfying goals (Simon (1956)) may be more predominant. Managers may be satisfied with the status quo when profits are high, and may seek to stimulate demand through R&D only when profits are low.

In high-profit industries, firms may be unwilling to introduce new products which will cannibalize the markets of existing products which are providing high rates of return. The argument is subject to some qualification. In the absence of other entry barriers, existing firms in the market may engage in product proliferation in order to pack the product space and hence close all niches for potential entrants (Scherer (1978), Schmalensee (1978)). Kamien and Schwartz (1978) have also considered the effect of profits on the level of R&D in the context of an optimal control problem. They conclude that when financing is not an active constraint on the firm, larger current profits retard new product development through their effect on reducing the net gain from innovation. In contrast, if a cash constraint is active then the role of current profits in providing needed cash dominates and incremental current profits hasten new product development. It remains for the empirical work to indicate the direction of the relation between profits and subsequent R&D, and to discern between the competing hypotheses.

Data

A time series of observations of R&D has been prepared for a cross-section of fourteen industries. The industry classifications are those selected by the National Science Foundation (NSF) and are shown in Appendix I. These classifications involve considerable aggregation, but are the most disaggregate data available, if the confidentiality of the data sources is to be maintained. The time series has been prepared by splicing together three separate time series. These are the Bureau of Labor Statistics (BLS) series for 1953-1956, the NSF-Census series for 1957-1975, and the series published by Business Week magazine for 1975-1978.

The data relate only to company-financed R&D. Government-sponsored R&D is excluded. The usual definitional problems must, of course, be addressed. R&D expenditure is broadly defined as expenditure on material research relating to the development of new products or services or the improvement of existing products or services. The NSF data is collected according to a detailed specification of what constitutes R&D (NSF, 1975). The Business Week series is constructed from those expenditures reported to the Securities and Exchange Commission on the SEC's forms 10K and 10Q. The definitions used for the SEC's forms are those set by the Financial Accounting Standards Board (1974). The Business Week series will not correspond to the NSF series in two respects; the first being that the definitions employed by the NSF and FASB are not identical, and the second that the FASB requires reporting of R&D only when it is in excess of one percent of sales revenue. Fortunately, the NSF and Business Week series overlap for the year 1975. On the assumption that the two series measure the same basic variable, the data has been spliced by the following simple proportional fitting

$$R\&D_t = \frac{\text{NSF value R\&D (1975)}}{\text{BW value R\&D (1975)}} \quad \begin{matrix}\text{(BW value R\&D (t))} \\ t = 1976,\ 1977,\ 1978\end{matrix}$$

In the empirical applications which follow, the GNP deflator is used to deflate the R&D series. More specific deflators, such as wages and salaries of engineers and scientists, have not been applied, since one wants to separate out only that part of the inflation due to generalized inflation, and retain that component which is paid to the engineer because of rising labor productivity.

Apparently, the only time series on corporate profits which is available according to industry classification comparable to that used by the NSF is the series on profits as a proportion of stockholders equity published in the Federal Trade Commission's Quarterly Financial Reports. A problem with this variable is that one wants to measure the return on all the capital stock of the company, including the debenture holdings of debt and preferred stock. Stigler (1963) suggests an approach which measured rate of return as profits plus interest as a proportion of shareholder equity plus debt. In the statistical analysis which follows, de-trended data series are employed and a slow trend towards either high or lower levels of leveraging will not produce any serious bias. If, however, the degree of leveraging of entire industries was moving erratically from year to year, then the profit as a proportion of stockholder equity would be an inappropriate measure of profitability. This latter possibility would not seem to be true of the U.S. economy.

Econometric Model

In this section explicit account is taken of the dynamic interactions between R&D and profits. This is achieved by allowing R&D to be a function of lagged profits, and profits to be a function of lagged R&D. As pooled time series cross-section data is being used, it is necessary to take account of the contemporaneous influences across industries. This is achieved by introducing a time specific error component in addition to the usual error component. The variables are defined below.

*Y_{it} - proportion changes in R&D in industry i for period t (defined $(RD_t - RD_{t-1})/RD_{t-1})$);

X_{it} - profits as percent of stockholder equity in industry i for period t ;

$i = 1, 2, \ldots, N$;

$t = 1, 2, \ldots, T$;

N - number of industries in cross-section;

T - number of periods in time series.

