Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
International Review of Financial Analysis 14 (2005) 304–325
IRFA
INTERNATIONAL REVIEW OF
Financial Analysis

The valuation relevance of R&D expenditures: Time series evidence

Jeffrey L. Callen*, Mindy Morel

Rotman School of Management, University of Toronto, 105 St. George Street, Toronto, Ontario, Canada M5S2E3

Abstract

The literature on the valuation relevance of R&D investments is based primarily on cross-sectional regressions or panel data regressions with time and firm (or industry) fixed effects such that the parameters relating R&D to market value are cross-sectionally constant. In an alternative approach, this paper investigates the value relevance of R&D investment using an earnings-based time series valuation model. Model parameters are estimated for each firm separately. In contradistinction to the results obtained from cross-sectional and fixed effects panel models, this study finds weak empirical support at best for the value relevance of R&D expenditures at the firm level.

JEL classification: G12; O32
Keywords: R&D; Market value; Time series; Ohlson model

1. Introduction

There is an extensive empirical literature showing that security prices impound the information contained in R&D investment.[1] Most studies measure R&D investment in terms of contemporaneous (and sometimes lagged) R&D expenditures. Other studies measure R&D investment in terms of some estimate of R&D capital. With few exceptions, these studies find that the impact of R&D on firm market values is significant and positive

* Corresponding author. Tel.: +1 416 946 5641; fax: +1 416 971 3048.
E-mail address: callen@rotman.utoronto.ca (J.L. Callen).

1057-5219/$ - see front matter
doi:10.1016/j.irfa.2004.10.007

irrespective of how R&D is measured.[2] The only significant exceptions to date are variance decomposition studies that find that R&D investment explains very little if any of the variance of firm (industry) returns.[3]

The purpose of this paper is to test the value relevance of R&D investment in a time series context. Despite the apparent robust result that R&D investment has a positive and significant effect on market values, we find that in a firm-level time series context the relationship between R&D and market values is significant at conventional levels for no more than 25% of our sample (and often far less), depending upon the specific valuation model. Much of the empirical evidence to date concerning the value relevance of R&D investment is based upon (pooled or annual) cross-sectional regressions.[4] The cross-sectional approach makes use of comparisons across firm (or industry) expenditures on R&D. The primary advantage of the cross-sectional approach comes where R&D expenditures vary substantially across firms and where there are a large number of sample firms. Then the data yield multiple comparisons from which the effects of R&D on market value may be isolated. However, comparisons across firms can only isolate the effects of R&D if they control for other influences on market value that may vary from one firm to the next. For example, most studies control for firm size because market values are likely to be at least partially size driven as are R&D expenditures. Absent a control for size, the relationship between market value and R&D may be spurious and size driven. Unfortunately, it is not always possible to observe and control for all firm differences that could affect market values. For example, no cross-sectional study relating R&D and market values to date has controlled for the talent and expertise of the managerial team, which may be driving both firm market values and R&D expenditures. This possibility of correlated omitted variables bias is the primary disadvantage of cross-sectional models of R&D. Moreover, in an attempt to solve the correlated omitted variables problem, ad hoc control variables may be included in the regressions having no intrinsic relationship to the

[1] Ballester, Garcia-Ayuso and Livnat (2003), Ben-Zion (1984), Bublitz and Ettredge (1989), Chan, Martin and Kensinger (1990), Chauvin and Herschey (1993, 1994), Cockburn and Griliches (1988), Connolly and Hirschey (1984), Doukas and Switzer (1992), Green, Stark, and Thomas (1996), Griliches (1981), Hall (1993a,b), Hirschey (1982, 1985), Hirschey and Spencer (1992), Hirschey and Weyengandt (1985), Johnson and Pazderka (1993), Jose, Nichols and Stevens (1986), Joseph (2001), Kotabe, Srinivasan and Aulakh (2002), Lev and Sougiannis (1996), Lev and Zarowin (1998), Pakes (1985), Sougiannis (1994), Sundaram, John and John (1996), Szewczyk, Tsetsekos and Zantout (1996), Woolridge (1988), Wu and Wei (1998), Zhao (2002). Hall (2000) provides a partial summary of the literature.

[2] There is also an extensive parallel literature on the relationship between market values and patents. Except for a number of studies that include both R&D and patents as explanatory variables, the patent literature is beyond the scope of this paper. However, it is worth noting that the relationship between R&D expenditures and market values is typically far more robust than the relationship between patents (counts or citations) and market values. Moreover, when both patent data and R&D expenditures are included as explanatory variables the former are often insignificant. There is some evidence that this may be due to the high correlation between them. On these issues, see Bosworth and Rogers (2001).

[3] See Lach and Schankerman (1989) and Toivanen and Stoneman (1998). In cross-sectional regressions, by contrast, Chan, Lakonishok, and Sougiannis (2001) find that R&D intensity and return volatility are positively correlated.

[4] See Ashenfelter, Ashmore, Baker, Gleason, and Hasken (2004) for an enlightening discussion of the econometric differences between cross-sectional and fixed effects panel techniques.

underlying model being tested. Finally, the coefficient estimates in cross-sectional studies may be unduly influenced by firm outliers.

A few studies use panel data techniques—specifically fixed firm (or industry) and time effects—to determine the relationship between R&D and firm market values by exploiting variations in R&D at fixed times.[5] This approach uses information on changes in R&D expenditures for a given firm (industry) at fixed times to measure the impact of R&D on firm value. The primary advantage of panel data techniques is that they mitigate the correlated omitted variables bias where most unobservable factors affecting firm value are unlikely to vary much for a given firm during a short time period. But, there are a number of disadvantages. First, the studies to date have limited time series so that estimates of R&D on market value may be quite imprecise. Second, even in those R&D studies where panel data techniques are used, except for time and firm intercept dummy effects, the crucial parameters of the model (such as the parameter relating R&D to market value) are assumed to be cross-sectionally constant. But, the parameter relating R&D to firm value may differ across firms. Third, fixed effects models tend to exacerbate the potential bias from measurement error in the explanatory variables biasing the parameter estimates to zero.[6] Fourth, unless autocorrelation of the errors is accounted for, the random variation in the dependent variable may be correlated over time so that the precision of the parameter estimates may be overstated.

An alternative approach used in this paper is to estimate the model on a firm-by-firm time series basis, accounting for potential autocorrelation in the errors and non-stationarity.[7] Not only does this approach mitigate the outlier problem but also, in a time series, each firm is its own control, so that the problem of correlated omitted variables is mitigated as well. This does not mean that a time series approach is a panacea. For one, panel data techniques are more efficient, although our sample size is sufficiently large that the loss in efficiency is unlikely to be critical. Also, a sufficiently lengthy time series of annual data naturally leads to survivorship bias so that the results may not generalize to the population at large. Survivorship bias is unlikely to be of issue in this study. Survivorship biases the results towards finding a positive relationship between R&D and market value since it is precisely successful firms that are likely to have benefited from R&D. Thus, the empirical evidence in this study of almost no relationship between market value and R&D is even more compelling.[8] Finally, there is the issue of stationarity. Accounting and market data tend to exhibit unit roots and they generally do not cointegrate.[9] As a result, time series regressions

[5] See, for example, Bosworth and Rogers (2001), Bosworth, Wharton and Greenhalgh (2000), Jaffe (1986), Kotabe et al. (2002).

[6] For discussions and evidence of this problem in the context of the R&D market value relation, see Bosworth and Rogers (2001), Bosworth et al. (2000) and Johnston and Dinardo (1997, p. 400).

