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# Estimating turning points using polynomial regression

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SUMMARY *This paper describes a method for estimating regime switches in non-monotonic relationships, using polynomial regressions. Data from the UK financial services industry are used to illustrate the technique. The methodology provides a means of statistically ascertaining the existence of turning points, as well as a means of locating them, should they exist. While the methodology is most suited to applications that involve cross-sectional data, it may also be useful in short-horizon time series turning point prediction.*

## 1 Introduction

The estimation of the turning points of non-monotonic relationships is of considerable importance in many business and natural science applications. A number of techniques have been used in such estimation. Piecewise regression is one commonly used methodology. Morck *et al.* (1988), McConnell and Servaes (1990) and Chen *et al.* (1995) are illustrations of this approach. Another method which is particularly popular in the business cycle literature is the extraction of the signal of a turning point from a leading indicator series. Turning point signals may be extracted by simple mechanical rules, such as the 'three consecutive decline' rule proposed by Vaccara and Zarnowitz (1977) for predicting a downturn. Alternatively, probabilistic event-oriented procedures based on the work of Neftci (1982) may be used. Artis *et al.* (1995) suggest a more general Bayesian signal extraction procedure. Diebold and Rudebusch (1989, 1991), de Leeuw (1991), Nemira (1991) and Berk and Bikker (1995) are examples of work in which various signal extraction methods are applied to leading indicator series to estimate turning points. Finally, turning points are sometimes directly estimated by rules of thumb. For instance, Jarrell and Poulsen (1988) examine the fit provided by alternative turning points.

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This paper describes a method for estimating turning points using polynomial regression. The method is particularly suitable for use in cases where the suspected number of regime switches for the data at hand is known within an order of magnitude, and where the specific statistical problem is three-fold: (1) the confirmation of the existence of regime switches; (2) the identification of the number of such switches; and (3) and location of the turning points.

The methodology uses the analytical properties of the polynomial to establish the closed-form solution for the turning points in terms of the parameters of the problem. These closed-form solutions may then be estimated and appropriate tests developed to determine whether confidence may be placed in the estimated turning points. The approach is expected to be quite general, because it is well known that any continuous function can be approximated arbitrarily closely over a bounded interval by a polynomial.

The methodology is explained through an illustrative example. Data from the UK financial services industry are used to estimate the relationship between managerial shareholding and the corporate rate of return. Specification tests reveal the relationship to be best estimated using a cubic functional form. Statistical tests of significance for the existence of turning points are developed for this functional form.

In Section 2, the existing literature related to the specific problem is surveyed and the proposed estimation methodology is described. The data and estimation are detailed in Section 3, while the analytic solutions and a discussion of the tests of significance are presented in Section 4. Section 5 concludes the paper.

## 2 Estimating the managerial stock ownership–firm performance relationship

A number of studies have sought to evaluate empirically the link between managerial share ownership and firm performance. Mehran (1995) provides evidence of a positive relation between managerial equity ownership and firm performance. Similarly, Wruck (1988) finds a strong and, on average, positive link between the change in ownership concentration and firm performance. However, most studies find evidence for a non-monotonic relationship between ownership concentration and the market value of the firm. Using a sample of 371 Fortune 500 firms, Morck *et al.* (1988) find that the relationship is positive for managerial ownership between 0 and 5%, negative between 5 and 25%, and positive thereafter. Hermalin and Weisback (1991) study 134 NYSE firms and use chief executive officer (CEO) stock ownership to represent managerial shareholding. They find the relationship to be positive for CEO stock ownership of 0–1%, negative between 1 and 5%, positive between 5 and 20%, and negative thereafter. McConnell and Servaes (1990) analyze 1976 data for a sample of 1173 firms and 1986 data for a sample of 1093 firms, and find the relationship to be positive between 0% and somewhere in the range 35–50%, and negative thereafter. Similar findings are reported by Jarrel and Poulsen (1988).

All these studies—and most related ones in the literature—use piecewise regression to estimate these non-monotonic relationships. To locate turning points using this methodology is rather cumbersome. Furthermore, there is typically no compelling reason to suspect that the derivative of the estimated function is discontinuous. Therefore, piecewise regressions tend to be *ad hoc* and often rough approximations.

