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AN EXTENDED ACCELERATOR MODEL OF R&D AND PHYSICAL INVESTMENT

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ABSTRACT

Using a multivariate autoregressive framework, we have found a simple causal structure for the variables of interest q, s, r, and i, which is consistent with our data. As expected from the stock market efficiency hypothesis, q, the stock market one period holding rate of return, is exogenous relative to the other three variables (or Granger causes them). As postulated in the traditional accelerator model of investment, the rate of growth of sales, s, can be also treated as exogenous to the rates of growth of R&D and physical investment, r and i. Moreover, no strong feedback interaction is detected between the last two (r and i).

Within the simple structure of the extended accelerator model, the substantive conclusion is that R&D and physical investment react very similarly to the growth of the sales and to movements in q; the response of R&D is, however, more stable or less irregular than that of physical investment. Expected demand and expected profitability thus both appear to be important determinants for R&D expenditures and physical investment.

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I. INTRODUCTION

The purpose of the present study is to investigate the determinants of both R-D and physical investment using a panel of firm data. In a standard neoclassical model of investment, the firm is assumed to choose an investment plan so as to maximize the present discounted value of net cash flows subject to the production technology, cost of adjustment function, initial capital stocks and other appropriate constraints (or else to minimize the present discounted total cost of production subject to the same constraints and an expected production plan). In full generality, this involves considering non linear stochastic control problems, and explicit solutions of the first order conditions are intractable without very restrictive assumptions. Assumptions such as static expectations about prices, a simple form of the production function, the absence of an explicit cost of adjustment function and the imposition of a given lag structure are usually made in order to derive the specification of the investment function.

In view of the complexities of a formal modelling of investment decisions, and also because of a lack of data on factor prices at the firm level, we have to settle for a looser approach in the spirit of data analysis as advocated by Sims (1972, 1977, 1980; Sargent and Sims, 1977). A priori, expected demand and profitability are important determinants for investment decisions. Both are unobservable. Following Pakes (this volume), we propose to use the stock market one period holding rate of return, q, as an indicator of changes in expectation about the firm's future profitability. For expected demand, we have used a more traditional distributed lag formulation in the rate of growth of sales s. These two variables plus the rates of growth of R-D and physical investment, r and i, are embedded in a multivariate autoregressive model. We perform a series of exogeneity tests to investigate the appropriateness of restricted versions of this general model which are of interest. In particular, we vindicate an extended form of the traditional accelerator model: extended both because it applied to R-D as well as to physical investment, and because it takes expected profitability, and not only demand, as a major explanatory factor. Considerations on our model specification are developed in Section II, while our results are presented in Section III. We end with a few remarks.

II. MODEL SPECIFICATION: STATISTICAL AND ECONOMIC CONSIDERATIONS

We start from what we call our general model and derive our extended accelerator model, discussing the meaning and specification of each equation in turn.

1. A general model - First of all let us denote the four variables which our study concentrates on by q_{nt}, s_{nt}, r_{nt}, and i_{nt}, where n and t represent firm and year subscripts (n = 1 to N, t = 1 to T) respectively. To simplify matters we shall suppress the firm subscript n in general and when convenient we shall also represent by $\underset{\sim}{y}_{nt}$ or $\underset{\sim}{y}_t$ the column vector of our four variables, i.e. $\underset{\sim}{y}_t = (q_t, s_t, r_t, i_t)'$.

q_t is the stock market one period holding rate of return and is defined as $q_t = (p_t - p_{t-1} + d_t)/p_t$, where p_t is the price of a share at the end of year t, and d_t is the dividend per share paid during this year. q_t is thus equal to the rate of change of the value of a one dollar share over the year plus the corresponding dividend. s_t, r_t and i_t denote the first difference between year t and year (t-1) of the logarithms of sales, R-D expenditures and gross investments respectively, and are thus approximately equal to their rate of change from year to year: $s_t = \mathrm{Log}\,(S_t/S_{t-1})$, $r_t = \mathrm{Log}(R_t/R_{t-1})$, $i_t = \mathrm{Log}\,(I_t/I_{t-1})$.[1]

Given our focus on these four variables, we are interested in investigating thoroughly their mutual dynamic interrelationships. Without pretending too much a priori knowledge about these interrelations we start by assuming that they can be represented by an autoregressive model:

$$(1)\quad \underset{\sim}{y}_t = A(L)\underset{\sim}{y}_{t-1} + \underset{\sim}{\lambda}_t + \underset{\sim}{\eta}_t$$

where $A(L)$ is a matrix of polynomials in the lag operator (L), $\underset{\sim}{\lambda}_t$ is a vector of time specific effects or year dummies, and $\underset{\sim}{\eta}_t$ is a vector of disturbances assumed to be normally distributed, uncorrelated over time but correlated across equations: η_t i.i.d. $N(0, \Sigma)$. η_t is also called the vector of "innovations" in the variables. We can write (1) more simply as:

$$(1') \qquad \underset{\sim}{y}_t = A(L)\, \underset{\sim}{y}_{t-1} + \underset{\sim}{\eta}_t$$

if we take care of the year effects $\underset{\sim}{\lambda}_t$ by measuring our variables relative to their year means, as we shall assume from now on.[2]

With an adequate number of lags, the autoregressive model is flexible enough to account well for the correlation structure of our variables and simulate their dynamic behavior. From a pure statistical standpoint, equivalent formulations can be obtained by multiplying both sides of (1') by any non singular (four by four) matrix B_0. Among them, recursive formulations may be of practical interest: especially one that corresponds to the causal ordering we are going to hypothesize between our variables: i.e. causality running from q to s, and from both q and s to r and i. This particular recursive formulation can be written as:

$$(1'') \qquad B_0\, \underset{\sim}{y}_t = B(L)\, \underset{\sim}{y}_{t-1} + \underset{\sim}{\zeta}_t$$

where $B(L) = B_0\, A(L)$ and $\underset{\sim}{\zeta}_t = B_0\, \underset{\sim}{\eta}_t$, B_0 being a triangular matrix with 0 above the diagonal and 1 in the diagonal and such that the transformed disturbances ζ_{jt} are orthogonal (i.e. uncorrelated across equations). B_0 is in fact uniquely determined; its inverse B^{-1} has the exact same lower triangular form with 1 on the diagonal and can be obtained from the appropriate Cholewski decomposition of the original variance covariance matrix σ. This can be written as $\underset{\sim}{\eta}_t = B^{-1} \underset{\sim}{\zeta}_t$, and amounts, in practice, to successive projections of the original disturbances η_{jt} which transform them into ζ_{jt}'s:

$$\eta_{1t} = \zeta_{1t}; \; \eta_{2t} = a \; \zeta_{1t} + \zeta_{2t}; \; \ldots \; .$$

Among the many statistically equivalent formulations, we endeavor to give a specific structural economic meaning to the pure autoregressive form (1), and we refer to it, therefore, as our general model. All four equations of the general model (q, s, r and i) can be interpreted and motivated by more or less precise economic considerations, and we can test whether the restrictions suggested by such considerations are compatible with our data.

2. Interpretation and Motivation

We can justify our i-equation as an investment demand equation, referring directly to Malinvaud's recent book on unemployment and profitability (1980; see also 1981). In this book, Malinvaud studies the implications of an investment model in which net investment depends on expected capacity need and expected profitability. While the influence of capacity needs corresponds to the well known accelerator phenomenon and is supported by the bulk of the vast number of econometric studies of investment, he stresses the importance of profitability as another major determinant. If we assume the investment equation to be log-linear and take first differences we get:

$$i^*_t = \phi \, q^e_{t-1} + \gamma \; s^e_{t-1}$$

where $i^*_t = \mathrm{Log}(NI_t/NI_{t-1})$ is the log change in desired net investment between periods (t-1) and t, $s^e_{t-1} = \mathrm{Log}(S^t_{t-1}/S^{t-1}_{t-2})$ and $q^e_{t-1} = \mathrm{Log}(Q^t_{t-1}/Q^{t-1}_{t-2})$ are the log changes or revisions of capacity need and profitability between these same periods and as expected one period before.