[7] Ballester et al. (2003) analyze R&D expenditures using both cross-sectional and time series models. They find that the two approaches yield quite different parameter estimates, although in both cases R&D is significant. However, since they disregard unit root and cointegration issues, their time series results are difficult to interpret.

[8] Another option is to use quarterly data. However, besides the unit root issue, quarterly data raise significant seasonality problems both with respect to the econometrics and the modeling. The modeling would require significant modifications such as incorporating a quarterly earnings dynamic in the style of Brown and Rozeff (1979), for example.

[9] For a recent study, see Qi, Wu, Xiang (2000).

involving market prices and accounting numbers are likely to yield spurious coefficient estimates.[10] This issue is addressed in the paper.

One should not interpret this study to imply that the time series approach is superior to other approaches and that the prior literature alone is problematic. All approaches have their strengths and weaknesses. Rather, the lesson to be learned is that the seemingly ubiquitous finding that market values are significantly and positively related to R&D depends both upon the econometric approach taken and the underlying valuation model. The relationship between market values and R&D is simply not as robust as most of the literature appears to indicate.

The paper is structured as follows. Section 2 briefly develops the valuation models. Section 3 describes the sample. Section 4 tests for unit roots and cointegration of the valuation equations. Section 5 estimates the models and presents the results. Section 6 briefly concludes.

2. The valuation models

2.1. The basic model

The purpose of this paper is to investigate the value relevance of R&D expenditures using firm-level time series data. In order to accommodate the impact of R&D expenditures on earnings and, hence, market values, we utilize modified versions of the linear valuation model proposed by Ohlson (1995). In addition to the fact that this model derives an explicit relationship between R&D and market value in a rigorous fashion, the model has a number of other characteristics that are useful in a study of this sort. First, despite the dynamic structure of the Ohlson model, the model's simplicity lends itself to empirical estimation. Second, by replacing dividends with (abnormal) earnings, the model ostensibly allows for estimating the firm value of non-dividend paying firms.[11] Third, by replacing dividends with (abnormal) earnings, the model makes use of the well-known empirical result that earnings are a better predictor of future firm returns than are cash flows.[12] This model is not without cost, however. In particular, the model assumes that (abnormal) earnings and R&D expenditures follow a multivariate AR(1) process ad infinitum. In particular, this means that the optimization process leading to the time series of R&D investments is not modeled directly.

It is worth noting that the Ohlson model is very similar in structure to the Hayashi and Inoue (1991) model utilized by Hall (1993b) in her well-known R&D study. The essential difference is that the Hayashi and Inoue model specifies the replacement cost value of the firm's assets as the benchmark with future rents defined in terms of excess returns above replacement cost value, whereas the Ohlson (1995) model specifies the book value of the

[10] See Granger and Newbold (1974).

[11] This is not a trivial consideration since approximately 25% of firms on the NYSE do not pay dividends currently.

[12] See Rayburn (1986), for example.

firm's assets as the benchmark with future rents defined in terms of excess earnings above the return to initial book value.[13] In the absence of replacement cost data, Hall (1993b) is forced to use book value data, which is inconsistent with the underlying Hayashi and Inoue model.

The Ohlson (1995) valuation model is derived from three assumptions. First, following the non-arbitrage arguments of Rubinstein (1976), firm value is assumed to be equal to the present value of expected future dividends conditional on current information. Second, a linear dynamic—describing the evolution over time of the firm's abnormal earnings and the evolution over time of a variable representing information other than earnings and book value—is assumed to follow a stationary multivariate AR(1) process. Abnormal earnings are defined as earnings less the product of the firm's cost of capital and the beginning period book value of the firm's assets.[14] The AR(1) assumption is based on the intuition that a firm's abnormal earnings are bound to mean revert because of competitive forces. Third, the model utilizes the accounting Clean Surplus identity to substitute accounting numbers for dividends, so that price can be written as the present value of future abnormal earnings.[15]

These three assumptions can be written formally as:

$$P_t = \sum_{\tau=1}^{\infty} R^{-\tau} E_t[d_{t+\tau}] \tag{1}$$

$$x^{\mathrm{a}}_{t+1} = \omega\, x^{\mathrm{a}}_t + v_t + \varepsilon_{1t+1} \tag{2a}$$

$$v_{t+1} = \gamma v_t + \varepsilon_{2t+1} \qquad 1>\omega, \gamma \geq 0 \tag{2b}$$

$$d_t = x^{\mathrm{a}}_t - \mathrm{bv}_t + R\ \mathrm{bv}_{t-1} \tag{3}$$

where P_t=firm value at the end of period t, d_t=dividends during period t, x_t=earnings during period t, bv_t=book value of common equity at the end of period t, ω,γ=parameters of the processes, R=one plus the firm's cost of capital,[16] ε_{it+1}=white noise error terms (i=1,2), $x^{\mathrm{a}}_t = x_t - (R-1)\mathrm{bv}_{t-1}$=abnormal earnings during period t. E_t=expectations operator at time t. v_t=a variable denoting information other than earnings and book values during period t.

[13] The finance literature defines excess earnings in a number of different ways, such as earnings above the return to total capital. The Ohlson definition of excess earnings is more than a matter of taste. It is essentially model driven.

[14] This product is an estimate of the firm's expected earnings in the coming year from assets in place.

[15] The Clean Surplus identity states that end of period book value is equal to beginning of period book value plus earnings less dividends, $\mathrm{bv}_t = \mathrm{bv}_{t-1} + x_t - d_t$. Eq. (3) is this identity transformed, however, by substituting abnormal earnings for earnings.

[16] Ohlson assumes a unique risk neutral probability measure. Risk is adjusted for in the numerator and the appropriate discount factor is the risk free rate. Since it is impossible for the empiricist to specify the synthetic probabilities for risk adjustment in the numerator, we make the same "leap of faith" as do all other empirical studies in this literature by assuming that risk is adjusted for in the denominator via the cost of capital.

Eq. (1) is the standard present value formula stated in terms of expected future dividends. Eq. (2a) describes the evolution of abnormal earnings. Most importantly, it should be noted that the evolution of abnormal earnings is affected directly by the information variable (v_t). Eq. (2b) describes the evolution of the information variable (v_t). Eq. (3) is the accounting Clean Surplus identity defined in terms of abnormal earnings.

Ohlson shows that these three assumptions yield the valuation equation:[17]

$$P_t = \mathrm{bv}_t + \frac{\omega}{(R-\omega)} x_t^{\mathrm{a}} + \frac{R}{(R-\omega)(R-\gamma)} V_t \tag{4}$$

In words, this dynamic valuation equation states that the value of the firm at time t is equal to the contemporaneous book value of the firm's assets plus goodwill where goodwill is measured as a multiple of contemporaneous abnormal earnings plus a multiple of the contemporaneous information variable.

2.2. The modified models

The value relevance of R&D expenditures in this study is evaluated through the prism of two modified versions of the Ohlson model. These modifications are necessary in order to accommodate non-stationary data. The fact that accounting data and market prices generally exhibit unit roots is well known. Our sample is no exception. Specifically, Section 4 below demonstrates that one cannot reject the hypotheses that each of (abnormal) earnings, book values of equity, security prices and R&D expenditures exhibit unit roots. On the other hand, the hypotheses that the first differences of these variables have unit roots are rejected. These empirical results lead us (1) to model R&D expenditures both as a random walk and as an IAR(1,1) process and (2) to model abnormal earnings as a random walk with drift conditional on R&D expenditures.[18]

R&D expenditures are assumed to affect price in the Ohlson model in two ways. First, R&D expenditures are in fact expenses, an outflow of resources from the firm. Therefore, R&D expenditures are assumed to negatively affect security prices through their normal impact on current (abnormal) earnings and book values, as would administrative expenses, for example. Second, current R&D expenditures are assumed to affect expected future earnings by providing capital markets with (noisy) information about those future earnings. Although the information contained in current R&D expenditures are valuable to the capital markets, it would not be reflected in current earnings or book values. Rather, it would be reflected in expected future earnings as modeled by the information variable v_t.