Consider the following relationship between the variables

$$(1) \qquad P(L)Y_{it} = Q(L)X_{it} + R(L)(\varepsilon_t + \nu_{it})$$

$$(2) \qquad S(L)X_{it} = T(L)Y_{it} + U(L)(\theta_t + \omega_{it}) \ .$$

Where ε_t and θ_t are the time specific error components which affect all industries simultaneously. It is assumed that:

$[\theta_t]$ are independently and identically distributed $(0, \sigma_\theta^2)$;

$[\varepsilon_t]$ are independently and identically distributed $(0, \sigma_\varepsilon^2)$;

$[\nu_{it}]$ are independently and identically distributed $(0, \sigma_\nu^2)$;

$[\omega_{it}]$ are independently and identically distributed $(0, \sigma_\omega^2)$;

further it is assumed that $[\theta_t]$, $[\varepsilon_t]$, $[\nu_{it}]$, and $[\omega_{it}]$ are all distributed independently of one another. In the estimation stage it will be additionally assumed that these variables follow a Gauss distribution. The terms $P(\cdot)$, $Q(\cdot)$, $R(\cdot)$, $S(\cdot)$, $T(\cdot)$, $U(\cdot)$ are polynomials, in this case in the lag operator L .

Equations (1) and (2) present the model in a structural form, that is, one in which specific interpretation can be given to the parameters of the model. For example, equation (1) indicates that R&D in any period is a function of past R&D with a lag structure given by $P(\cdot)$, and is a function of past profits with a lag structure given by $Q(\cdot)$. Profits are also affected by the lagged effects of various disturbances which are of types both general to the economy and specific to the industry. Now we can also consider the reduced from or moving average representation of these processes which can be obtained by solving equations (1) and (2) in terms of Y_{it} and X_{it} , on the assumption that the appropriate invertibility conditions are satisfied. (See Appendix 2.)

$$(3) \qquad Y_{it} = \frac{\frac{Q(L)}{P(L)}\cdot\frac{U(L)}{S(L)}(\theta_t+\omega_{it}) + \frac{R(L)}{P(L)}(\varepsilon_t+\nu_{it})}{1-\frac{Q(L)}{P(L)}\cdot\frac{T(L)}{S(L)}}$$

$$(4) \qquad X_{it} = \frac{\frac{T(L)}{S(L)}\cdot\frac{R(L)}{P(L)}(\varepsilon_t+\nu_{it}) + \frac{U(L)}{S(L)}(\theta_t+\omega_{it})}{1-\frac{Q(L)}{P(L)}\cdot\frac{T(L)}{S(L)}} .$$

In the reduced form we have, for example in equation (3), that R&D is a lagged function of previous values of R&D and previous values of the disturbances θ_t , ω_{it} , ε_t , ν_{it} . A similar observation may be made for equation (4). Now let us decompose the R&D and profit series into the components which are specific to the industry itself, and the components which are due to the systematic effect of the over-all economy on each industry. Equations (3) and (4) may be rewritten as

$$(5) \qquad Y_{it} = \phi_t + \chi_{it}$$

$$(6) \qquad X_{it} = \psi_t + \xi_{it}$$

where

$$\phi_t = \frac{\frac{Q(L)}{P(L)}\cdot\frac{U(L)}{S(L)}\theta_t + \frac{R(L)}{P(L)}\varepsilon_t}{1 - \frac{Q(L)}{P(L)}\cdot\frac{T(L)}{S(L)}}$$

$$\chi_{it} = \frac{\frac{Q(L)}{P(L)}\cdot\frac{U(L)}{S(L)}\omega_{it} + \frac{R(L)}{P(L)}\nu_{it}}{1 - \frac{Q(L)}{P(L)}\cdot\frac{T(L)}{S(L)}}$$

and similar definitions hold for ψ_t and ξ_{it} .

The decomposition shows that, for this model, R&D and profits are correlated with one another through the systematic influence of the economy at large on each of the individual series (ϕ_t and ψ_t) and through the conditions within a particular industry itself which caused R&D and profits to interact in some specific manner (χ_{it} and ξ_{it}).

Apart from its intuitive value the decomposition given in equations (5) and (6) is extremely useful in the development of an estimation procedure for parameterizing the polynomials $P(\cdot)$, $Q(\cdot)$, $R(\cdot)$, $S(\cdot)$, $T(\cdot)$ and $U(\cdot)$. These issues are discussed in the following section.