The revision in the expected profitability q^e_{t-1} is presumably due to new information about the future which become available between (t-2) and (t-1). Such revisions should have direct bearing on the movements of stock prices during the same period, and hence will be reflected in the lagged values q_{t-2} and q_{t-1} of our stock market holding rate of return variable. We will interpret, therefore, q_{t-1} and q_{t-2} as reasonable indicators of the unobservable q^e_{t-1} in the investment equation.[3]

In the absence of any direct information on expectations about capacity, the usual and simple procedure in most econometric studies is to treat them as a function of past levels of output or sales. We can take, likewise, the revision in the expected capacity need s^e_{t-1} as a distributed lag function of past changes in sales $s_{t-\tau}$, justifying thereby why lagged values $s_{t-\tau}$ should appear in the investment equation. More generally we can consider s^e_{t-1} as a forecast function depending not only on the past $s_{t-\tau}$, but also on the past values of other relevant variables. Assuming rational expectations, the actual change in sales s_t should be itself an unbiased "forecast" of the expected s^e_{t-1} conditional on all the information available in period (t-1), and s^e_{t-1} should only differ from s_t by an uncorrelated forecast error. In particular, one would think that q_{t-1}, being a forward looking variable, has a predictive value for both s^e_{t-1} and s_t, and will, therefore, enter significantly in the forecast function even in the presence of lagged $s_{t-\tau}$ terms. Thus, one should find that q_{t-1} influences investment both directly and indirectly, via its effect on expected sales.

Finally, the change in the desired net investment variable i_t^* itself is also unobservable, and its relationship with the actual change in gross investment must be specified. The various kinds of delays occuring between the decision and the execution of investment plans, as well as an approximate proportionality of retirements to past investments, suggest reasons why lagged investment terms should also appear in the investment equation.

In sum, starting from Malinvaud's theoretical equation and taking into account all the necessary transformations for its empirical implementation, we get to an equation which is very close to the investment equation of our general model. Clearly, such a tentative and informal derivation involves many problematic assumptions and issues. Be that as it may, our investment equation consists of two main factors: scale and intensity, as indicated by sales and stock market profitability respectively, and allows for a quite flexible lag structure. The standard objection one could raise is that more explanatory variables should have been included, mainly the relative cost of labor and capital and the financial liquidity of the firm. It is difficult though to get relevant information about factor prices at the firm level; it is also plausible that they tend to move roughly parallel for all firms, and that will be taken care of by the year dummies in the equation. As for financial liquidity of the firm, it could be gauged by the importance of past profits, and it may be worthwhile to consider this possibility in further research.

The r equation can be justified along the same lines as the i equation and interpreted in terms of an R-D demand equation. One of our basic topics of interest is to assess whether R-D and physical investment behave more or less similarly.

From what we have already said the s or sales equation can be understood as a forecast function purporting to account for the expectations of firms about their future sales. It seems plausible, however, that these expectations might also depend on other variables besides the ones already included in the equation.

The q or stock market holding rate of return equation has little economic justification. For the sake of symmetry with the s-equation it could be viewed also as a forecast function of expectations on q_t. However, it is usually admitted that q_t cannot be predicted by its own past values or that of any other variable. This property is known as Fama's semi-strong test of stock market efficiency (Fama 1970, 1976). Conditional on the information available at the beginning of period t, the expected value of q_t should, by standard arbitrage argument, equal the prevailing market rate of interest. In other words, a trading rule based on public information alone would not allow traders to achieve any excess return on average.

3. <u>An extended accelerator model</u> - The considerations we have just developed suggest a causal ordering of the variables and specific restrictions on the equations.

We have touched on the issue of stock market efficiency. The hypothesis of stock market efficiency simplifies our general model importantly, the q-equation reducing itself to $q_t = \eta_{1t}$ $(= \zeta_{1t})$. In other words, q is exogenous relatively to the other variables or s, r and i do not cause q in the sense of Granger (Pierce and Haugh, 1977 and 1979; Granger, 1980). Such a hypothesis has been generally accepted in empirical work, but rather than taking it for granted, it seems better to test it also on our data.[4]

Our central interest, however, is in the appropriateness of the traditional formulation of the accelerator model. This formulation postulates that sales or expected sales are exogenous relative to investment, thus ruling out feed-back effects from investment to sales. This is a major assumption since without it, not only the usual estimates of the so-called accelerator effect might be biased, but the whole notion itself might not be very meaningful. Within our general model, the accelerator assumption requires that i, as well as r by analogy, does not appear in the s-equation and is directly testable. Besides the questions of stock market efficiency and appropriateness of the accelerator assumption, we have also considered two other issues of lesser significance. The first concerns the interrelations of physical and R-D investment. There seems to be no reason why physical investment should influence R-D investment per se. One might expect, however, that the converse would not be true. A successful R-D program would lead to product or process innovations, which could result in turn in new programs of investment. There is, however, little evidence in our data of such a causal ordering from R-D to investment. While we do not find any significant influence of past i on r, the influence of past r on i is not significant either, and at best appears to be rather weak.

The second issue relates to the existence of contemporaneous reciprocal influences, or "instantaneous causality", between our variables. In our general model (1), this amounts to testing the diagonality of the variance-covariance matrix Σ (i.e. no correlation across equations among the disturbances η_{jt}), while in the transformed recursive formulation (1"), it becomes the test of the restriction that the contemporaneous value of a variable does not enter as a regressor (i.e. B_0 is an identity matrix or else $\eta_{jt} = \zeta_{jt}$). A year being a long enough period for interactions between variables to develop, one would expect instantaneous causality to occur and hence the diagonality restriction to be strongly rejected. This is indeed what happens. Another explanation why the disturbances in our model may be correlated across equations is of course the omission of relevant (common or correlated) variables. One would thus expect the disturbances in the investment and R-D equations (η_{3t} and η_{4t}) to be correlated with each other, and also with the disturbance in the sales equation (η_{2t}). Indeed, this last disturbance can proxy for variables influencing sales expectations but actually omitted from our forecast equation; as such it should enter in both the investment and the R-D equation, accounting partly for the correlation of their disturbances. The structure of the disturbances and their correlations is clearly revealed by the appropriate Cholewski decomposition $\underset{\sim}{\eta}_t = B^{-1} \underset{\sim}{\zeta}_t$, as previously indicated.

We can focus our interest primarily on two restricted versions of the general model: the first one assuming only stock market efficiency, and the second one assuming also the appropriateness of the accelerator formulation. We call the latter restricted model the accelerator model or the <u>extended accelerator model</u> since it extends the traditional investment accelerator to research and development expenditures, and also because it tries, through the use of the q variable, to incorporate expected profitability as an important determinant of investment and R-D. Since interactions between investment and R-D do not appear to be significant, we generally consider the extended accelerator model without them - but this need not be so in principle.

4. Moving average representation and multipliers

Changing slightly our notation but still measuring variables relatively to their year means, the extended accelerator model can be written:

$$
(2)\qquad
\begin{aligned}
q_t &= \eta_{1t} \\
s_t &= \beta(L)\, q_{t-1} + \alpha(L)\, s_{t-1} + \eta_{2t} \\
r_t &= \phi(L)\, q_{t-1} + \gamma(L)\, s_{t-1} + \theta(L)\, r_{t-1} + \eta_{3t} \\
i_t &= \psi(L)\, q_{t-1} + \delta(L)\, s_{t-1} + \mu(L)\, i_{t-1} + \eta_{4t}
\end{aligned}
$$

where the η_{jt} are mutually correlated across equations (but uncorrelated over time). The causal structure of the model is simple and can be illustrated by the path diagram in figure 1. Changes in q induce variations in s, r and i and changes in s move r and i, but there is no feed-back from r and i to s, and from s to q; there is also no interaction between r and i. As we already stated, in view of this specific structure, there is one appropriate and economically meaningful decomposition of the correlated $\underset{\sim}{\eta}_t$ in terms of uncorrelated $\underset{\sim}{\zeta}_t$. Renaming these ε_t, u_t, v_t and w_t (instead of ζ_{jt}), we can write

$$
(2')\qquad
\begin{aligned}
\eta_{1t} &= \varepsilon_t \\
\eta_{2t} &= a\,\varepsilon_t + u_t \\
\eta_{3t} &= b\,\varepsilon_t + cu_t + v_t \\
\eta_{4t} &= d\,\varepsilon_t + eu_t + fv_t + w_t
\end{aligned}
$$