The two modifications of the model differ in terms of the assumed dynamic of R&D expenditures and also, as we shall see, in their treatment of the informational content of R&D expenditures. In the random walk model, the levels of R&D expenditures are assumed to be the information variable, whereas in the IAR(1,1) model, changes in R&D

[17] The transversality condition $\lim R_t^{-k}\, y_{t+k}=0$ as $k \rightarrow \infty$ must also be assumed.

[18] We obtain similar results when R&D expenditures are modeled as a random walk with drift.

expenditures are assumed to be the information variable. In effect, the random walk-levels model assumes that the time series of R&D expenditures provides value relevant information about future earnings. The IAR(1,1)-changes model assumes that the time series of changes in R&D expenditures provides value relevant information about future earnings.

More formally, the information dynamic of the random walk-levels model takes the form:

$$\Delta x_t^{\mathrm{a}} = a + \theta_1 \mathrm{RD}_{t-1} + \theta_2 \mathrm{RD}_{t-2} + \varepsilon_{1,t} \tag{5a}$$

$$\Delta \mathrm{RD}_t = \varepsilon_{2,t} \tag{5b}$$

where Δ is the first-differencing operator, RD_t denotes R&D expenditures in year t and a, θ_1, θ_2 are parameters. It is shown in Appendix A that, together with the other standard assumptions of the Ohlson model listed in Section 2.1, this information dynamic yields the valuation equation:

$$P_t = \frac{Ra}{(R-1)^2} + \mathrm{bv}_t + \frac{1}{(R-1)} x_t^{\mathrm{a}} + \frac{\theta_1 R}{(R-1)^2} \mathrm{RD}_t + \frac{\theta_2 R}{(R-1)^2} \mathrm{RD}_{t-1} \tag{6}$$

This version of the model is essentially the same as the original Ohlson framework but with three minor modifications. First, because abnormal earnings exhibit unit roots but their first differences do not, it is assumed that abnormal earnings are a random walk with drift conditional on R&D expenditures. Second, it is assumed that the information variable in the Ohlson model (v_t) is R&D expenditures. Moreover, abnormal earnings are potentially affected by two periods of R&D expenditures. Clearly, R&D expenditures are not valuation relevant if both θ_1 and θ_2 are zero. If only one of θ_1 or θ_2 is non-zero, then only one period's R&D expenditures is valuation relevant. Third, because R&D expenditures exhibit unit roots but their first differences do not, R&D expenditures are assumed to be a random walk.

It is important to note that the lag structure of the abnormal earnings dynamic [Eq. (5a)] determines the lag structure of valuation Eq. (6). As shown by Morel (1999), a linear lag structure for R&D expenditures of order q in the earnings dynamic necessarily generates a linear lag structure for R&D expenditures of order $q-1$ in the valuation equation. Therefore, any assumed lag structure in the valuation equation that does not correspond to the lag structure of the earnings dynamic is arbitrary and implies that R&D is valued for its own sake rather than what it implies about future earnings. To see this, suppose that Eq. (6) is arbitrarily assumed to include two lags of R&D expenditures (in addition to contemporaneous R&D expenditures), instead of just one lag. This would imply that in addition to the information conveyed by R&D expenditures about future earnings, RD_{t-2} is also valuable to the capital markets. But since RD_{t-2} does not enter the valuation equation as a consequence of the relationship between R&D and future earnings, it must be that RD_{t-2} is valuable for its own sake.

This has implications for the econometrics. Since the structure and the parameters of the earnings dynamic and the R&D dynamic [Eq. (5a,b)] determine the structure

and the parameters of the valuation Eq. (6), all three equations should be estimated as a system. The estimation of Eq. (6) is problematic, however, because, as we shall see in Section 4, non-cointegration of the variables in Eq. (6) cannot be rejected for most of the firms in our sample. Therefore, we also estimate this model in the first difference form:

$$\Delta x_t^{\mathrm{a}} = \Delta x_{t-1}^{\mathrm{a}} + \theta_1 \Delta \mathrm{RD}_{t-1} + \theta_2 \Delta \mathrm{RD}_{t-2} + \varepsilon_{1,t} \tag{7a}$$

$$\Delta \mathrm{RD}_t = \varepsilon_{2,t} \tag{7b}$$

$$\Delta P_t = \Delta \mathrm{bv}_t + \frac{1}{(R-1)} \Delta x_t^{\mathrm{a}} + \frac{\theta_1 R}{(R-1)^2} \Delta \mathrm{RD}_t + \frac{\theta_2 R}{(R-1)^2} \Delta \mathrm{RD}_{t-1} \tag{8}$$

The IAR(1,1)-changes model—the second modified version of the Ohlson model—is characterized by the alternative information dynamic:

$$\Delta x_t^{\mathrm{a}} = a + \theta \Delta \mathrm{RD}_{t-1} + \varepsilon_{1,t} \tag{9a}$$

$$\Delta \mathrm{RD}_t = b + \gamma \Delta \mathrm{RD}_{t-1} + \varepsilon_{2,t} \tag{9b}$$

It is shown in Appendix A that the information dynamic consisting of Eq. (9a,b) yields the valuation equation:

$$P_t = \frac{aR}{(R-1)^2} + \frac{\theta b R}{(1-\gamma)(R-1)^2} - \frac{\theta b R}{(1-\gamma)\left[\left(R-(1-\gamma)^2\right)\right]} + \mathrm{bv}_t + \frac{1}{(R-1)} x_t^{\mathrm{a}} + \frac{\theta\ R}{(R-1)(R-\gamma)} \Delta \mathrm{RD}_t \tag{10}$$

If θ is equal to zero then changes in R&D expenditures are not value relevant. Otherwise, they are value relevant. Again, since we find below that non-cointegration of the variables in Eq. (10) cannot be rejected for most of the firms in our sample, we also estimate a first differences form, thereby yielding the alternative system:

$$\Delta x_t^{\mathrm{a}} = a + \theta \Delta \mathrm{RD}_{t-1} + \varepsilon_{1,t} \tag{11a}$$

$$\Delta \mathrm{RD}_t = b + \gamma \Delta \mathrm{RD}_{t-1} + \varepsilon_{2,t} \tag{11b}$$

$$\Delta P_t = \Delta \mathrm{bv}_t + \frac{1}{(R-1)} \Delta x_t^{\mathrm{a}} + \frac{\theta R}{(R-1)(R-\gamma)} (\Delta \mathrm{RD}_t - \Delta \mathrm{RD}_{t-1}) \tag{12}$$

In summary, we evaluate four models in total: (a) two for which the level of R&D expenditures is valuation relevant and R&D expenditures are a random walk and (b) two

Table 1
Distribution of sample by industry

SIC codes	Industry	Number of firms
1000–1999	Mining/Construction	5
2000–3999	Manufacturing	264[a]
4000–4999	Regulated	3
5000–5999	Wholesale/Retail	4
7000–9999	Services	8
1000–9999	Total	284

This table shows the number of sample firm-observations by two-digit SIC codes and industry.
[a] Of these, 90 firms are in the 2000–2999 range and 174 firms are in the 3000–3999 range.

for which changes in R&D expenditures are valuation relevant and R&D expenditures are IAR(1,1).