Estimation

Maximum likelihood procedures are developed in this section for the estimation of equations (1) and (2) making use of the reduced form decomposition given in equations (5) and (6).

Since maximum likelihood procedures are being employed the usual assumption of normality of the disturbance terms is envoked. Let

$$Y = \begin{bmatrix} Y_{11} \\ \vdots \\ Y_{1T} \\ Y_{21} \\ \vdots \\ Y_{NT} \end{bmatrix}, \quad X = \begin{bmatrix} X_{11} \\ \vdots \\ X_{1T} \\ X_{21} \\ \vdots \\ X_{NT} \end{bmatrix}$$

and let

$$\mathrm{Var}(\phi) = \Omega_{\phi\phi}$$

$$\mathrm{Cov}(\phi\psi) = \Omega_{\phi\psi}$$

and in a similar fashion define $\Omega_{\chi\chi}$, $\Omega_{\xi\xi}$, $\Omega_{\psi\psi}$, and $\Omega_{\xi\chi}$. Now the distribution of the observed R&D and profit series may be written

$$\begin{bmatrix} X \\ Y \end{bmatrix} \sim N(0,\Omega)$$

where

$$\Omega = \begin{bmatrix} I_N \otimes \Omega_{\chi\chi} + e_N e_N' \otimes \Omega_{\phi} & I_N \otimes \Omega_{\chi\xi} + e_N e_N' \otimes \Omega_{\phi\psi} \\ I_N \otimes \Omega_{\xi\chi} + e_N e_N' \otimes \Omega_{\xi\phi} & I_N \otimes \Omega_{\xi\xi} + e_N e_N' \otimes \Omega_{\psi\psi} \end{bmatrix}$$

where e_N is an $(N \times 1)$ vector of units.

Since the joint density function of $[Y \quad X]$ is now known it is possible to proceed to estimate the parameters of the model by maximizing the likelihood function

$$\mathcal{L}(P, Q, R, S, T, U, \sigma_{\varepsilon}, \sigma_{\theta}, \sigma_{\nu}, \sigma_{\omega})$$

$$\propto |\Omega|^{-1/2} \exp\left\{-\frac{1}{2}[Y' \quad X'] \; ^{-1}\begin{bmatrix} Y \\ X \end{bmatrix}\right\} .$$

In this form however the variance covariance matrix is very complicated. It is necessary to consider the decomposed expression in equations (5) and (6), from the the auto-covariance generating functions for $[\theta_t]$, $[\psi_t]$, $[\chi_{it}]$, and $[\xi_{it}]$ and then proceed to identify their auto-covariances. When moderately complex lag structures are involved this is a particularly burdensome task. Furthermore, even after taking account of the regularity of Ω it would be at least necessary to invert a $(T \times T)$ matrix each time Ω^{-1} is to be evaluated. In maximum likelihood search procedures for large T this may become prohibitively expensive.

It is proposed to use a spectral analytic method introduced by Hannan (1969) to simplify the variance-covariance matrix. Following Hannan define a matrix G

$$G = \begin{bmatrix} g_0 \\ g_1 \\ \vdots \\ g_{T-1} \end{bmatrix}$$

where

$$g_j = \frac{1}{\sqrt{T}}[1e^{i2\pi\frac{j}{T}} e^{i2\pi\frac{2j}{T}} \dots e^{i2\pi\frac{(T-1)j}{T}}]$$

and

G^* as the transpose of the complex conjugate of G .

$GG^* = I_T$.

Consider now a transformation of Y and X of the form

$$(8) \qquad Z_1 = \begin{bmatrix} I_N \otimes G & 0 \\ 0 & I_N \otimes G \end{bmatrix} \begin{bmatrix} Y \\ X \end{bmatrix} .$$

The variance-covariance matrix of the transformed variable Z_1 , denoted Γ_1 may now be written,

$$(9a) \qquad \Gamma_1 = 2\pi \begin{bmatrix} I_N \otimes G\,\Omega_{\chi\chi}G^* + e_N e_N' \otimes G\Omega_{\phi\phi}G^* & I_N \otimes G\Omega_{\chi\xi}G^* + e_N e_N' \otimes G\Omega_{\phi\psi}G^* \\ I_N \otimes G\Omega_{\xi\chi}G^* + e_N e_N' \otimes G\Omega_{\psi\phi}G^* & I_N \otimes G\Omega_{\xi\xi}G^* + e_N e_N' \otimes G\Omega_{\psi\psi}G^* \end{bmatrix} .$$