In this form the independent errors ε_t, u_t, v_t and w_t are intrinsically related to the different equations of the accelerator model. They can be regarded as the exogenous and unobservable (or unobserved) basic factors of our model accounting for the evolution of our observed variables. A change or "shock" in

ε_t, or an innovation in q_t, can thus be interpreted as a shift in the firm's future profitability as expected by the traders on the stock market. We shall call such a shock an expected profitability shock, or q-shock, and the dynamic responses of our variables to it the q-effects or q-multipliers. Similarly, a change or a "shock" in u_t, or an independent innovation in s_t, can be viewed as a shift in the expectation of the rate of growth of sales, and we shall speak of a demand-shock, or s-shock, and of the s-effects on s-multipliers. It is of some interest to separate in the (total) q or s-effects the own effects and the additional or cross-effects. The own effects are computed in the absence of instantaneous causality (i.e. a=b=c=d=e=f=0 or $\underset{\sim}{\eta}_t = \underset{\sim}{\zeta}_t$); they result directly from the initial change in q_t or s_t corresponding to a shock in ε_t or u_t, as if there was no other immediate impact of such shocks.[5]

In order to illustrate the q and s-multipliers and how a shock in ε or u actually affects the movements of our variables, we can consider a simplified version of the accelerator model in which we keep only one lagged variable (i.e. a first order autoregressive model), ignore the correlations of the disturbances across equations (i.e. Σ is diagonal) and drop the i-equation (since i and r behave in the same way). It is enough to consider:

$$q_t = \varepsilon_t$$
$$s_t = \beta\, q_{t-1} + \alpha\, s_{t-1} + u_t$$
$$r_t = \phi\, q_{t-1} + \gamma\, s_{t-1} + \theta\, r_{t-1} + v_t$$

with $|\alpha| < 1$, $|\theta| < 1$ and ε_t, u_t, v_t mutually uncorrelated. For this simple system, we can write the moving average representation explicitly as:

$$q_t = \varepsilon_t$$

$$s_t = \beta \sum_{\tau=1}^{\infty} \alpha^{\tau-1} \varepsilon_{t-\tau} + \sum_{\tau=0}^{\infty} \alpha^{\tau} u_{t-\tau}$$

$$r_t = \sum_{t=1}^{\infty} \omega_\tau \varepsilon_{t-\tau} + \sum_{\tau=1}^{\infty} \rho_\tau u_{t-\tau} + \sum_{\tau=0}^{\infty} \theta^{\tau} v_{t-\tau}$$

where ρ_τ and ω_τ are such as:

$$\rho_\tau = \theta\rho_{\tau-1} + \gamma\alpha^{\tau-1} \quad \text{and} \quad \omega_\tau = \phi\theta^{\tau-1} + \beta\rho_{\tau-1}$$

with $\rho_o = 0$ and for $\tau = 1, 2, \ldots$

The response pattern of our variables is described completely by this moving average representation. For example, ω_τ is the effect on r after τ years of a one period-one unit shock in ε. Thus, $\sum_{\tau=1}^{k} \omega_\tau$ is the cumulative effect on r over a period of k years due to this shock, that is the proportional change in the level of R-D after k years. It appears that a shock induces decaying fluctuations in growth rates and puts the levels on higher growth paths. Essentially, the effects on growth rates are transitory, while the changes in levels are permanent.

The long run effects of a one period-one unit in ε or u on the levels of sales and R-D can be easily computed and are given in table 1. A one percent increase in u will induce sales and R-D to increase respectively by $\sum_{\tau=1}^{\infty} \alpha^{\tau} = 1/(1-\alpha)$ and $\sum_{\tau=1}^{\infty} \rho_\tau = \gamma/(1-\theta)(1-\alpha)$. The ratio of these two effects: $\gamma/(1-\theta)$ is the elasticity of R-D with respect to sales, and thus can be called the long run accelerator effect or multiplier. The long run elasticity of R-D with respect to q is $\sum_{\tau=1}^{\infty} \omega_\tau = \phi/(1-\theta) + \beta\gamma/(1-\theta)(1-\alpha)$. This expression indicates clearly that q can affect R-D both directly and indirectly through its impact on sales: the direct effect being $\phi/(1-\theta)$ and the indirect effect being the product of the impact of q on sales $\beta/(1-\alpha)$ and the long run accelerator $\gamma/(1-\theta)$.

III. - EMPIRICAL RESULTS

1. Tests and estimates

The empirical implementation of our study is based on a sample of 93 firms with data from 1962 to 1977. This sample derives from the Griliches and Mairesse (this volume) restricted sample of 103 firms with no major merger problems. We had to discard 10 firms because of the lack of all of the necessary information to construct the q variable. Although our sample may seem small in terms of number of firms and cannot be taken as representative of the corporate sector in any definite sense, it is, in fact, of about the largest size possible for R-D doing firms over a sufficiently long period (at least 10 good years for our type of time-series cross-section analysis).

The sample means and standard deviations of our variables over the twelve years 1966-1977, as well as the standard deviations of our variables measured relative to their year means, are the following:

q = .104	s = .062	r = .025	i = .036
(.433)	(.120)	(.217)	(.465)
[.362]	[.107]	[.211]	[.444]

As could be expected the stock market rate of return is extremely variable. So is physical investment; it is not rare that for a firm physical investment doubles (or goes down by half) from one year to the other. Note that R-D expenditures are also quite variable, though much less so than is true for physical investment.

We have estimated all our models by Zellner's seemingly unrelated regression least squares method (based on the variance-covariance matrix Σ estimated once and for all for the general model case). The parameters estimates of the general model, the extended accelerator model and also its simplified first order autoregressive version are given in tables 2 and 3, while all the different test results are brought together in table 4.

The general model uses four lagged values of each of the four variables and is therefore estimated over the twelve years period 1966-1977, including also twelve year dummies. We have experimented some with shorter lags, but four lags seemed to be necessary to capture the dynamic behavior of our variables adequately. We have also checked for the possibility of serial correlation of the disturbances. It is apparently negligible, the first and second order autocorrelation coefficients of the residuals $\hat{\eta}_{jt}$ in each equation being rather small uniformly (-.01 and -.06 for the q-equation residuals, respectively; -.02 and -.03 for the s-equation residuals; -.03 and -.01 for the r-equation residuals, and -.01 and -.07 for the i-equation residuals).

On the contrary, the contemporaneous correlations of the residuals $\hat{\eta}_{jt}$ across equations are rather high (.19, .07, and .07 between the q equation and the s, r and i equations residuals respectively; .18 and .26 between the s equation and the r and i equations residuals; .18 between the r and i equations residuals). The test of diagonality is indeed strongly rejected. Using the Cholewski decomposition we can write:

$$\hat{\eta}_{1t} = \hat{\varepsilon}_t$$

$$\hat{\eta}_{2t} = .055\ \hat{\varepsilon}_t + \hat{u}_t$$

$$\hat{\eta}_{3t} = .040\ \hat{\varepsilon}_t + .329\ \hat{u}_t + \hat{v}_t$$

$$\hat{\eta}_{4t} = .079\ \hat{\varepsilon}_t + .974\ \hat{u}_t + .284\ \hat{v}_t + \hat{w}_t$$

the standard deviations of the uncorrelated ε_t, u_t, v_t and w_t being .358, .101, .194 and .380, respectively. It appears from these estimates that u, the independent innovation in s, has an immediate and strong impact on i and a more moderate one on r, while the immediate effect of ε, the innovation in q, is quite weak. Note also that the independent innovation in r has a sizeable effect on i as well.

Considering the estimated equations of the general model in turn, it is clear that all the implications suggested by the economic interpretation are by and large supported. All the coefficients of the q-equation (i.e. the 16 coefficients of the lagged values of q, s, r and i except for the time dummies) are insignificant and even taken together the hypothesis of their joint nullity cannot be rejected at the 5% significance level. This is another confirmation of the unpredictability of q from past information and thus also of the hypothesis of stock market efficiency.