It is suggested that a more satisfactory method of locating turning points is to use polynomial regressions. As mentioned, there are strong reasons for preferring polynomials to piecewise regressions, on the grounds of realism and plausibility. The suggested methodology proceeds in three steps.

*Step 1.* Run specification tests on estimating polynomial regressions of increasing order. Stepwise regression with variable inclusion tests and tests of regressor parsimony (such as the Akaike information criterion, the Amemiya prediction criterion, etc.) are possible approaches for choosing the estimating polynomial regression to be used.

*Step 2.* Obtain sufficient conditions for turning points of the estimating polynomial to exist and derive the analytic solutions for the turning points. The sufficient conditions and the analytic solutions must be expressed in terms of the estimated regression parameters.

*Step 3.* Set up the procedure to test whether the estimated sufficient conditions and analytic solutions are statistically significant within the estimating polynomial regression.

## 3 Data and specification tests

In this section, the data and specification tests are presented. Therefore, it is concerned with undertaking Step 1 of the methodology described in Section 2.

### *3.1 Data*

The primary source of data is Datastream, supplemented by the London Business School Risk Measurement Service (LBSRMS). Data relate to the UK financial services sector. The data set comprised a total of 111 firms, and included banks, merchant banks, insurance companies and insurance brokers. The sizes of firms in the data set are strongly positively skewed—indeed, J-shaped—as revealed in Fig. 1. Data on cross-sectional variables relate to June 1994. The rate of return data relate to dividends plus capital gains at the end of each firm's accounting period in 1994, computed relative to the same data in 1992.

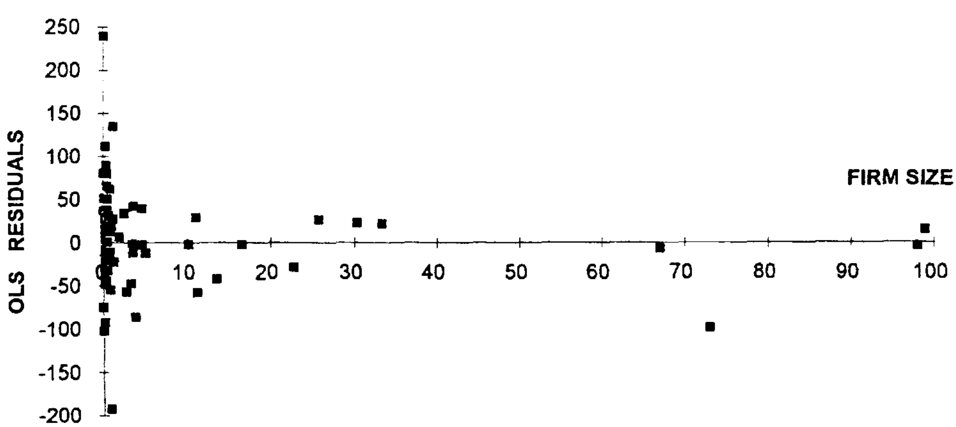


Fig. 1. Plot of ordinary least-squares (OLS) residuals against firm size.

The measure of firm performance that is used is the actual rate of return, denoted by ACROR, and is the percentage of capital appreciation plus the dividend yield over the year, where gross dividends are assumed to be reinvested in the firm's shares at the end of the month in which they are paid. This is an absolute measure of performance. However, the results are virtually unaffected even when the performance of the firm's shares relative to the market as a whole is used instead. In the interests of brevity, only results using ACROR are presented. Managerial shareholding is measured by the level of equity held by directors. The measure of directors' equity is equal to the sum of the percentage stake owned beneficially and non-beneficially by directors of each company. This variable is denoted by DIROWN. (Data on share options were not available.).