3. Sample selection

The sample is selected from the period 1962 to 1996, a maximum of 34 years of annual data. The sample selection criteria follow.

(1) The following financial data must be available for each firm on at least 25 years of Compustat Primary, Secondary, and Tertiary, Full Coverage, and Research Annual Industrial Files:[19] annual earnings, book values of equity, total liabilities, common equity shares outstanding, the adjustment factor for stock splits and dividends, and the closing price at the end of the third month after the firm's fiscal year-end.[20]
(2) Firms with less than 16 years of R&D expenditure data are excluded.
(3) Book values of equity must be greater than zero.
(4) Firms in the financial sector are excluded.

The selection process yielded 284 firms with a total of 6819 firm-years of data, approximately 24 annual data points per firm. The distribution of sample-firm one digit SIC codes is listed in Table 1. Because of the R&D expenditures filter (2), it is not surprising to find that most sample firms are in manufacturing.

[19] The 25-year requirement limits the generality of this paper because of potential survivorship bias. It is necessitated by the firm-level time series analysis.
[20] Annual earnings are defined as earnings per share before extraordinary items and discontinued operations (Annual Compustat item 58), book value is defined as common equity (Annual Compustat item 60), and price is defined as the closing price at the end of the third month of the first quarter after the firm's fiscal year-end (Quarterly Compustat item 14). All items that are listed in per share form are scaled by the adjustment factor (Annual Compustat item 27). Since this study investigates whether annual earnings and book values are reflected in stock price valuation and since annual earnings are generally released towards the end of the first quarter, stock prices at the end of the first quarter are used in the analysis.

Table 2
Pearson–Spearman correlations

Panel A

	x'_t	bv_t	RD_t	RD_{t-1}	RD_{t-2}
x'_t	–	0.308	0.215	0.140	0.114
bv_t	0.360	–	0.838	0.799	0.756
RD_t	0.235	0.850	–	0.923	0.855
RD_{t-1}	0.195	0.819	0.906	–	0.931
RD_{t-2}	0.191	0.783	0.836	0.911	–

Panel B

	$\Delta x'_t$	Δbv_t	ΔRD_t	ΔRD_{t-1}	ΔRD_{t-2}
$\Delta x'_t$	–	0.477	0.035	−0.108	−0.205
Δbv_t	0.451	–	0.343	0.050	0.045
ΔRD_t	0.055	0.284	–	0.054	0.021
ΔRD_{t-1}	−0.131	0.116	0.123	–	0.133
ΔRD_{t-2}	0.004	0.099	0.085	0.133	–

This table shows Spearman (below the diagonal) and Pearson (above the diagonal) correlations for the independent variables in the regressions. These correlations are computed as the median cross-sectional correlations across all 284 firms in the sample. With one exception, these correlations are significant at p=0.001 based on a cross-sectional t-test computed as the mean coefficient divided by the standard error over all firms. The one exception, namely, the correlation between $\Delta x'_t$ and ΔRD_{t-2}, is insignificant for the Pearson and significant at p=0.037 for the Spearman.
bv_t=Book value per share end of year t.
x'_t=Abnormal annual earnings per share in year t defined as $x_t-(R_{ft}-1)\ bv_{t-1}$, where R_{ft} is computed as one plus the annualized 1 month Treasury Bill rate.
RD_{t-k}=R&D expenditures in year $t-k$, k=0, 1, 2.

Table 2 presents Spearman and Pearson median correlations—correlations are computed separately for each firm and the median cross-sectional correlation is reported—among the independent variables that are used in the regression analysis. Panel A provides correlations of the levels data, whereas Panel B gives correlations of the first differenced data.[21] Not surprisingly, levels are highly correlated, whereas differences much less so. Multicollinearity concerns are therefore another reason beyond unit roots to run regressions in first difference form.

4. Unit roots and cointegration tests

At the empirical level, the standard Ohlson (1995) model assumes that the variables of the model, including abnormal earnings, are stationary. Otherwise, the estimated parameters are both biased and inefficient. Unfortunately, the empirical evidence indicates that the accounting and market data are non-stationary. In particular, we test

[21] x_t' is also defined to be abnormal earnings in the tables that follow, although it differs from x_t^a. Both definitions are similar except that the former definition uses the risk free rate and the latter uses the firm's cost of capital.

Table 3
Cross-sectional distribution of p-values of the Phillips–Perron test for stationarity

Variable	Mean	5%	25%	50%	75%	95%
Panel A—levels						
x_t	0.363	0.003	0.033	0.218	0.733	0.999
x'_t	0.325	0.003	0.026	0.181	0.573	0.998
bv_t	0.685	0.162	0.469	0.716	0.984	0.999
RD_t	0.673	0.134	0.459	0.697	0.977	0.999
P_t	0.621	0.001	0.326	0.666	0.936	0.999
Panel B—first differences						
$x_t - x_{t-1}$	0.031	0.001	0.001	0.001	0.004	0.126
$x'_t - x'_{t-1}$	0.027	0.001	0.001	0.001	0.003	0.088
$\mathrm{bv}_t - \mathrm{bv}_{t-1}$	0.088	0.001	0.002	0.013	0.075	0.465
$\mathrm{RD}_t - \mathrm{RD}_{t-1}$	0.067	0.001	0.001	0.005	0.035	0.348
$P_t - P_{t-1}$	0.007	0.001	0.001	0.001	0.001	0.019

This table shows the cross-sectional distribution of the p-values from the Phillips and Perron (1988) test of stationarity for each of the variables in the regressions and their first differences.
x_t=Annual earnings per share year t.
bv_t=Book value per share end of year t.
R_{ft}=One plus the risk-free rate in year t (as proxied by the annualized 1 month T. Bill rate).
x'_t=Abnormal earnings per share year t=$x_t-(R_{ft}-1)\ \mathrm{bv}_{t-1}$.
P_t=Firm value 3 months after year-end t.

our sample for unit roots using a Phillips and Perron (1988) unit root test.[22] Panel A of Table 3 shows the cross-sectional distribution of the p-values of the Phillips–Perron test for our sample for each of earnings, abnormal earnings (above the risk-free return on initial book value), book values, R&D expenditures and security prices. Non-stationarity cannot be rejected for each one of these variables at conventional significance levels. In contrast, Panel B of Table 3 shows the cross-sectional distribution of the p-values of the Phillips–Perron test after first-differencing the data. The results allow us to reject nonstationarity at conventional significance levels for each one of these variables. Both of these results together suggest that accounting data and security prices are integrated of order one.

Since accounting numbers appear to be integrated of order one, either the model must be estimated in first differences or the variables in the equation must cointegrate. Table 4 tests for cointegration of the variables in valuation Eq. (6) [Panels A and B] and in valuation Eq. (10) [Panel C]. Table 4 shows the cross-sectional distribution of the τ-values and z-values of the Phillips (1987) and Phillips and Ouliaris (1990) cointegration tests for the two valuation equation variants.[23] In the case of valuation Eq. (6), two sub-

[22] The Phillips–Perron test is more general than the (augmented) Dickey and Fuller (1979, 1981) tests in that the former does not require the error terms to be statistically independent and of constant variance.

[23] Because the cost of capital is estimated endogenously, x^a_t could not be pre-specified in Table 4. Instead, x^a_t was replaced by x'_t and the latter broken down into its component parts $[x_t-(R_{ft}-1)\mathrm{bv}_{t-1}]$ so that, as a result, the cointegrating equations in Table 4 also have a bv_{t-1} term.