All eight coefficients of the lagged r and i terms are insignificant in the s equation. Assuming stock market efficiency their joint nullity (together with that of the coefficient of q_{-2}, q_{-3} and q_{-4} which are also individually insignificant) cannot be rejected at a 5% level of significance. We can accept thus the hypothesis that s and q are exogenous relatively to r and i, that the accelerator model is a reasonable specification, even though at first it appeared to be a rather strong simplification.[6]

In the r equation, the four lagged i terms and likewise the four lagged r terms in the i equation are all insignificant, except for the coefficient of r_{-1} on i which is on the verge of individual significance at the 5% significance level. As a group, they are insignificant at the 5% significance level. We can accept the absence of interactions between r and i, other than instantaneous, and hence the accelerator model without such interactions. On the other hand, the hypothesis (considered by way of illustration) that the accelerator is first order autoregressive is strongly rejected.

2. Dynamic and long-run multipliers

The implications of our results are best described by the dynamic responses of our variables to the different shocks and the q and s-effects or multipliers. All long-run multipliers are given in table 5, while the q and s dynamic multipliers are represented in figures 2 to 5. We shall comment on them in turn.

The eight matrices in table 5 consist of the own and total effects estimated in case of the general model with and without stock market efficiency, the extended accelerator model (without r and i interactions) and also the first order autoregressive accelerator version. We have not endeavoured to compute the standard deviations of these coefficients.[7] However, the comparison of their values for the four different specifications gives us a feeling for their precision. As we have seen the general model with market efficiency and the extended accelerator are not statistically different at the 5% significance level; indeed all the estimated effects for these two models are very close. The general model without market efficiency differs mainly from that with market efficiency by the estimated effect of s (or u) on q; however, this effect should not be statistically significant, corresponding mainly to the large insignificant coefficient of s_{-1} in the q-equation (see table 2). The largest discrepancies between the extended accelerator model and its first order autoregressive version occurs in the estimated effects of s (or u) on r and i (and also of i (or w) on itself); these discrepancies are probably significant since they correspond to the significant coefficients of s_{-2}, and s_{-4} in the r and i equations (and also of i_{-2}, i_{-3} and i_{-4} in the i equation).

The comparison of the own and total effects shows the importance of the contemporaneous influences of q and s on r and i (i.e. the importance of instantaneous causality). This was already clear from the Cholewski decomposition given above, showing the correlation structure of the innovations in our variables. Consider the one very striking case: the long run impact of a one percent s or u shock on the level of physical investment would amount only to .35 percent, instead of about .85, if the contemporaneous dependence between s and i were eliminated.

The four figures 2 to 5 consist each of three graphs, depicting the yearly q or s (total) effects on the three rates of growth s, r, and i, or on the three percentage changes in levels $\Delta S/S$, $\Delta R/R$, $\Delta I/I$ (these effects being estimated for the extended accelerator model). The responses of s and r to the q or s shocks are similar enough, damping down rapidly with most of the effects dissipated in three years. The investment growth rate i reacts more strongly and irregularly. In response to a one percent q-shock, it goes up to about .15 in the first year and down to .10 and -.05 in the second and third years, then cycles down quickly to zero. In response to a one percent s shock, after an immediate impact of about 1, it plunges to 0 and -.25 in the first and second years, then cycles back quickly to zero. In coherence with these patterns of response, the levels of sales and R-D expenditures increase steadily toward their new long run values while investment starts by overshooting its own, all cumulated effects being practically completed in five years.

The long run (total) effects of a one percent q shock on sales, R-D and investment levels are respectively about .15, .20 and .30. These elasticities appear to be rather small; however, gauged in terms of the standard deviations of the corresponding rates of growth, they are quite sizeable. A one standard deviation q shock induces changes in the levels of sales, R-D and investment of about .55, .40 and .25 of their respective standard deviations.

The absolute long run effects of a one percent s shock are much larger than those of a one percent q shock, moving the levels of sales, R-D and investment by about 1.4, .95 and .85, respectively. Yet, measured in units of standard deviations, s shocks are not more effective than q shocks in driving R-D and physical investments: the changes induced by the formers being about .50 and .20 to be compared to .40 and .25 for the latter. In this regard it should be noted that only 30 percent of the q effect on R-D and 55 percent of the q effect on investment relies on the direct influence of q, the remaining effect resulting from the impact of q on s. This remark shows that in considering an R-D or an investment equation in isolation, one might be led to a serious underestimate of the significance of the q variable.

For comparison with the results of other investment studies, it is interesting to translate the long run s effects into the usual accelerator elasticities $(\Delta I/I)/(\Delta S/S)$ or $(\Delta R/R)/(\Delta S/S)$: they are about .7 ($\sim .85/1.4$) and .6 ($\sim .85/1.4$) for physical investment and R-D respectively. The latter estimate .6 accords well with the elasticity of R-D capital stock reported to be around .5 to .8 by Nadiri and Bitros (1980) in the only other study investigating investment and R-D demand jointly. The former estimate of .7 is, however, lower than their estimated elasticity of around 1. for physical capital stock. A unitary elasticity is implied by the standard Jorgensonian factor demand framework (i.e., the inverse of the returns to scale in the production function, which presumably are not very far from being constant), and is in fact found in many econometric studies (for example, Jorgenson and Stephenson, 1967; Jorgenson, 1971). Because of the various differences in specification, it is difficult to pinpoint the actual reasons for our relatively low accelerator estimate. It probably arises from our rate of growth formulation. Using a similar formulation, Eisner found an even lower estimate of about .4 (Eisner, 1978; see also Oudiz, 1978).[8] Eisner's explanation which is similar to Friedman's permanent income hypothesis, may also be applicable to our results. In our specification of the accelerator model, the q and s shocks are assumed to be free from errors or contamination by any noise. In reality, the fluctuations in q and s have large transitory components, which will have presumably little impact on i and r. Our estimates of the accelerator elasticity and, more generally, of the q and s effects might be larger, if we could disentangle the transitory variations from the permanent changes in q and s.

IV - FINAL REMARKS

Using a multivariate autoregressive framework, we have found a simple causal structure for the variables of interest q, s, r, and i, which is consistent with our data. As expected from the stock market efficiency hypothesis, q, the stock market one period holding rate of return is exogenous relatively to the other three variables (or Granger causes them). As postulated in the traditional accelerator model of investment, the rate of growth of sales, s, can be also treated as exogenous to the rates of growth of R-D and physical investment, r and i. Moreover, no strong feedback interaction is detected between the last two (r and i).

Within the simple structure of the extended accelerator model, the substantive conclusion is that R-D and physical investment react very similarly to the growth of sales and to movements in q; the response of R-D is however more stable or less irregular than that of physical investment. Expected demand and expected profitability thus appear to be both important determinants for R-D expenditures and physical investment.

It would be important to check our findings against other bodies of data. Also, our study could be improved by incorporating other variables of interest (see Ben-Zion; this volume). In further work, it would be particularly interesting to go deeper in two directions:

1. The multivariate autoregressive setup proved to be useful and convenient for studying the dynamic relationships between variables. However, a more elaborate specification might help to filter out the permanent from the transitory components of the variables. This issue is related to our choice of growth rates formulation, which has many advantages but also tends to magnify the relative importance of transitory components or errors in the variables.

2. The fact that past q's, though probably error ridden, are significantly correlated with s, r and i confirms that movements in stock prices carry valuable expectational information about future profitability. This interpretation of the q variables should be substantiated, however, more rigorously and its relation to "Tobin's Q" clarified. More generally, the extended accelerator model should be grounded more firmly in theory and provided with a more definite behavioral interpretation.