This variance-covariance matrix may be rewritten,

$$(9b) \qquad \Gamma_1 = 2\pi \begin{bmatrix} I_N \otimes \Gamma_{\chi\chi} + e_N e_N' \otimes \Gamma_{\phi\phi} & I_N \otimes \Gamma_{\chi\xi} + e_N e_N' \otimes \Gamma_{\phi\psi} \\ I_N \otimes \Gamma_{\xi\chi} + e_N e_N' \otimes \Gamma_{\psi\phi} & I_N \otimes \Gamma_{\xi\xi} + e_N e_N' \otimes \Gamma_{\psi\psi} \end{bmatrix} .$$

For T large, $\Gamma_{\chi\chi}$, $\Gamma_{\phi\phi}$, $\Gamma_{\xi\chi}$, $\Gamma_{\psi\phi}$, $\Gamma_{\xi\xi}$, and $\Gamma_{\psi\psi}$ are approximately diagonal. To illustrate with general notation (α,β) for the subscripts, let

$$
(10) \qquad \Gamma_{\alpha\beta} = \begin{bmatrix}
f_{\alpha\beta}(\lambda_1) & & & & & & & \\
& \ddots & & & & & \bigcirc & \\
& & f_{\alpha\beta}(\lambda_2) & & & & & \\
& & & \ddots & & & & \\
& & & & f_{\alpha\beta}(\lambda_m) & & & \\
& & & & & \ddots & & \\
& & & & & & f_{\alpha\beta}(\lambda_1) & \\
& \bigcirc & & & & & \ddots & \\
& & & & & & & f_{\alpha\beta}(\lambda_m)
\end{bmatrix}
$$

(the $f_{\alpha\beta}(\lambda_0)$ has been dropped for convenience of notation; when the data is in the form of deviations from the mean, this term is zero). For T odd

$$M = \left[\frac{T-1}{2}\right]$$

$$\lambda_k = \frac{2\pi k}{T}$$

and $f_{\alpha\alpha}$ and $f_{\alpha\beta}$ are the spectral and cross-spectral density functions respectively. To illustrate further consider the series $\{\alpha_t\}$ and $\{\beta_t\}$ as ARMA processes defined below, where $A(\cdot)$ and $B(\cdot)$ are rational polynomials.

$$\alpha_t = A(L)\eta_t$$

$$\beta_t = B(L)\eta_t \ .$$

Then

(11a) $$f_{\alpha\alpha}(\lambda) = \frac{\sigma_\eta^2}{\pi} A(e^{i\lambda})A(e^{-i\lambda})$$

(11b) $$f_{\alpha\beta}(\lambda) = \frac{\sigma_\eta^2}{2\pi} A(e^{-i\lambda})B(e^{i\lambda}) \ .$$

The spectral density functions $f(\cdot)$ evaluated at some frequency λ can be interpreted as the amount of the variance in the time series which can be explained by a wave of frequency λ .

Due to the regular form of Γ_1 , an additional set of transformations can be identified which will block diagonalize the variance covariance matrix, and leave it entirely in terms of real variables. To do this a number of matrices are defined below. Let

(12) $$R = \frac{1}{\sqrt{2}}\left[I_M \otimes \begin{bmatrix} 1 \\ i \end{bmatrix} : J_M \otimes \begin{bmatrix} 1 \\ -i \end{bmatrix} \right]$$

Where J_M is an M-dimensional matrix with units on the non-principal diagonal and zeros elsewhere, and i is the imaginary number. Let

(13) $$H_1 = \left[I_M \otimes \begin{bmatrix} I_2 \\ 0_2 \\ \vdots \\ 0_2 \end{bmatrix}_{2N\times 2} : I_M \otimes \begin{bmatrix} 0_2 \\ I_2 \\ \vdots \\ 0_2 \end{bmatrix}_{2N\times 2} : \dots : I_M \otimes \begin{bmatrix} 0_2 \\ 0_2 \\ \vdots \\ I_2 \end{bmatrix}_{2N\times 2} \right]$$

and let

(14) $$H_2 = \left[I_M \otimes \begin{bmatrix} I_{2N} \\ 0_{2N} \end{bmatrix} : I_M \otimes \begin{bmatrix} 0_{2N} \\ I_{2N} \end{bmatrix} \right] .$$