The relationship between managerial shareholding (DIROWN) as a cause and firm performance (ACROR) as an effect is the one that is used for illustrative purposes in this paper. (The direction of causality is the same as that used in the previous literature on this relationship. The validity of this assumption is not studied here.) To estimate this relationship, it is necessary to normalize for a number of company-specific financial factors. The first factor is the level of control exercised by the managers of the company. The measure of managerial control used is that proposed by Cubbin and Leech (1983). It takes account of the equity concentrated with the management, as well as the degree of dispersion of the remaining shares. It is defined to be

$$\alpha_1 = F\left[\frac{(m_1)}{(H - m_1^2)^{1/2}}\right] \tag{1}$$

where $F[.]$ is the standard normal distribution function, $m_1$ is the percentage holding of the largest shareholding group and $H$ is the Herfindahl index of concentration, defined as $H = \Sigma_j(m_j)^2$, where $m_j$ is the percentage holding of the $j$th largest shareholding group. The Cubbin–Leech index specified in equation (1) is denoted by ALPHA.

The second factor is the level of the firm's risk. The level of systematic risk is measured by BETA. This is the standard measure derived from the capital asset pricing model (CAPM) and is obtained from Datastream. The risk of non-market-related fluctuations in share prices is measured by the firm's coefficient of specific risk. This is denoted by SRISK and is obtained from the LBSRMS.

The third factor that must be taken into account is firm size. Given that the sample consists of firms in the financial services sector, the interpretation of measures of turnover is not straightforward. Therefore, the size of the firm is measured by using its capital base—specifically, the firm's market capitalization, denoted by MCAP. This methodology is open to the criticism that firms may differ in their technology, i.e. firms may use differing levels of capital intensity, so that two firms of the same size may have different levels of market capitalization. However, when market capitalization is compared with another input-based measure of firm size, i.e. employment, the two are in close agreement. This suggests that the technology, as represented by capital–labour intensity, is roughly the same for all firms in the industry. Consequently, market capitalization is a good measure of firm size.

The equation to be estimated is therefore of the form

$$\begin{aligned}\text{ACROR} = \theta_0 + \sum_{l=1}^{N} \theta_l\,(\text{DIROWN})^l + \gamma_1\,\text{ALPHA} + \gamma_2\,\text{BETA} \\ + \gamma_3\,\text{SPRISK} + \gamma_4\,\text{MCAP} + u\end{aligned} \tag{2}$$

TABLE 1. OLS estimation: Breusch–Pagan test for heteroscedasticity

| | Polynomial order | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 |
| $\chi^2$ statistic; ($p$-value) | 82.6344 (0.000) | 104.8610 (0.000) | 57.9607 (0.000) | 70.2863 (0.000) | 63.3167 (0.000) | 72.0805 (0.000) |
| Degrees of freedom | 4 | 5 | 6 | 7 | 8 | 9 |

where $u$ is the error term. The focus of the analysis is on the relationship between DIROWN and ACROR, so the other four regressors may be marginalized. Consequently, equation (2) may be rewritten as

$$\text{ACROR} = \theta_0 + \sum_{I=1}^{N} \theta_I\,(\text{DIROWN})^I + \Theta(.) + u \qquad (3)$$

where $\Theta(.)$ is the linear combination of the regressors ALPHA, BETA, SPRISK and MCAP. Therefore, the relationship between DIROWN and ACROR is conditional on the values of these four regressors.

### *3.2 Specification tests*

The equation to be estimated is equation (3), for varying values of the polynomial order $N$. Estimates are generated for all orders from 0 to 5, initially using ordinary least squares (OLS). However, examining the residual plots, we find considerable evidence of heteroscedasticity relating to firm size. (As an illustration of the problem, the residual plot of the polynomial regression of order 3 is depicted in Fig. 1.) This is confirmed by noting that the OLS estimates conclusively fail the test of Breusch and Pagan (1979). The values of the Breusch–Pagan statistic for polynomial regressions of order 0 to 5 are presented in Table 1.

Two alternative means of correcting for this problem are adopted. First, weighted least squares (WLS) estimates are generated using firm size as measured by employment as the weighting variable. It may be seen in Table 2 that using WLS ensures that the Breusch–Pagan test is satisfied for all the estimated polynomial orders. Secondly, the model is estimated with assumed multiplicative heteroscedasticity, using the method of maximum likelihood.