Table 4
Cross-sectional distribution of τ- and z-values for Phillips–Ouliaris cointegration tests

Panel A: valuation Eq. (6)—one parameter variant						
Test[a]	Mean	5%	25%	50%	75%	95%
τ-values	−3.701	−5.778	−4.409	−3.490	−2.868	−2.022
z-values	−17.420	−26.917	−21.541	−16.852	−12.811	−8.528
Valuation equation: $P_t - \mathrm{bv}_t = c_0 + c_1\, x_t' + c_2\, \mathrm{bv}_{t-1} + c_3\, \mathrm{RD}_t$						
Panel B: valuation Eq. (6)—two parameter variant						
Test[b]	Mean	5%	25%	50%	75%	95%
τ-values	−3.865	−6.244	−4.525	−3.670	−3.009	−2.114
z-values	−18.188	−27.638	−22.596	−17.625	−13.694	−9.243
Valuation equation: $P_t - \mathrm{bv}_t = c_0 + c_1\, x_t' + c_2\, \mathrm{bv}_{t-1} + c_3\, \mathrm{RD}_t + c_4\, \mathrm{RD}_{t-1}$						
Panel C: valuation Eq. (10)						
Test[c]	Mean	5%	25%	50%	75%	95%
τ-values	−3.458	−5.899	−4.205	−3.231	−2.590	−1.852
z-values	−15.976	−26.810	−20.430	−15.194	−11.400	−6.937
Valuation equation: $P_t - \mathrm{bv}_t = c_0 + c_1\, x_t' + c_2\, \mathrm{bv}_{t-1} + c_3\, \Delta\mathrm{RD}_t$						

This table shows the cross-sectional distribution of the τ-values and z-values of the Phillips (1987) and Phillips and Ouliaris (1990) cointegration tests for various valuation equation variants. Critical τ-values and z-values are from Davidson and MacKinnon (1993, p. 722).

[a] Critical τ-values and z-values are −4.43 and −38.2, respectively, at the 5% significance level.

[b] Critical τ-values and z-values are −4.72 and −43.5, respectively, at the 5% significance level.

[c] Critical τ-values and z-values are −4.12 and −32.8, respectively, at the 5% significance level.

cases are evaluated for noncointegration. In the one-parameter variant [Panel A], only one period of R&D expenditures is assumed to be value relevant. In the two-parameter variant [Panel B], two periods of R&D expenditures are assumed to be value relevant. Based on the τ-values, no cointegration fails to be rejected for over 50% of the firms in the sample at the 5% significance level. The results for the z-values are even more unequivocal. No co-integration fails to be rejected for the entire sample at the 5% significance level. These results are suggestive rather than conclusive since both cointegration tests assume a single equation linear regression, whereas we estimate the models by a nonlinear systems approach. Nevertheless, given these results, we elect to estimate each model in first differences as well as in levels to avoid potential spurious regressions.

5. Model estimation

5.1. Estimation issues

Both the levels and differences models are each a system of three equations with potential for cross-equation correlation in the error terms. Moreover, of the three equations, the earnings dynamic and the valuation equation are nonlinear in the

Table 5
Summary parameter values from a system of nonlinear regressions random walk-levels model

Model type	N	a^	RP^	θ_1^	θ_2^	R_t^−1
One parameter	284	0.093	0.140***	0.275	–	0.213
model (θ_2=0)		(1.4)	(8.4)	(3.1)		–
Two parameter	284	0.029	0.155*	0.120	0.253	0.226
model		(0.7)	(4.3)*	(0.7)	(0.8)	–

System equations:

$$\Delta x_t^{\mathrm{a}} = a + \theta_1 \mathrm{RD}_{t-1} + \theta_2 \mathrm{RD}_{t-2} + \varepsilon_{1,t}$$

$$\Delta \mathrm{RD}_t = \varepsilon_{2,t}$$

$$P_t = \frac{R_t a}{(R_t - 1)^2} + \mathrm{bv}_t + \frac{1}{(R_t - 1)} x_t^{\mathrm{a}} + \frac{\theta_1 R_t}{(R_t - 1)^2} \mathrm{RD}_t + \frac{\theta_2 R_t}{(R_t - 1)^2} \mathrm{RD}_{t-1} + \varepsilon_{3,t}$$

This table provides cross-sectional summary statistics of the estimated parameters of the random walk-levels model [Eqs. (5a,b) and (6)]. Table entries are median coefficients over all sample firms. Figures in parentheses are the median of the Wald statistic (the square of the pseudo t-statistic) over all sample firms. The Wald statistic in these tables tests if the parameter estimate is statistically different from zero (1 for R_t^). It is distributed asymptotically Chi-squared with one degree of freedom.
x_t=Annual earnings per share year t.
bv_t=Book value per share end of year t.
R_{ft}=One plus the risk-free rate in year t (proxied by the annualized 1 month T. Bill rate).
x_t^{a}=Abnormal earnings per share year t=$x_t-(R_{t-1})\mathrm{bv}_{t-1}$.
P_t=Firm value 3 months after year-end t.
a, RP, θ_1, θ_2, R_t=system parameters. Note RP=R_t-R_{ft}.
a^, RP^, θ_1^, θ_2^, R_t^=system parameter estimates. Note RP^=R_t^$-R_{ft}$.
N=number of observations (firms).
* Significant at the 10% level.
*** Significant at the 1% level.

parameters. Therefore, each of the models is estimated (for each firm in the sample separately) as a system of equations using nonlinear (SUR).[24]

Typically, empirical applications of the Ohlson model use cost of capital estimates from other models—such as the Fama and French (1997) three factor industry model—or the cost of capital is simply assumed to take on some cross-sectionally constant arbitrary value. Since firm value and the cost of capital are determined simultaneously, the cost of capital must logically be estimated endogenously using the Ohlson model itself. Moreover, since firms differ in terms of their risk profiles and since the risk-free (treasury bill) rate has varied historically over time, the endogenous cost of capital estimates must vary both cross-sectionally and over time.

To permit the firm's cost of capital R to vary over time for estimation purposes and yet still allow for the endogenous estimation of the model parameters on a firm level

[24] Since the system is triangular, simultaneous equation bias is not an issue.

basis, we assume that the cost of capital (denoted now by R_t instead of R) can be represented by

$$R_t = R_{ft} + \mathrm{RP} \tag{13}$$

where R_{ft} is one plus the risk-free rate of interest at time t and RP denotes the firm's risk premium. More specifically, we assume that each firm's cost of capital is composed of two components, a time varying (but cross-sectionally constant) risk-free rate and a cross-sectionally varying (but time independent) risk-premium. Thus, each firm's cost of capital R_t varies both cross-sectionally and over time.