The effects of the above matrices when used to transform Z, will be as follows. R rotates the variables so that only real variables will appear as elements in the variance covariance matrix. H_1 and H_2 will be used to collect the elements in Z_1 according to the frequency of the wave associated with the transformation which produced that element. Now define

$$(15) \qquad Z_2 = H_2 \cdot \begin{bmatrix} H_1 & 0 \\ 0 & H_1 \end{bmatrix} \cdot \begin{bmatrix} I_N \otimes R & 0 \\ 0 & I_N \otimes R \end{bmatrix} \cdot Z_1 \ .$$

Since the transformations in equations (8) and (15) are linear transformations it follows that the normality of the transformed variables is preserved, so that

$$Z_2 \sim N(0, \Gamma_2) \ .$$

The variance-covariance matrix of the newly transformed variables Z_2 is block diagonal as shown below

$$\Gamma_2 = \begin{bmatrix} \begin{bmatrix} \gamma_{11}(\lambda_1) & \gamma_{12}(\lambda_1) \\ \gamma_{21}(\lambda_1) & \gamma_{22}(\lambda_1) \end{bmatrix}_{4N\cdot 4N} & & \bigcirc \\ & \ddots & \\ \bigcirc & & \begin{bmatrix} \gamma_{11}(\lambda_m) & \gamma_{12}(\lambda_m) \\ \gamma_{21}(\lambda_m) & \gamma_{22}(\lambda_m) \end{bmatrix}_{4N\cdot 4N} \end{bmatrix}$$

Where

$$\gamma_{11}(\lambda) = I_N \otimes \begin{bmatrix} f_{\chi\chi}(\lambda) & 0 \\ 0 & f_{\chi\chi}(\lambda) \end{bmatrix} e_N e_N' \otimes \begin{bmatrix} f_{\phi\phi}(\lambda) & 0 \\ 0 & f_{\phi\phi}(\ ) \end{bmatrix}$$

$$\gamma_{22}(\lambda) = I_N \otimes \begin{bmatrix} f_{\xi\xi}(\lambda) & 0 \\ 0 & f_{\xi\xi}(\lambda) \end{bmatrix} e_N e_N' \otimes \begin{bmatrix} f_{\psi\psi}(\lambda) & 0 \\ 0 & f_{\psi\psi}(\lambda) \end{bmatrix}$$

$$\gamma_{21}(\lambda) = I_N \otimes \begin{bmatrix} c_{\xi\chi}(\lambda) & q_{\xi\chi}(\lambda) \\ q_{\xi\chi}(\lambda) & c_{\xi\chi}(\lambda) \end{bmatrix} e_N e_N' \otimes \begin{bmatrix} c_{\psi\phi}(\lambda) & q_{\psi\phi}(\lambda) \\ q_{\psi\phi}(\lambda) & c_{\psi\phi}(\lambda) \end{bmatrix}$$

$$\gamma_{12}(\lambda) = I_N \otimes \begin{bmatrix} c_{\chi\xi}(\lambda) & q_{\chi\xi}(\lambda) \\ q_{\chi\xi}(\lambda) & c_{\chi\xi}(\lambda) \end{bmatrix} e_N e_N' \otimes \begin{bmatrix} c_{\phi\phi}(\lambda) & q_{\phi\psi}(\lambda) \\ q_{\phi\phi}(\lambda) & c_{\phi\psi}(\lambda) \end{bmatrix}$$

The terms $c(\cdot)$ and $q(\cdot)$ are defined as cross-spectrum and quadrative and are respectively associated with the real and imaginary components of the cross-spectral density function, so that, to illustrate

$$f_{\chi\xi}(\lambda) = c_{\chi\xi}(\lambda) - iq_{\chi\xi}(\lambda)$$

$$f_{\xi\chi}(\lambda) = c_{\xi\chi}(\lambda) - iq_{\xi\chi}(\lambda)$$

and it is readily shown that

$$c_{\chi\xi}(\lambda) = c_{\xi\chi}(\lambda)$$

$$q_{\chi\xi}(\lambda) = -q_{\xi\chi}(\lambda) \ .$$

The $\gamma_{ij}(\cdot)$'s are of a regular form

$$I_N \otimes A + e_N e_N' \otimes B$$

and their inverses can be readily identified to be

$$I_N \times A^{-1} + e_N e_N' \times (-1)\cdot(A + NB)^{-1} C^{-1} B \ .$$

Making use of partitioning of the block diagonal elements of Γ_2 and the straightforward form of the inverse of the $\gamma_{ij}(\cdot)$'s the task of inverting the variance-covariance matrix can be reduced to that of performing T inverses of (2×2) matrices.