The WLS estimates are subjected to tests of regressor parsimony and to variable inclusion tests. It may be seen in Table 2 that the $R^2$ value (adjusted for degrees of freedom) rises continuously up to order 4 and then falls. This test is generally considered to be rather crude, because it does not adequately penalize the model for the loss of degrees of freedom. Therefore, two more sensitive tests for regressor parsimony are carried out, i.e. the Akaike information criterion and the Amemiya prediction criterion. Both are in agreement, indicating that the cubic specification ($N = 3$) provides the best fit to the data.

Variable inclusion is tested using the $F$ statistic from a series of stepwise regressions. The results of this test are also presented in Table 2 and support the specification suggested by the tests of regressor parsimony. In particular, variable inclusion results in a statistically significant improvement of fit up to the estimated polynomial order of 3. Thereafter, the introduction of higher order terms does not yield a significant improvement in fit.

TABLE 2. WLS and maximum-likelihood estimation: specification tests

| | Polynomial order | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 |
| *WLS estimates* | | | | | | |
| Breusch–Pagan $\chi^2$ | 7.336 | 6.550 | 6.427 | 5.446 | 7.472 | 5.336 |
| df | (4) | (5) | (6) | (7) | (8) | (9) |
| $p$-value | 0.1192 | 0.2560 | 0.3769 | 0.6056 | 0.4866 | 0.8041 |
| Adj. $R^2$ | 0.4729 | 0.5161 | 0.5112 | 0.5340 | 0.5505 | 0.5459 |
| Amemiya prediction criterion | 690.4169 | 640.5182 | 653.7684 | 609.7220 | 613.5576 | 626.1236 |
| Akaike information criterion | 12.3950 | 12.3199 | 12.3402 | 12.0026 | 12.2764 | 12.2964 |
| Stepwise $F$ statistic | — | 8.5646 | 9.3658 | 17.4291 | 2.7818 | 0.2273 |
| df | | (1,84) | (1,83) | (1,82) | (1,81) | (1,80) |
| $p$-value | | 0.0044 | 0.0030 | 0.0001 | 0.0992 | 0.6345 |
| *Maximum-likelihood estimates* | | | | | | |
| Stepwise likelihood ratio (LR) test: | — | 6.4894 | 9.1614 | 12.0098 | 3.7984 | 1.9076 |
| $\chi^2(1)$; ($p$-value) | | (0.0109) | (0.0025) | (0.0005) | (0.0513) | (0.1672) |

*Note*: df, degrees of freedom.

Next, a specification test is applied to the maximum-likelihood estimates. A likelihood ratio test is applied in a stepwise manner to assess the impact of including successively higher order polynomial terms. These results also appear in Table 2. It may be seen that inclusion of higher order terms cannot be rejected for estimating polynomials up to order 3. However, the inclusion of the terms of the fourth and fifth powers may be rejected. Here again, the specification indicated is cubic.

## 4 Estimation of turning points

This section describes Steps 2 and 3 of the turning point location methodology given in Section 2. The appropriate polynomial has now been chosen. In Step 2, the analytic solution must be derived and expressed in terms of the estimated regression parameters. It may be noted that the relevant specification is

$$\text{ACROR} = \theta_0 + \theta_1\,(\text{DIROWN}) + \theta_2\,(\text{DIROWN})^2 + \theta_3\,(\text{DIROWN})^3 + \Theta(.) \quad (4)$$

by substituting the order $N = 3$ into equation (3). Whether or not equation (4) possesses turning points depends on its derivative, because turning points, by definition, are local extrema. Thus, equation (4) will exhibit turning points if its derivative has real roots. These roots are the turning points of the cubic. The derivative may be written as

$$\frac{\partial \text{ACROR}}{\partial \text{DIROWN}} = \theta_1 + 2\theta_2\,(\text{DIROWN}) + 3\theta_3\,(\text{DIROWN})^2 \quad (5)$$

A necessary and sufficient condition for equation (5) to have different real roots is

$$\theta_2^2 - 3\theta_1\theta_3 > 0 \quad (6)$$

Of course, even if one or two real roots exist, there is no guarantee that they lie between 0 and 100, which are the realistic boundary values for DIROWN. Thus, to have real roots that are relevant, not only must equation (6) be satisfied, but the roots must also lie between 0 and 100.