FIGURE 1

Path diagram of the Extended Accelerator Model

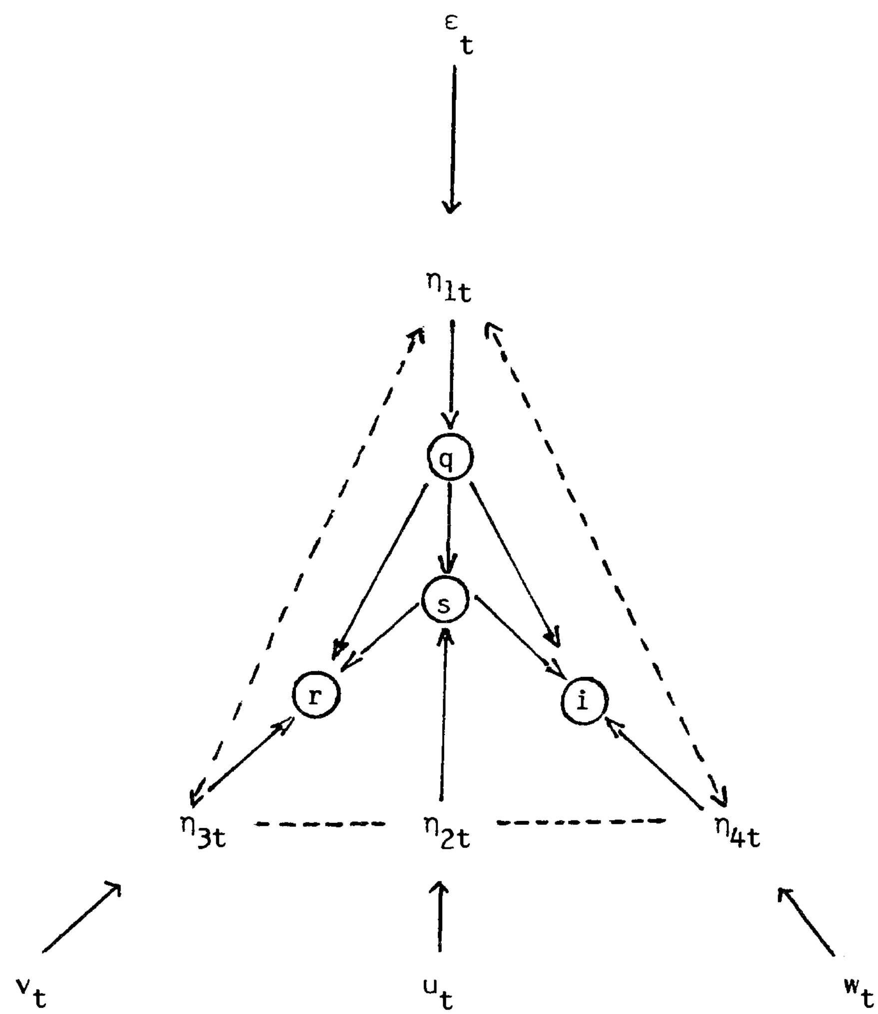


TABLE 1 : Long Run multipliers in the first order autoregressive Accelerator Model

Shock or innovation	Percentage change in level	
	$\Delta S/S$	$\Delta R/R$
ε or q	$\frac{\beta}{1-\alpha}$	$\frac{\phi}{1-\theta} + \frac{\beta\gamma}{(1-\theta)(1-\alpha)}$
u or s	$\frac{1}{1-\alpha}$	$\frac{\gamma}{(1-\theta)(1-\alpha)}$

TABLE 2 : Parameter Estimates-General Model*

	q	s	r	i
q_{-1}	-.005 (.027)	.044 (.008)	.067 (.015)	.172 (.030)
q_{-2}	.002 (.025)	.008 (.007)	.034 (.014)	.171 (.028)
q_{-3}	-.009 (.022)	.004 (.006)	.021 (.012)	.055 (.025)
q_{-4}	.037 (.027)	.011 (.006)	-.006 (.012)	.051 (.025)
s_{-1}	-.161 (.109)	.116 (.031)	.335 (.060)	.288 (.121)
s_{-2}	-.043 (.108)	-.028 (.031)	.097 (.060)	-.006 (.120)
s_{-3}	-.076 (.109)	.089 (.031)	.102 (.060)	.097 (.121)
s_{-4}	.069 (.107)	.050 (.031)	.072 (.059)	.112 (.119)
r_{-1}	-.012 (.055)	.023 (.016)	-.243 (.031)	.140 (.061)
r_{-2}	-.047 (.062)	-.015 (.018)	-.132 (.034)	-.013 (.068)
r_{-3}	-.016 (.065)	.026 (.019)	.142 (.036)	-.103 (.072)
r_{-4}	-.106 (.057)	-.016 (.016)	-.009 (.031)	-.054 (.063)
i_{-1}	-.064 (.028)	-.001 (.008)	.003 (.015)	-.344 (.031)
i_{-2}	-.062 (.029)	.012 (.008)	.003 (.016)	-.332 (.032)
i_{-3}	-.004 (.029)	-.007 (-.008)	-.023 (.016)	-.209 (-.032)
i_{-4}	-.019 (.028)	-.004 (.008)	.002 (.015)	-.143 (.031)
	Wt. RSS = 4464 df = 4346			

* The parameters estimates of the s, r and i equations do not differ in the general model without market efficiency and that with market efficiency, while the q-equation vanishes in the latter.

TABLE 3 : Parameter Estimates - Extended Accelerator Model

	Extended Accelerator Model			First order autoregressive Accelerator Model		
	s	r	i	s	r	i
q_{-1}	.043 (.008)	.068 (.015)	.174 (.030)	.041 (.007)	.063 (.015)	.194 (.029)
q_{-2}		.034 (.013)	.170 (.026)			
q_{-3}		.020 (.012)	.052 (.024)			
q_{-4}		-.012 (.012)	.038 (.024)			
s_{-1}	.143 (.029)	.345 (.058)	.354 (.119)	.154 (.028)	.384 (.057)	.256 (.114)
s_{-2}	-.000 (.028	.108 (.058)	.047 (.116)			
s_{-3}	.106 (.028)	.095 (.059)	.074 (.117)			
s_{-4}	.052 (.028)	.072 (.058)	.077 (.115)			
r_{-1}		-.258 (.029)			-.227 (.028)	
r_{-2}		-.125 (.033)				
r_{-3}		.138 (.034)				
r_{-4}		-.002 (.030)				
i_{-1}			-.337 (.029)			-.190 (.027)
i_{-2}			-.346 (.030)			
i_{-3}			-.203 (.030)			
i_{-4}			-.146 (.029)			
	Wt.RSS = 4519		df = 4381	Wt. RSS = 4777		df = 4402

TABLE 4 : Test statistics*

Hypothesis	Weighted Residuals Sum of squares	Degrees of freedom	Test against the general model H_o			Test against the general model with market efficiency H_1		
			Number of restrictions	Value f of F-statistic	Prob (F>f)	Number of restrictions	Value f of F-statistic	Prob (F>f
H_o: General Model	4 464	4 346	-	-	-	-	-	-
H'_o: General Model with the diagonality restriction	4 650	4 352	6	30.2	.000	-	-	-
H_1: General Model with stock market efficiency	4 490	4 362	16	1.6	.060	-	-	-
H_2: Extended Accelerator with r and i interactions	4 508	4 373	27	1.6	.030	11	1.6	.092
H_3: Extended Accelerator without r and i interactions	4 519	4 381	35	1.5	.030	19	1.5	.075
H_4: First Order Autoregressive Accelerator	4 777	4 402	56	5.4	.000	40	7.0	.000