5.2. Empirical results

Table 5 provides cross-sectional summary statistics for the parameters of the random walk-levels model [Eqs. (5a,b) and (6)]. In the one-parameter version of the model, last period's R&D expenditures provide information about next period's future abnormal

Table 6
Summary parameter values from a system of nonlinear regressions first differences form of the random walk-levels model

Model type	N	RP^	θ_1^	θ_2^	R_t^−1
One parameter	284	0.174*	0.014	–	0.247
model (θ_2=0)		(4.9)	(0.8)		–
Two parameter	284	0.174*	0.002	0.085	0.246
model		(4.5)	(0.9)	(0.6)	–

System equations:

$$\Delta x_t^{\mathrm{a}} = \Delta x_{t-1}^{\mathrm{a}} + \theta_1 \Delta \mathrm{RD}_{t-1} + \theta_2 \Delta \mathrm{RD}_{t-2} + \varepsilon_{1,t}$$

$$\Delta \mathrm{RD}_t = \varepsilon_{2,t}$$

$$\Delta P_t = \Delta \mathrm{bv}_t + \frac{1}{(R_t - 1)} \Delta x_t^{\mathrm{a}} + \frac{\theta_1 R_t}{(R_t - 1)^2} \Delta \mathrm{RD}_t + \frac{\theta_2 R_t}{(R_t - 1)^2} \Delta \mathrm{RD}_{t-1}$$

This table provides cross-sectional summary statistics of the estimated parameters of the first-difference form of the random walk-levels model [Eqs. (7a,b) and (8)]. Table entries are median coefficients over all sample firms. Figures in parentheses are the median of the Wald statistic (the square of the pseudo t-statistic) over all sample firms. The Wald statistic in these tables tests if the parameter is statistically different from zero (1 for R_t^). It is distributed asymptotically Chi-squared with one degree of freedom.
Δ=first-difference operator.
x_t=Annual earnings per share year t.
bv_t=Book value per share end of year t.
R_{ft}=One plus the risk-free rate in year t (proxied by the annualized 1 month T. Bill rate).
x_t^{a}=Abnormal earnings per share year t=$x_t-(R_{t-1})\mathrm{bv}_{t-1}$.
P_t=Firm value 3 months after year-end t.
a, RP, θ_1, θ_2, R_t=system parameters. Note RP=R_t-R_{ft}.
a^, RP^, θ_1^, θ_2^, R_t^=system parameter estimates. Note RP^=R_t^$-R_{ft}$.
N=number of observations (firms).
* Significant at the 10% level.

earnings. In the two-parameter version of the model, two periods of past R&D expenditures provide information about next period's abnormal earnings. In both versions, R&D expenditures are assumed to be a random walk.

In the one-parameter model, the cross-sectional median estimate of the risk premium coefficient (and hence cost of capital) is significant at the 1% level on the basis of a standard Wald statistic.[25] The cross-sectional median estimate of the R&D valuation parameter is not significant at conventional significance levels. In the two-parameter model, the cross-sectional median risk premium (cost of capital) coefficient is significant at the 10% level. Neither one of the cross-sectional median R&D valuation parameters is significant. Thus, Table 5 indicates that R&D expenditures are not valuation relevant for over half of the sample. In fact, R&D coefficients are significant for only about 25% of the sample at the 5% significance level. As it turns out, the latter are significant at the 1% level as well.

Since the variables in the valuation equation of Table 5 are apparently not cointegrated, we also estimate the model in first differences [Eqs. (7a,b) and (8)]. Table 6 shows the results for both the one-parameter and two-parameter versions of this first difference formulation. Again, only the cross-sectional median cost of capital is significant for the one-parameter and the two-parameter versions at the 10% significance level. Again, there is no evidence that R&D expenditures are value relevant. Indeed, less than 10% of the sample firms had significant R&D valuation parameter estimates (at the 5% level) for either the one or two parameter version.

Table 7 presents results for the IAR(1,1) models [Eqs. (9a,b) and (10) and Eqs. (11a,b) and (12)]. Again, similar to the results of Table 6, there is little evidence that changes in R&D expenditures are directly valuation relevant. Only, the cross-sectional median risk premium estimates are significant at the 5% level.

With the exception of the one-parameter random walk-levels model (Table 5), which is potentially non-cointegrated, the R&D valuation parameter estimates (θ_i's) in the other models are not significant (at the 5% level) for over 90% of the sample firms. Yet, for the one-parameter levels model, we find that the R&D valuation parameter estimates (θ_1) are in fact significant at the 1% level for about 25% of the sample firms. This raises the issue: what characterizes those firms for which R&D expenditures are directly valuation relevant in this model? To investigate this issue, we separate the sample firms into quartiles on the basis of the p-values of the θ_1 parameter. The smaller the p-value presumably the more confidence we have in the value relevance of R&D expenditures. Average (over time) earnings–price ratios, R&D expenditures to price ratios—a measure of R&D intensity—book to market ratios, and firm costs of capital are computed for each firm in the sample. Firms in the top p-value quartile of the θ_1 parameter are then compared to firms in the bottom p-value quartile of the θ_1 parameter with respect to these four ratios. If R&D expenditures are value relevant at the firm level, then we should expect that firms with lower earnings–price ratios, lower book to market ratios, and higher R&D intensity ratios should yield more value relevant R&D expenditures. In addition, one should expect that firms that are riskier (have higher average costs of capital) should yield more value relevant R&D expenditures to the extent that the

[25] The Wald statistic is distributed $\chi^2(1)$.

Table 7
Summary parameter values from a system of nonlinear regressions IAR(1,1)-changes model

Model type	N	a^	b^	γ^	RP^	θ^	R_t^−1
Panel A: level form							
Price-level model	284	0.083	0.000	−0.100*	0.050**	−0.238	0.123
		(2.5)	(0.8)	(4.3)	(6.9)	(1.9)	–

System equations:

$$\Delta x_t = a + \theta \Delta \mathrm{RD}_{t-1} + \varepsilon_{1,t}$$

$$\Delta \mathrm{RD}_t = b + \gamma \Delta \mathrm{RD}_{t-1} + \varepsilon_{2,t}$$

$$P_t = \frac{a\ R_t}{(R_t-1)^2} + \frac{\theta b R_t}{(1-\gamma)(R_t-1)^2} - \frac{\theta b R_t}{(1-\gamma)\left[R_t-(1-\gamma)^2\right]} + \mathrm{bv}_t + \frac{1}{(R_t-1)} x_t^{\mathrm{a}} + \frac{\theta R_t}{(R_t-1)(R_t-\gamma)} \Delta \mathrm{RD}_t$$

Model type	N	a^	b^	γ^	RP^	θ^	R_t^−1
Panel B: first-differences form							
Price-differences model	284	0.029	0.018	0.065	0.160**	−0.420	0.232
		(0.2)	(0.7)	(0.6)	(6.5)	(1.5)	–

System equations:

$$\Delta x_t = a + \theta \Delta \mathrm{RD}_{t-1} + \varepsilon_{1,t}$$

$$\Delta \mathrm{RD}_t = b + \gamma \Delta \mathrm{RD}_{t-1} + \varepsilon_{2,t}$$

$$\Delta P_t = \Delta \mathrm{bv}_t + \frac{1}{(R_t-1)} \Delta x_t^{\mathrm{a}} + \frac{\theta R_t}{(R_t-1)(R_t-\gamma)} \left[\Delta \mathrm{RD}_t - \Delta \mathrm{RD}_{t-1}\right]$$

This table provides cross-sectional summary statistics of the estimated parameters of the IAR(1,1)-changes model. Panel A shows the levels form of the model [Eqs. (9a,b) and (10)] and Panel B shows the first-differences form of the model [Eqs. (11a,b) and (12)]. Table entries are median coefficients over all sample firms. Figures in parentheses are the median of the Wald statistic (the square of the pseudo t-statistic) over all sample firms. The Wald statistic in these tables tests if the parameter is statistically different from zero (1 for R_t^). It is distributed asymptotically Chi-squared with one degree of freedom.
Δ=first-difference operator.
x_t=Annual earnings per share year t.
bv_t=Book value per share end of year t.
R_{ft}=One plus the risk-free rate in year t (proxied by the annualized 1 month T. Bill rate).
x_t^{a}=Abnormal earnings per share year t=$x_t-(R_{t-1})\mathrm{bv}_{t-1}$.
P_t=Firm value 3 months after year-end t.
a, b, γ, RP, θ, R_t=system parameters. Note RP=R_t-R_{ft}.
a^, b,^, γ^, RP^, θ^, R_t=system parameter estimates. Note RP^=R_t^−R_{ft}.
N=number of observations (firms).
* Significant at the 10% level.
** Significant at the 5% level.