TABLE 3. WLS and maximum-likelihood estimation: cubic specification

| Regressor | WLS estimates | Maximum-likelihood estimates[a] |
|---|---|---|
| Constant | − 118.66 (3.43)*** | − 98.568 (2.09)* |
| ALPHA | 1.6880 (2.90)** | 0.95748 (2.57)* |
| BETA | 91.332 (3.84)*** | 82.094 (3.48)*** |
| SPRISK | 0.2456 (0.40) | 1.3470 (2.74)** |
| MCAP | − 0.005095 (2.65)** | − 0.003474 (2.55)* |
| DIROWN | 4.3445 (2.48)* | 5.4165 (3.33)*** |
| $(\text{DIROWN})^2$ | − 0.28142 (2.27)* | − 0.34171 (2.27)* |
| $(\text{DIROWN})^3$ | 0.005384 (2.25)* | 0.005971 (2.21)* |
| *Estimates of the variance process* | | |
| $(S_u)^2$ | — | 3215.3 (6.64)*** |
| SIZE | — | − 0.037597 (4.61)*** |
| *Diagnostics* | | |
| Log-likelihood | − 543.9371 | − 523.9665 |
| Adj. $R^2$ | 0.5340 | — |
| Joint exclusion restriction on DIROWN coefficients $F$ statistic, (3,82); $p$-value | 13.3225; 0.0000 | — |
| Joint exclusion restriction on DIROWN coefficients LR test $\chi^2(3)$; $p$-value | 14.2886; 0.00254 | 21.6958; 0.0000 |
| Iterations | — | 28 |

*Notes*: $t$ statistics are in parentheses. Estimates significant at the 5%, 1% and 0.2% level are marked with *, ** and ***, respectively. Dependent variable, ACROR.

[a] The estimated model is the linear model with multiplicative heteroscedasticity. It sets the conditional variance as a linear function of firm size. OLS estimates are used as starting values.

Equation (6) is a non-linear restriction on the parameters of the problem. Therefore, the existence of turning points requires that the parameters $\theta_1$, $\theta_2$ and $\theta_3$ be individually and jointly non-zero (to confirm the cubic specification), and that equation (6) holds.

Finally, assuming that equation (4) has turning points, these will be a local maximum followed by a local minimum if the derivative has a minimum value which is negative. The reverse is true if the derivative has a minimum value which is positive.

The analytic solutions, the implied restrictions and the appropriate tests have now been specified in terms of the parameters of the estimating polynomial. This completes Step 2 of the methodology.

In Step 3, it is necessary to examine the estimating polynomial and test the above restrictions on the parameters. The WLS and maximum-likelihood estimates of equation (4) are presented in Table 3, together with the relevant diagnostics. The estimates of the parameters $\theta_1$, $\theta_2$ and $\theta_3$ are individually found to be significantly different from zero, using the standard $t$ test. Furthermore, the hypothesis of their being jointly zero is strongly rejected. This conclusion is based on a likelihood ratio test run on the joint exclusion restriction of all three DIROWN coefficients for the WLS and the maximum-likelihood estimates. In the case of the WLS estimates, a joint $F$ test on the restricted residuals supports the same conclusion.

Using the estimates of the parameters $\theta_1$, $\theta_2$ and $\theta_3$, it is possible to compute numerical estimates of the turning points of equation (4). However, while the

TABLE 4. Estimation of turning points in the effect of managerial shareholding on the firm's rate of return

| | WLS | Maximum likelihood |
|---|---|---|
| $\theta_1$ | 4.3445 | 5.4165 |
| $\theta_2$ | −0.28142 | −0.34171 |
| $\theta_3$ | 0.00538 | 0.00597 |
| Negative root | 11.5412 | 11.2317 |
| Positive root | 23.3065 | 26.9249 |
| Equation (5) min. value | −0.5589 | −1.1028 |
| $\theta_2^2 - 3\theta_1\theta_3$ | 0.00908 | 0.01976 |
| ($t$ statistic) | (2.16) | (3.00) |
| Wald test: $\chi^2(1)$ | 4.6618 | 9.0146 |
| ($p$ value) | (0.0400) | (0.0053) |