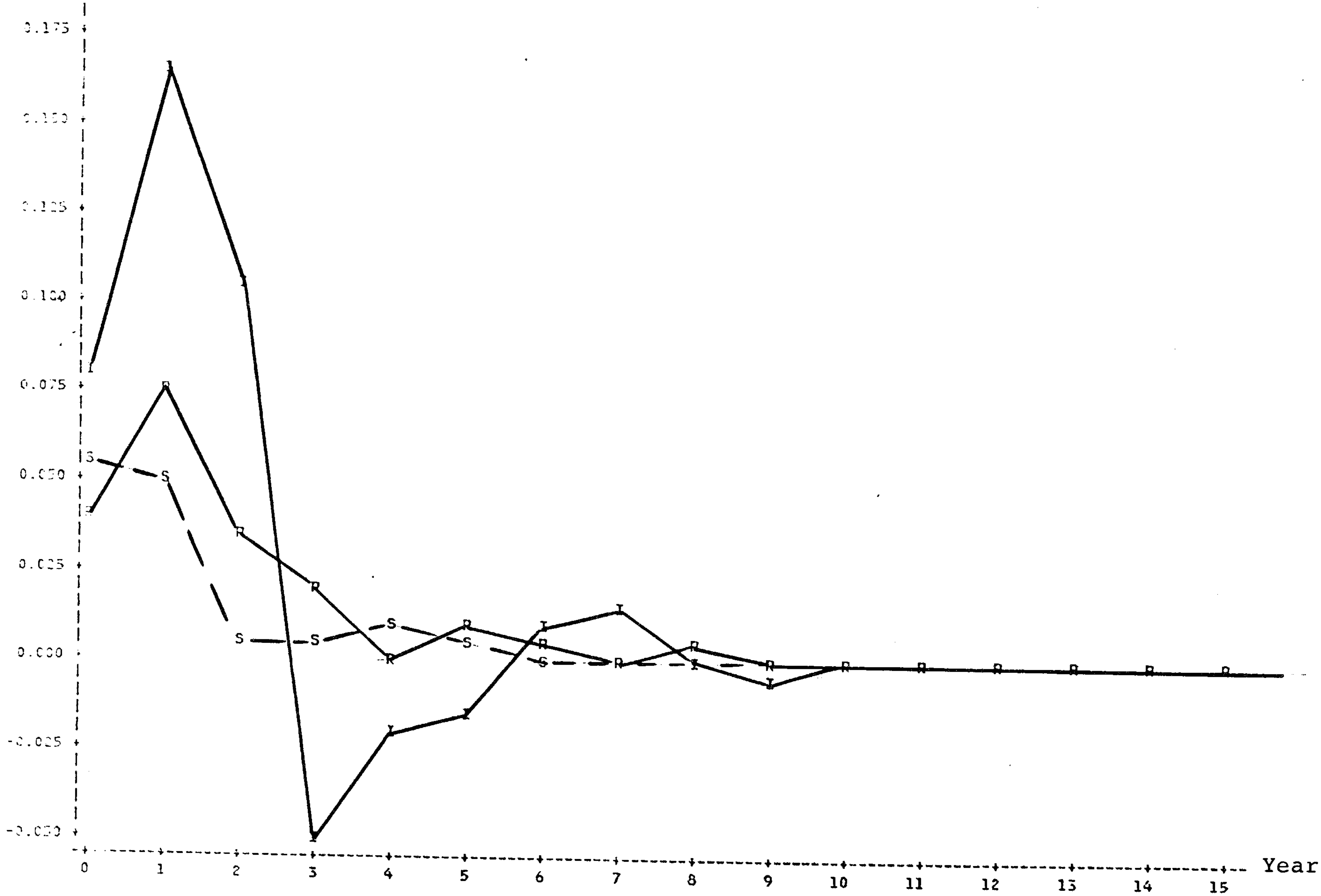
*The test statistics are the standard F - statistics computed from the weighted residuals sum of squares. These are based on the Σ matrix estimated under the alternative hypothesis of the general model.

TABLE 5 : Long run multipliers

Model	Shocks on	Total effects				Own effects			
		ε	u	v	w	ε	u	v	w
General model	q	.915	-.528	-.162	-.069	.949	-.414	-.143	-.069
	S	.155	1.267	.004	-.006	.085	1.271	.006	-.006
	R	.190	.826	.791	-.015	.127	.579	.795	-.015
	I	.276	.658	.093	.477	.229	.208	-.043	.477
General model with stock market efficiency	q	1	0	0	0	1	0	0	0
	S	.169	1.357	.031	.005	.093	1.342	.029	.005
	R	.208	.936	.824	-.001	.138	.665	.825	-.001
	I	.301	.818	.142	.497	.244	.333	.001	.497
Extended Accelerator Model	q	1	0	0	0	1	0	0	0
	S	.141	1.431	0	0	.062	1.431	0	0
	R	.191	.978	.805	0	.119	.714	.805	0
	I	.288	.849	.140	.492	.229	.369	0	.492
First order Autoregressive Accelerator Model	q	1	0	0	0	1	0	0	0
	S	.114	1.181	0	0	.049	1.181	0	0
	R	.120	.637	.814	0	.067	.369	.814	0
	I	.253	1.072	.239	.840	.173	.254	0	.840

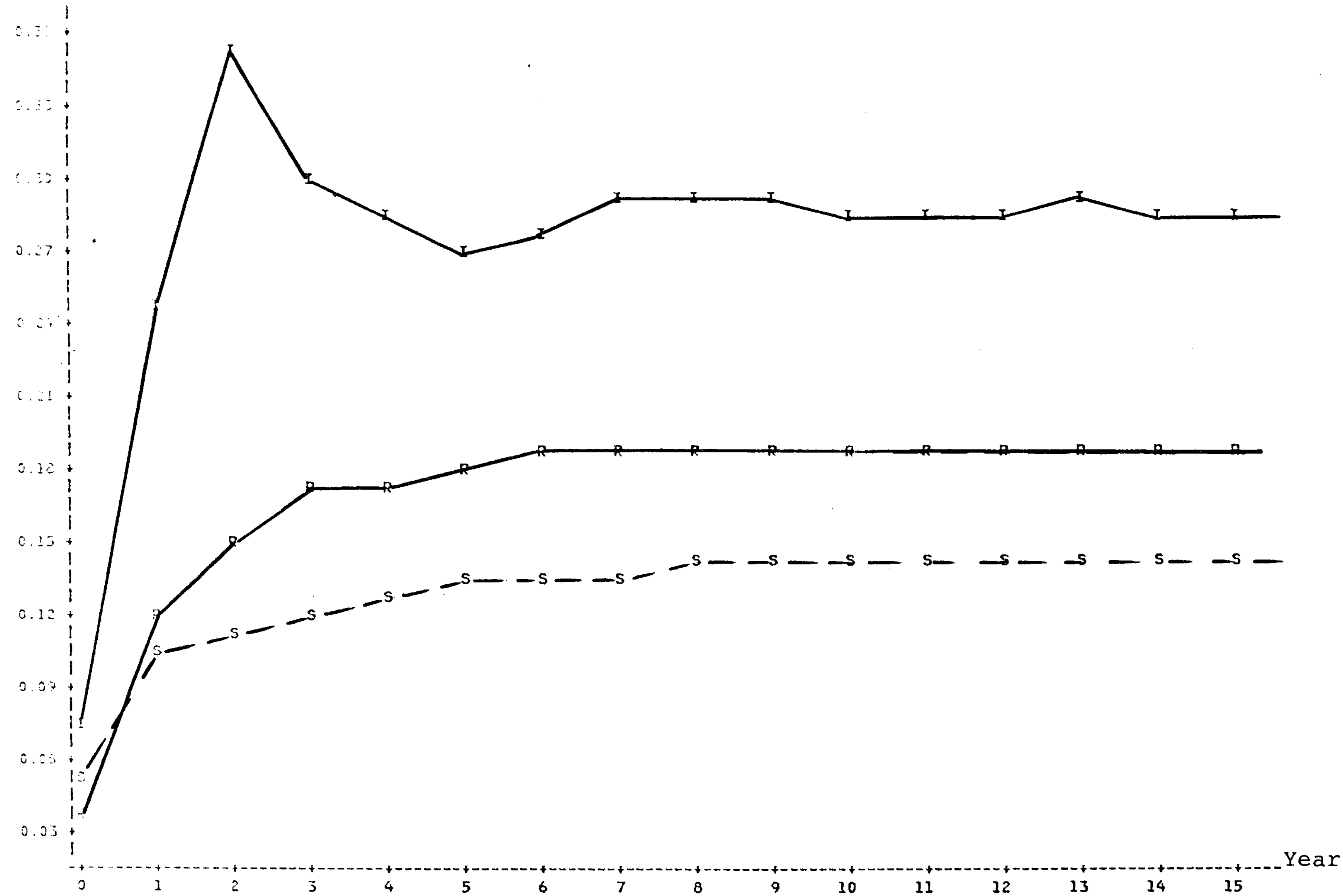
Extended Accelerator Model - Total Effects.
Changes in growth rates s, r, i due to a
one unit q shock.