option value of R&D is greater for riskier firms. Table 8 shows that although firms in the top quartile have lower (higher) mean earnings–price ratios and book to market ratios (R&D intensity ratios and costs of capital) by comparison to firms in the bottom quartile, only the book to market ratio differences are significant on the basis of t-tests and Wilcoxon tests. Thus, we find limited evidence that R&D expenditures are directly

Table 8
Comparison of mean and median firm characteristics for the top and bottom quartiles of the p-values of the θ_1 parameter

Panel A					
Earnings–price ratio (E/P)					
	N	Mean	Median	T-test	Wilcoxon
NS	71	0.065	0.072	−1.38	−1.86
S	71	0.054	0.063	(0.17)	(0.06)
Panel B					
R&D intensity (RD/P)					
	N	Mean	Median	T-test	Wilcoxon
NS	71	0.048	0.034	−0.35	0.40
S	71	0.051	0.034	(0.73)	(0.69)
Panel C					
Book to market ratio (BV/P)					
	N	Mean	Median	T-test	Wilcoxon
NS	71	0.836	0.834	−3.56	−3.59
S	71	0.637	0.556	(0.00)	(0.00)
Panel D					
Costs of capital (R_t^)					
	N	Mean	Median	T-test	Wilcoxon
NS	71	0.217	0.226	1.41	1.09
S	71	0.244	0.230	(0.16)	(0.28)

This table compares four financial ratios of two portfolios. These two portfolios comprise firms in the bottom quartile and firms in the top quartile of the p-values of the θ_1 R&D valuation parameter obtained from levels model [Eqs. (5a,b) and (6)]. The financial ratios include the earnings–price ratio, R&D intensity as measured by the R&D expenditures to price ratio, book to market ratio and the cost of capital as measured by the R_t^ parameter estimate from the levels model. The earnings–price ratio, R&D intensity and book to market ratio are firm-level time averages. Reported mean and median numbers in the above tables are cross-sectional means and medians of these time averages across the firms in each quartile. Differences between the two portfolios are computed using a t-test and Wilcoxon. Figures in parentheses are (two-tailed) p-values. N is the number of firms.
NS=Bottom quartile of sample firms characterized by an insignificant R&D valuation parameter in the levels model.
S=Top quartile of sample firms characterized by a significant R&D valuation parameter (at the 1% significance level) in the levels model.

value relevant for those firms with greater growth opportunities as measured by book to market ratios.

We also could not find any evidence that firms with significant R&D valuation parameters are more concentrated in specific R&D intensive industries (e.g., pharmaceuticals) relative to firms with insignificant R&D valuation parameters.

6. Conclusion

Cross-sectional and panel data studies of R&D investment consistently show that R&D expenditures (or R&D capital) are value relevant and impounded in security prices. Using firm level time series models that incorporate the effect of R&D expenditures on earnings, we find very weak empirical support for the value relevance of R&D expenditures. At best, R&D investment significantly affects firm valuation for only 25% of the sample firms.

There are of course other explanations for these results. Our time series data are limited to an average of 24 years of R&D expenditure data (per firm) and that may not be sufficient to adequately estimate the model coefficients at the firm level. Also, the empirical tests are a joint test of the underlying model and the value relevance of R&D expenditures. An alternative model might yield different results. Nevertheless, this paper raises significant doubts about the seemingly robust finding that R&D and corporate values are positively and significantly related.

Acknowledgements

We wish to thank an anonymous referee and colleagues at the University of Toronto, New York University, the Hebrew University, and Ben-Gurion University for their helpful comments.

References

Ashenfelter, O., Ashmore, D., Baker, J. B., Gleason, S., & Hosken, D. S. (2004). *Econometric Methods in Staples.* Working Paper (April 9), Princeton University.

Ballester, M., Garcia-Ayuso, M., & Livnat, J. (2003). Estimating the R&D intangible. *European Accounting Review*, *12*, 605–633.

Ben-Zion, U. (1984). The R&D and Investment Decision and its Relationship to the Firm's Market Value: Some Preliminary Results. In Z. Griliches (Ed.), *R&D, patents and productivity. NBER Conference Report*. Chicago, IL: University of Chicago Press.

Bosworth, D., & Rogers, M. (2001). Market value, R&D and intellectual property: An empirical analysis of large Australian firms. *Economic Record*, *77*, 323–337.

Bosworth, D., Wharton, D., & Greenhalgh, C. (2000). Intangibles assets and the market valuation of U.K. companies: Evidence from fixed effects model. *Oxford intellectual research property. W.P.*, *vol. 2*. Oxford: St. Peter's College.

Brown, L. D., & Rozeff, M. S. (1979). Univariate time-series models of quarterly accounting earnings per share: A proposed model. *Journal of Accounting Research*, *17*, 179–189.

Bublitz, B., & Ettredge, M. (1989). The information in discretionary outlays: Advertising, research, and development. *The Accounting Review*, *64*, 108–124.

Chan, L. K. C., Lakonishok, J., & Sougiannis, T. (2001). The stock market valuation of research and development expenditures. *Journal of Finance*, *56*, 2431–2456.

Chan, S. H., Martin, J. D., & Kensinger, J. W. (1990). Corporate research and development expenditures and share value. *Journal of Financial Economics*, *26*, 255–276.

Chauvin, K. W., & Hirschey, M. (1993). Advertising, R&D expenditures and the market value of the firm. *Financial Management*, *22*, 128–140.

Chauvin, K. W., & Hirschey, M. (1994). Goodwill, profitability, and the market value of the firm. *Journal of Accounting and Public Policy*, *13*, 159–180.

Cockburn, I., & Griliches, Z. (1988). Industry effects and appropriability measures in the stock market's valuation of R&D and patents. *American Economic Review*, *78*, 419–423.

Connolly, R. A., & Hirschey, M. (1984). R&D market structure and profits: A value-based approach. *Review of Economics and Statistics*, *66*, 682–686.

Davidson, R., & MacKinnon, J. G. (1993). *Estimation and inference in econometrics*. New York, NY: Oxford University Press.

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*, *74*, 427–431.

Dickey, D. A., & Fuller, W. A. (1981). Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica*, *49*, 1057–1072.

Doukas, J., & Switzer, L. (1992). The stock market's valuation of R&D spending and market concentration. *Journal of Economics and Business*, *44*, 95–114.

Fama, E. F., & French, K. R. (1997). Industry costs of equity. *Journal of Financial Economics*, *43*, 153–193.

Granger, C. W. J., & Newbold, P. (1974). Spurious regressions in econometrics. *Journal of Econometrics*, *2*, 111–120.

Green, J. P., Stark, A. W., & Thomas, H. M. (1996). UK evidence on the market valuation of research and development expenditures. *Journal of Business Finance and Accounting*, *23*, 191–216.

Griliches, Z. (1981). Market value, R&D and patents. *Economic Letters*, *7*, 187–193.

Hall, B. (1993a). The stock market valuation of R&D investment during the 1980's. *American Economic Review*, *83*, 259–264.

Hall, B. (1993b). Industrial research during the 1980s: Did the rate of return fall? *Brookings Papers on Economic Activities*. *Microeconomics*, *vol. 2* (pp. 289–343).

Hall, B. (2000). Innovation and market value. In R. Barrell, G. Mason, & M. O'Mahony (Eds.), *Productivity, innovation and economic performance* (pp. 177–198). Cambridge, NY: Cambridge University Press.