*Notes*: The estimated derivative is

$$\frac{\partial \text{ACROR}}{\partial \text{DIROWN}} = 3\theta_3\,\text{DIROWN}^2 + 2\theta_2\,\text{DIROWN} + \theta_1$$

The roots and minimum value of this derivative are presented in the table. $\theta_2^2 - 3\theta_1\theta_3 > 0$ guarantees that the derivative has two real roots. This is a non-linear restriction on the parameters and is tested using a non-linear Wald test.

hypothesis of these parameters being individually and jointly zero has been rejected, it remains to be established that the non-linear restriction in equation (6) is satisfied and that the estimated value is statistically significant. This non-linear restriction may be tested using a Wald test, which generates a $\chi^2$ statistic with one degree of freedom. In addition, because the sample size is large, the relevant asymptotic standard error may be estimated with a linear Taylor series approximation. This standard error may be used to run a fairly reliable $t$ test on the significance of the estimated value of the restriction.

The results of the turning point estimation exercise are presented in Table 4. The estimates of the parameters $\theta_1$, $\theta_2$ and $\theta_3$ are used to compute the roots of equation (5), and the derivative extremum occurs at DIROWN $= (-\theta_2/3\theta_3)$. This extremum is verified to be a minimum using the estimated second-order conditions. The Wald test indicates that the restriction in equation (6) is satisfied, and the associated $t$ test supports this finding.

Examining the solutions for the roots of equation (5) in Table 4, it may be seen that the estimated relation between managerial shareholding and firm performance is non-monotonic. The WLS and the maximum-likelihood estimates, which make an explicit correction for heteroscedasticity, indicate that the relation is positive for a managerial shareholding of between 0% and approximately 11%. It is then negative between approximately 11% and 25%. This effect has been called the 'entrenchment effect' in the literature (Jensen & Meckling, 1976; Fama & Jensen, 1983; Jensen & Ruback, 1983). When managerial shareholding exceeds about 25%, the relationship becomes positive again—an effect that has been called the 'convergence effect'.

Under the entrenchment effect, a greater managerial stake entrenches and insulates management from the market for corporate control. This results in weaker incentives for managers to maximize profits as their protection from takeover increases. Under the convergence effect, the relationship between managerial stake and market value of the firm is positive, as management and shareholder interests

TABLE 5. Convergence and entrenchment effects in the sample firms

| | Managerial shareholding (DIROWN) | | |
|---|---|---|---|
| | 0–11% | 12–25% | 26–100% |
| Predominant effect | Convergence | Entrenchment | Convergence |
| No. of firms | 80 | 12 | 19 |
| Percentage of firms | 72.07 | 10.81 | 17.12 |

converge. These two effects are at odds with one another, and it is theoretically impossible to prove which will dominate. Our estimates seem to indicate that the entrenchment effect dominates for managerial shareholdings between about 11% and 25%. (The number of firms in each of the three estimated categories is provided in Table 5.)

It is not the objective of this study to examine the effect of financial variables on the performance of firms in the financial sector. None the less, it is interesting to note that increases in BETA are associated with higher returns, as would be predicted by the CAPM (see, for example, Sharpe, 1978.) Furthermore, increasing levels of managerial control (as opposed to ownership), as measured by ALPHA, are also associated with higher returns.

## 5 Concluding remarks

This paper has illustrated a method for estimating turning points in non-monotonic relationships, highlighting the statistical testing procedures that become relevant. It is particularly suited to situations where the existence of turning points needs to be established, and it is a convenient way of estimating the number and location of regime switches. Obviously, this means that it is unsuitable for use in situations where the expected number of turning points is extremely large, because the procedure would then require estimating a polynomial of a very high order. This would suggest that it is most suitable for use with cross-sectional data. However, with time series data, where the concern is with estimating the location of the next turning point over a short time horizon, the methodology may have some applicability.