The likelihood function may now be written

$$\mathcal{L}(P, Q, R, S, T, U, \sigma_\varepsilon, \sigma_\nu, \sigma_\theta, \sigma_\omega) \tag{16}$$
$$\propto |\Gamma_2|^{-1/2} \exp\left\{-\frac{1}{2} Z_2' \cdot \Gamma_2^{-1} \cdot Z_2\right\} \ .$$

It is this form of the likelihood function which is employed in the empirical results presented below.

Empirical Results

The model most successfully fitted to the data is reported below in equations (17) and (18).† The estimated model was obtained from an initial model which included x_{it}, x_{it-1}, x_{it-2} on the right hand side of equation (17) and y_{it-2}, y_{it-3}, y_{it-4}, y_{it-5}, y_{it-6} on the left hand side of equation (18). The model was fitted repeatedly to the data and on each occasion dropping the least significant of the estimated parameters. These equations are of the form of equations (1) and (2) where again Y is the R&D variable and X is the profit variable, expressed in terms of deviations from industry means.

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†Standard errors are given in brackets. These are asymptotic approximations which rely on T, the number of time period being large. Since data is only available for $T = 25$ years these standard errors should be interpreted appropriately.

(17) $$Y_{it} = \underset{(0.18)}{-0.48}X_{it} + \varepsilon_t + \nu_{it} - \underset{(0.16)}{0.58}(\varepsilon_{t-1} + \nu_{it-1})$$

(18) $$X_{it} = \underset{(0.21)}{0.74}Y_{it-3} + \underset{(0.56)}{1.96}Y_{it-4} + \theta_t + \omega_t - \underset{(0.09)}{0.56}(\theta_{t-1} + \omega_{it-1}) .$$

The result that profits have a negative impact on R&D is consistent with three possible hypotheses introduced in Section 2 of this paper. It is possible, as Kamien and Schwartz (1978) suggest in their theoretical model, that high profits make it relatively unattractive to cannibalize existing product markets which are already yielding high rates of return. This result should not be taken as a contradiction of the Scherer (1978), Schmalensee (1978) hypotheses on the packing of product space. The present paper is primarily concerned with short-run dynamics and although firms may be engaged in a long run systematic research program to create a patent portfolio necessary to pre-empt entrants, the short-run attractiveness of such a policy may vary during the trade cycle. Second, years of high profits may also be associated with strong product demand and this market growth may create pressures for expansion of production facilities. Available funds may then be diverted to high priority investment in physical capital and away from R&D.

Third, there is the hypothesis that in time of high profits business management becomes lax and satisfied with the status quo. In this environment, management is unwilling to seek new products which will stimulate demand. While this is a familiar hypothesis it is not well tested by the present data set. Since the model is concerned only with the effects of profits lagged one period on R&D we are definitely in the world of short-run. Managerial lassitude would then have to set-in very rapidly for a rise in profits in the preceding period to cause the firm to drastically cut back its R&D effort. It should also be noted that this effect may be asymmetric. The negative coefficient on the profit variable suggests that in cases of falling profits firms actively undertake R&D to stimulate growth in the market. To discern between these two effects, one needs, in principle, two equations--one to explain the movements in R&D when profits are rising and one to explain movements in R&D when profits are falling.

In terms of the lagged effect of R&D on profit, it appears that very few effects are felt for the first two years and that the first returns to the R&D are perceived in the third year. In the fourth year there are considerably returns, but in the fifth year the returns are negligible. Higher order lag terms were not found to be statistically significant. This result is surprising, as it was not expected that the returns to R&D would have tapered off so quickly. In cases where inventions can be adequately protected by patents, it might be expected that profits from R&D would persist; however, it is unlikely that patentable (and protectable) inventions cover more than a moderately small amount of information and knowledge generated by R&D. It seems more likely that the general case will be that of a firm in an industry introducing a new product or process and other firms then hurrying to imitate or surpass the initial inventor or entrant (Scherer (1967)). In such an environment, a firm introducing a new product can only expect to make super-normal profits in the period between when the product is introduced and the time at which rivals bring their imitations onto the market.