Figure 2



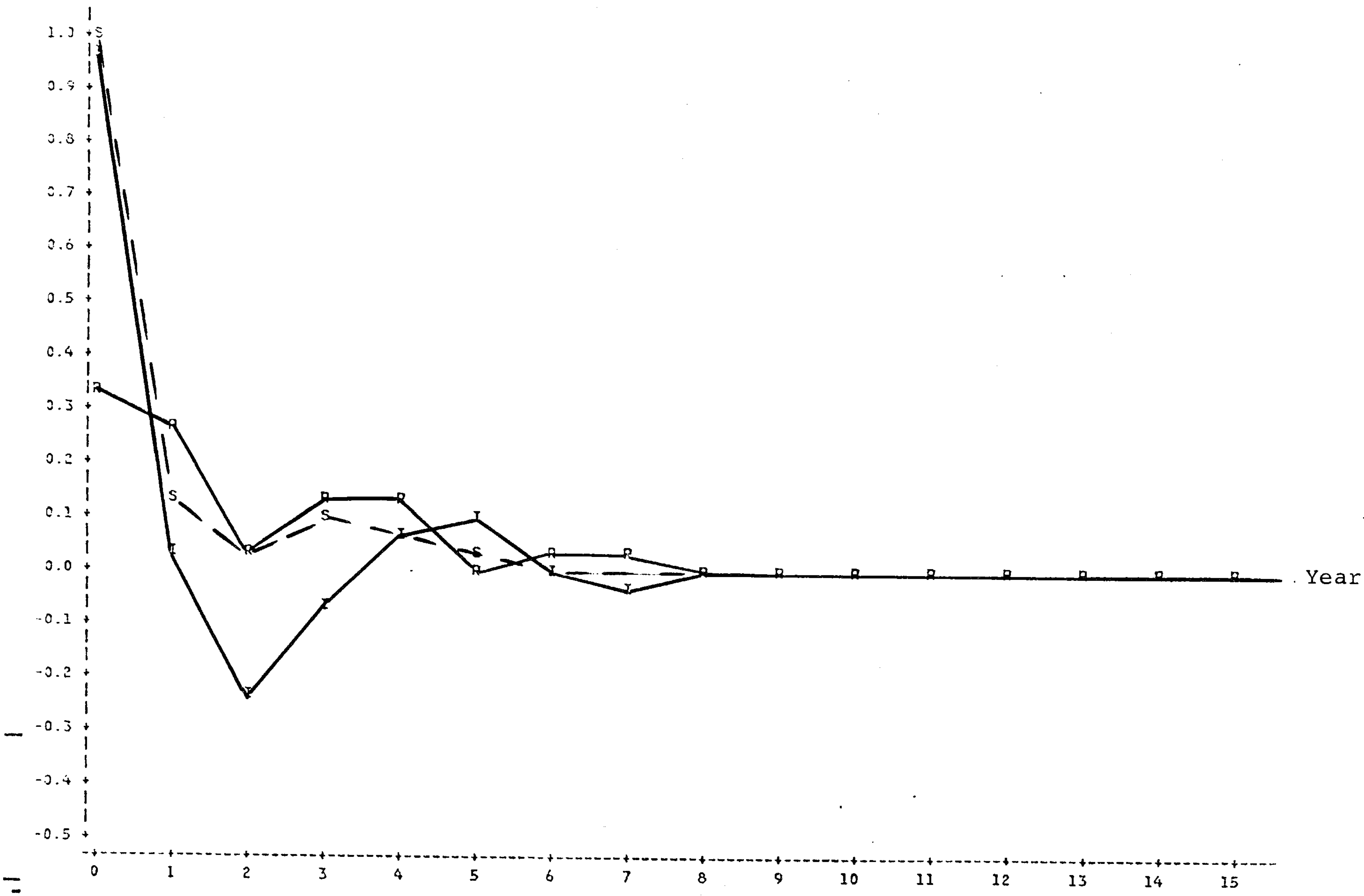
Extended Accelerator Model - Total Effects.
Changes in percentage levels $\Delta S/S$, $\Delta R/R$, $\Delta I/I$ due to a one unit q shock.

<u>Figure 3</u>



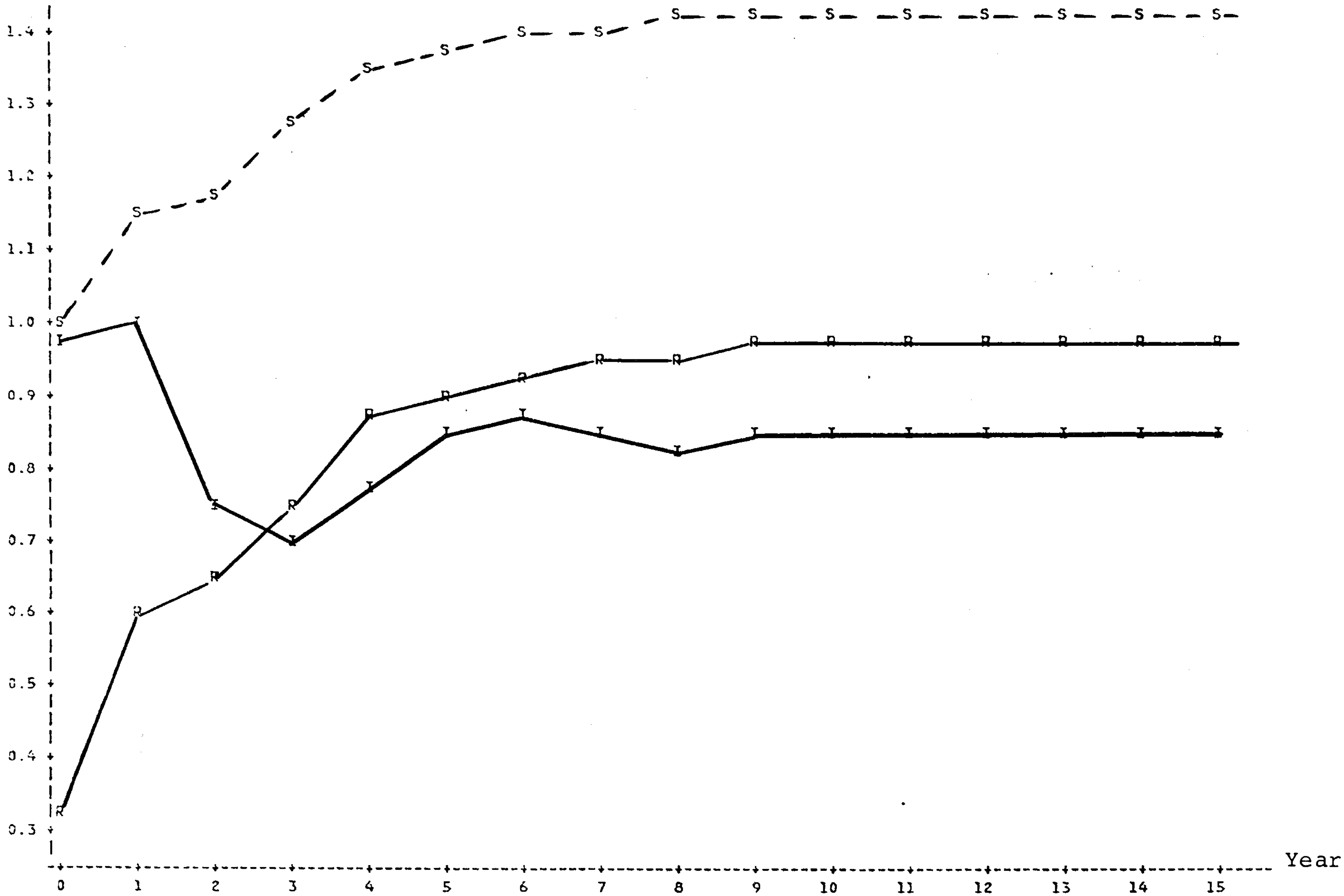
Extended Accelerator Model - Total Effects.
Changes in growth rates s, r, i due to a
one unit s shock.