## REFERENCES

ARTIS, M. J., BLADEN-HOVELL, R. C., OSBORN, D. R., SMITH, G. W. & ZHANG, W. (1995) Turning point prediction for the UK using CSP leading indicators, *Oxford Economic Papers*, 47, pp. 397–417.

BERK, J. M. & BIKKER, J. A. (1995) International interdependence of business cycles in the manufacturing industry: the use of leading indicators for forecasting and analysis, *Journal of Forecasting*, 14, pp. 1–23.

BREUSCH, T. & PAGAN, A. (1979) A simple test for heteroscedasticity and random coefficient variation, *Econometrica*, 47, pp. 1287–1294.

CHEN, R., HAWALESHKA, O. & STRONG, D. R. (1995) Analytical approach for determining the cost optimum raw material quality level, *Journal of Applied Statistics*, 22, pp. 375–388.

CUBBIN, J. & LEECH, D. (1983) The effect of shareholding dispersion on the degree on control in British companies: theory and measurement, *Economic Journal*, 93, pp. 351–369.

DE LEEUW, F. (1991) Towards a theory of leading indicators. *In:* K. LAHIRI & G. H. MOORE (Eds), *Leading Indicators: New Approaches and Forecasting Records* (Cambridge, Cambridge University Press).

DIEBOLD, F. X. & RUDEBUSCH, G. D. (1989) Scoring the leading indicators, *Journal of Business*, 62, pp. 369–391.

DIEBOLD, F. X. & RUDEBUSCH, G. D. (1991) Turning point prediction with the composite leading index. *In:* K. LAHIRI & G. H. MOORE (Eds), *Leading Indicators: New Approaches and Forecasting Records* (Cambridge, Cambridge University Press).

FAMA, E. F. & JENSEN, M. C. (1983) Separation of ownership and control, *Journal of Law and Economics*, 26, pp. 301–325.

HERMALIN, B. & WEISBACK, M. S. (1991) The effect of board composition and direct incentives on corporate performance, *Financial Management*, 20, pp. 101–112.

JARREL, G. & POULSEN, A. (1988) Dual-class recapitalization as an anti-takeover mechanism: the recent evidence, *Journal of Financial Economics*, 20, pp. 87–128.

JENSEN, M. C. & MECKLING, W. H. (1976) Theory of the firm: managerial behavior, agency costs and ownership structure, *Journal of Financial Economics*, 3, pp. 305–360.

JENSEN, M. C. & RUBACK, R. (1983) The market for corporate control: the scientific evidence, *Journal of Financial Economics*, 11, pp. 5–50.

MCCONNELL, J. J. & SERVAES, H. (1990) Additional evidence on equity ownership and corporate value, *Journal of Financial Economics*, 27, pp. 595–612.

MEHRAN, H. (1995) Executive compensation structure, ownership and firm performance, *Journal of Financial Economics*, 38, pp. 163–184.

MORCK, R., SHLEIFER, A. & VISHNY, R. W. (1988) Management ownership and market valuation: an empirical analysis, *Journal of Financial Economics*, 20, pp. 293–315.

NEFTCI, S. N. (1982) Optimal prediction of cyclical downturns, *Journal of Economic Dynamics and Control*, 4, pp. 225–241.

NEMIRA, M. P. (1991) An international application of Neftci's probability approach for signalling growth recessions and recoveries using turning point indicators. *In:* K. LAHIRI & G. H. MOORE (Eds), *Leading Indicators: New Approaches and Forecasting Records* (Cambridge, Cambridge University Press).

SHARPE, W. F. (1978) *Investments*, 2nd Edn (Englewood Cliffs, NJ, Prentice-Hall).

VACCARA, B. N. & ZARNOWITZ, V. (1977) How good are the leading indicators?, *Proceedings of the Business and Economic Statistics Section*, pp. 41–50 (American Statistical Association).

WRUCK, K. H. (1988) Equity ownership concentration and firm value, *Journal of Financial Economics*, 23, pp. 3–28.