Conclusion

This paper represents a first attempt at examining the dynamic interactions between industry profits and R&D. The results are somewhat tentative and further testing of alternative specifications will be necessary. The results are, however, broadly consistent with a considerable section of the theoretical literature, and this is indeed an encouraging finding. The econometric methodology introduced to study this problem is new and it allows a far larger body of data to be applied to the problem than was previously possible. The econometric methodology would seem to be of independent general interest to researchers concerned with using cross-sectional data to improve the efficiency of estimators derived from time series models.

APPENDIX I

Industry Group	SIC Code
Food and Kindred Products	20
Chemicals and Allied Products	28
Petroleum Refining and Extraction	29, 13
Rubber Products	30
Stone Clay and Glass Products	32
Ferrous Metals and Products	331-32, 3391, 3399
Non-Ferrous Metals and Prodcuts	333-36, 3392
Fabricated Metal Products	34
Machinery	35
Electrical Equipment and Communications	36, 48
Motor Vehicle and Motor Vehicle Equipment and Other Transport Equipment	371, 373-75, 379
Aircraft and Missiles	312, 19
Professional and Scientific Instruments	38
Non-Manufacturing Industries	07-12, 14-17, 41-47, 49-67, 739, 807, 891

APPENDIX 2

The formulation used in equations (1) and (2) was selected to facilitate exposition of the economics content of the discussion. Alternative representations of the same process can yield more useful insights into other questions. Consider rewriting equations (1) and (2) in the following form.

$$\sum_{j=0}^{\Delta_P} P_j L^j Y_{it} = \sum_{j=0}^{\Delta_2} q_j L^j X_{it} + \sum_{j=0}^{\Delta_R} r_j h^j (\varepsilon_t + \nu_{it})$$

$$\sum_{j=0}^{\Delta_s} s_j L^j X_{it} = \sum_{j=0}^{\Delta_T} t_j L^j Y_{it} + \sum_{j=0}^{\Delta_U} u_j L^j (\theta_t + W_{it}) .$$

Where Δ^* is the order of the relevant polynomial. These equations can be rewritten

$$\sum_{j=0}^{\eta} B(j) \cdot L^j W_{it} = \sum_{j=0}^{m} A(j) \cdot L^j e_{it}$$

where

$$W_{it} = \begin{bmatrix} Y_{it} \\ X_{it} \end{bmatrix} \quad \text{and} \quad e_{it} = \begin{bmatrix} \varepsilon_t + \nu_{it} \\ \theta_t + W_{it} \end{bmatrix}$$

$$B(j) = \begin{bmatrix} P_j & -q_j \\ -t_j & s_j \end{bmatrix} \quad \text{and} \quad A(j) = \begin{bmatrix} r_j & 0 \\ 0 & u_j \end{bmatrix}$$

$$\eta = \text{Max}\{\Delta_p, \Delta_q, \Delta_s, \Delta_T\}$$

$$M = \text{Max}\{\Delta_R, \Delta_U\} .$$

Define

$$H_{(z)} = \sum_{j=0}^{n} B(j) z^j$$

$$J_{(z)} = \sum_{j=0}^{m} A(j) z^j$$

then equations (1) and (2) can be written in matrix form as

$$H(L) \cdot W_{it} = J(L) \cdot e_{it} \ .$$

Collecting cross-sectional observations, write

$$W_t = \begin{bmatrix} W_{it} \\ W_{2t} \\ \vdots \\ W_{Nt} \end{bmatrix}, \quad e_t = \begin{bmatrix} e_{it} \\ e_{2t} \\ \vdots \\ e_{Nt} \end{bmatrix}$$

the entire process may be written

$$(I_N \otimes H(L)) \cdot W_t = (I_N \otimes J(L)) \cdot e_t \ .$$

The condition for the invertibility of this process, required to write the system in the form or equations (3) and (4) in the main text, is that the determinant $|I_N \otimes H_{(z)}|$ has all its roots outside the unit circle. This condition is satisfied when the determinant $|H_{(z)}|$ has all its roots outside the unit circle.

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