Figure 4



Extended Accelerator Model - Total Effects:
Changes in percentage levels $\Delta S/S$, $\Delta R/R$,
$\Delta I/I$ due to a one unit s shock.

Figure 5



Footnotes

1. In the empirical implementation, q_t is adjusted for stock splits when they occur. Sales are deflated using industry price indices; R-D and investment expenditures are also deflated by an overall price index. There is the possibility of some mismatch in timing between s_t, r_t and i_t, which are based on the companies' fiscal year, and q_t which is based on calendar year. From previous work, we know that fiscal and calendar years do not coincide for a large enough proportion of firms; an attempt to correct for this problem had, however, very little impact on our results. We preferred not to make any such correction in the present study.

2. Our adoption of a formulation in terms of rates of growth of the variables or log differences results from a number of considerations. Using first differences is usually advised in the time-series literature in order to get more stationary processes (Granger and Newbold, 1978). Actually, when we tried to estimate the autoregressive model in the levels of variables, the results suggested a first difference formulation (some of the roots of the characteristic equation associated with the model being close to one in absolue values). Going to first differences is also a simple way to avoid dealing with firm specific effects, while the formulation in terms of levels raises the well known difficulties of estimating a dynamic model with such effects (Balestra and Nerlove, 1966). First differences have, however, the drawback of magnifying the problems of errors in the variables (augmenting the ratio of error to true variance).

3. The usefulness of stock market valuation as an indicator of expectations about future profitabilty in an investment function can be traced back to

Grunfeld (1960), and more recently to the literature on "Tobin's Q" (Tobin 1971). Our q variable will be equal to the percentage change in Tobin's Q variable, if debts are proportional to equity and there is no change in the replacement value of the firm. Actually, the correlation between our q variable and the change in Tobin's Q variable, as computed otherwise, is quite high in our sample. Our study is thus related to the studies investigating Tobin's Q as a determinant of investment. See, for example, Engle and Foley (1975), Von Fustenberg (1977) and Summers (1980) among others.

4. Doubts have been recently expressed about the efficiency of stock markets. Schiller (1981) pointed out that the actual stock prices fluctuate too much to reconcile with the stable and smooth series of the present value of subsequent real dividends. See also Malinvaud (1981) and Summers (1982).

5. The formulations (1') and (1") of the general model can be also written: $\underset{\sim}{y}_t = P(L)\underset{\sim}{\eta}_t$ and $\underset{\sim}{y}_t = T(L)\underset{\sim}{\zeta}_t$, P(L) and T(L) being respectively the matrix of the own and total effects with: $P(L) = (I - A(L)L)^{-1} = (I - B^{-1}B(L)L)^{-1}$ and $T(L) = P(L)B_0^{-1}$.

6. The fact that we cannot reject both exogeneity tests of q (stock market efficiency) and of s (accelerator model) is all the more meaningful as our sample has a large number of observations (see, for example, Leamer 1978, Chapter 4).

7. The total and own effects are highly nonlinear and complicated expressions of the estimated parameters, making the derivation of their standard deviations a problematic task (see footnote 5).

8. To be precise, Eisner's dependent variable is the deviation from the firm mean of the investment-capital ratio, or the rate of growth of the capital stock plus its rate of depreciation.

References

Balestra, P., and M. Nerlove: "Pooling Cross Section and Time Series Data in the Estimation of a Dynamic Model," Econometrica, 34 (1966), 585-612.

Ben-Zion, U.: "R&D and Investment Decision and Their Relationship to Stock Market Values and Sales: Preliminary Results," this volume.

Eisner, R.: Factors in Business Investment, National Bureau of Economic Research General Series No. 102, Cambridge: Ballinger Publishing Company (1978).

____________: "Cross Section and Time Series Estimates of Investment Functions," Annales de l'INSEE, no.30-32 (1978), 99-129.

Engle, R. and D. Foley: "An Asset Price Model of Aggregate Investment," International Economic Review, 16 (1975), 625-647.

Fama, E.F.: "Efficient Capital Markets: A Review of Theory and Empirical Work," Journal of Finance, XXV (1970), 383-417.

____________: Foundation of Finance, Basic Books, (1976).

Von Fustenberg, G.: "Corporate Investment: Does Market Valuation Matter in the Aggregate?" Brookings Papers for Economic Activity 2 (1977), 347-408.

Granger, C.W. and P. Newbold: Forecasting Economic time series, New York, Academic Press (1977).

Granger, C.W.: "Testing for Causality, A Personal Viewpoint," Journal of Economic Dynamics and Control, 2 (1980), 329-352.

Griliches, Z., and J. Mairesse: "Productivity and R&D at the Firm Level," this volume.

Grunfeld, Y.: "The Determinants of Corporate Investment," in The Demand for Durable Goods, ed. by A.C. Harberger, Chicago: University of Chicago Press (1960) pp.211-266.

Jorgenson, D.W., and J.A. Stephenson: "Investment Behaviour in U.S. Manufacturing, 1947-1960," Econometrica, 35 (1967), 169-220.

Jorgenson, D.W.: "Econometric Studies of Investment Behavior: A Survey", Journal of Economic Literature, 9 (1971), 1111-1147.

Leamer, E.L.: Specification Searches: Ad Hoc Inferences With Nonexperimental Data, New York, John Wiley and Sons (1978).

Malinvaud, E.: Profitability and Unemployment, Cambridge University Press, 1980.

____________: "Profitabilité et investissement," Document de travail ENSAE et Unité de Recherche, INSEE, Paris (1981).

Nadiri, M.I., and G.C. Bitros: "Research and Development Expenditures and Labor Productivity at the Firm Level: A Dynamic Model," in New Developments in Productivity Measurement and Analysis, ed. by J.W. Kendrick and B.N. Vaccara, National Bureau of Economic Research, Studies in Income and Wealth, vol. 44. Chicago: University of Chicago Press (1980) pp.387-312.

Oudiz, G.: "Investment Behavior of French Industrial Firms: A Study on Longitudinal Data", Annales de l'INSEE, no.30-32 (1978), 511-541.

Pakes, A.: "Patents, R&D and the Stock Market Rate of Return," this volume.

Pierce, D.A. and Haugh, L.A.: "Causality in Temporal Systems: Characterizations and a Survey," Journey of Econometrics 5 (1977), 265-293.

____________: "The characterization of instantaneous causality: a comment," Journal of Econometrics 70 (1979), 257-259.

Sargent, T.J., and C.A. Sims: "Business Cycle Modelling Without Pretending to Have Too Much A Priori Economic Theory," in New Methods of Business Cycle Research, ed. by C.A. Sims, Minneapolis: Federal Reserve Bank of Minneapolis (1977) pp.45-109.

Shiller, R.J.: "Do Stock Prices Move Too Much to Be Justified by Subsequent Changes in Dividends?" American Economic Review, 71 (1981), 421-436.

Sims, C.A.: "Money, Income and Causality," American Economic Review, 62 (1972), pp.540-552.

Sims, C.A.: "Are there exogenous variables in short-run production relations?" Annals of Economic and Social Measurement, 1 (1972), 17-36.

____________: "Exogeneity and Causal Ordering in Macroeconomic Models," in New Methods of Business Cycle Research, ed. by C.A. Sims, Minneapolis: Federal Reserve Bank of Minneapollis, 1977, pp.23-43.

____________: "Macroeconomics and Reality," Econometrica, 48 (1980), pp.1-48.

Summers, L.H.: "Inflation, Taxation and Corporate Investment: A Q Theory Approach," National Bureau of Economic Research Working Paper No. 604, (1980).

____________: "Do We Really Know That Financial Markets Are Efficient?" National Bureau of Economic Research Working Paper No. (1982).

Tobin, J.: "A General Equilibrium Approach to Monetary Theory," in his Essays in Economics: Macroeconomics, vol. 1, Chicago: Markham Publishing Company (1971), pp.332-38.