Hayashi, F., & Inoue, T. (1991). The relation between firm growth and Q with multiple capital goods: Theory and evidence from panel data on Japanese firms. *Econometrica*, *59*, 731–754.

Hirschey, M. (1982). Intangible capital aspects of advertising and R&D expenditures. *Journal of Industrial Economics*, *30*, 375–390.

Hirschey, M. (1985). Market structure and market value. *Journal of Business*, *58*, 89–98.

Hirschey, M., & Spencer, R. S. (1992). Size effects in the market valuation of fundamental factors. *Financial Analyst Journal*, *48*, 91–95.

Hirschey, M., & Weygandt, J. J. (1985). Amortization policy for advertising and research and development expenditures. *Journal of Accounting Research*, *23*, 326–335.

Jaffe, A. B. (1986). Technological opportunity and spillovers of R&D: Evidence from firms' patents profits, and market value. *American Economic Review*, *76*, 984–1001.

Johnston, J., & Dinardo, J. (1997). *Econometric methods* (4th ed.). New York: McGraw-Hill.

Johnson, L. D., & Pazderka, B. (1993). Firm value and investment in R&D. *Managerial and Decision Economics*, *14*, 15–24.

Jose, M. L., Nichols, L. M., & Stevens, J. L. (1986). Contributions of diversification, promotion, and R&D to the value of multiproduct firms: A Tobin's q approach. *Financial Management*, *15*, 33–42.

Joseph, G. (2001). An incremental and relative analysis of the valuation of R&D intensive firms. *Accounting Enquiries*, *10*, 243–274.

Kotabe, M., Srinivasan, S. S., & Aulakh, P. S. (2002). Multinational and firm performance: The moderating role of R&D and marketing capabilities. *Journal of International Business Studies*, *33*, 79–97.

Lach, S., & Schankerman, M. (1989). Dynamics of R&D and investment in the scientific sector. *Journal of Political Economy*, *97*, 880–904.

Lev, B., & Sougiannis, T. (1996). The capitalization, amortization, and value-relevance of R&D. *Journal of Accounting and Economics*, *21*, 107–138.

Lev, B., & Zarowin, P. (1998). The Market Valuation of R&D Expenditures. New York University, mimeo.

Morel, M. (1999). Multi-lagged Specification of the Ohlson Model. *Journal of Accounting, Auditing and Finance*, *14*, 147–161.

Ohlson, J. A. (1995). Earnings, book values, and dividends in security valuation. *Contemporary Accounting Research*, *11*, 661–687.
Pakes, A. (1985). On patents, R&D, and the stock market rate of return. *Journal of Political Economy*, *93*, 399–409.
Phillips, P., & Perron, P. (1988). Testing for a Unit Root in Time Series Regression. *Biometrica*, *75*, 335–346.
Phillips, P. C. B. (1987). Time series regression with a unit root. *Econometrica*, *55*, 277–301.
Phillips, P. C. B., & Ouliaris, S. (1990). Asymptotic properties of residual based tests for cointegration. *Econometrica*, *58*, 165–193.
Qi, D. D., Wu, W., & Xiang, B. (2000). Stationarity and cointegration tests of the Ohlson model. *Journal of Accounting, Auditing and Finance*, *15*, 141–160.
Rayburn, J. (1986). The association of operating cash flow and accruals with security returns. *Journal of Accounting Research*, *24*, 112–133.
Rubinstein, M. (1976). The valuation of uncertain income streams and the pricing of options. *Bell Journal of Economics*, *7*, 407–425.
Sougiannis, T. (1994). The accounting based valuation of corporate R&D. *The Accounting Review*, *69*, 44–69.
Sundaram, A. K., John, T. A., & John, K. (1996). An empirical analysis of strategic competition and firm values: The case of R&D competition. *Journal of Financial Economics*, *40*, 459–486.
Szewczyk, S. H., Tsetsekos, G. P., & Zantout, Z. (1996). The valuation of corporate R&D expenditures: Evidence from investment opportunities and free cash flows. *Financial Management*, *25*, 105–110.
Toivanen, O., & Stoneman, P. (1998). Dynamics of R&D and investment: UK evidence. *Economic Letters*, *58*, 119–126.
Woolridge, R. (1988). Competitive decline and corporate restructuring: Is a myopic stock market to blame? *Journal of Applied Corporate Finance*, *1*, 26–36.
Wu, C., & Wei, K. C. J. (1998). Cooperative R&D and the value of the firm. *Review of Industrial Organization*, *13*, 425–446.
Zhao, R. (2002). Relative value relevance of R&D reporting: An international comparison. *Journal of International Financial Management and Accounting*, *13*, 153–174.

Appendix A. Modified Ohlson models

A.1. The random walk levels model

The information dynamic has the form:

$$E_t\left[x^{\mathrm{a}}_{t+1}\right] = x^{\mathrm{a}}_t + a + \theta_1 \mathrm{RD}_t + \theta_2 \mathrm{RD}_{t-1}$$

$$E_t[\mathrm{RD}_t] = \mathrm{RD}_{t-1}$$

Thus,

$$E_t\left[x^{\mathrm{a}}_{t+2}\right] = x^{\mathrm{a}}_{t+1} + a + \theta_1 \mathrm{RD}_t + \theta_2 \mathrm{RD}_{t-1} = x^{\mathrm{a}}_t + 2a + 2\theta_1 \mathrm{RD}_t + 2\theta_2 \mathrm{RD}_{t-1}$$

$$E_t\left[x^{\mathrm{a}}_{t+3}\right] = x^{\mathrm{a}}_{t+2} + a + \theta_1 \mathrm{RD}_{t+2} + \theta_2 \mathrm{RD}_{t+1} = x^{\mathrm{a}}_t + 3a + 3\theta_1 \mathrm{RD}_t + 3\theta_2 \mathrm{RD}_{t-1}$$

$$E_t\left[x^{\mathrm{a}}_{t+4}\right] = x^{\mathrm{a}}_{t+3} + a + \theta_1 \mathrm{RD}_{t+3} + \theta_2 \mathrm{RD}_{t+2} = x^{\mathrm{a}}_t + 4a + 4\theta_1 \mathrm{RD}_t + 4\theta_2 \mathrm{RD}_{t-1}$$

$$E_t\left[x^{\mathrm{a}}_{t+5}\right] = x^{\mathrm{a}}_{t+4} + a + \theta_1 \mathrm{RD}_{t+4} + \theta_2 \mathrm{RD}_{t+3} = x^{\mathrm{a}}_t + 5a + 5\theta_1 \mathrm{RD}_t + 5\theta_2 \mathrm{RD}_{t-1}$$

In general,

$$E_t\left[x^{\mathrm{a}}_{t+k}\right] = x^{\mathrm{a}}_t + ka + k\theta_1 \mathrm{RD}_t + k\theta_2 \mathrm{RD}_{t-1}.$$

Noting that

$$\sum_{k=1}^{\infty} kz^k = z/(1-z)$$

for $-1<z<1$, it can be shown that

$$P_t = \sum_{k=1}^{\infty} R_t^{-k} E_t\left[x^{\mathrm{a}}_{t+k}\right] = \frac{R_t a}{(R_t-1)^2} + \mathrm{bv}_t + \frac{1}{(R_t-1)} x^{\mathrm{a}}_t + \frac{\theta_1 R_t}{(R_t-1)^2}\mathrm{RD}_t + \frac{\theta_2 R_t}{(R_t-1)^2}\mathrm{RD}_{t-1}$$

A.2. The IAR(1,1) differences model

The information dynamic has the form:

$$E_t\left[x^{\mathrm{a}}_{t+1}\right] = x^{\mathrm{a}}_t + a + \theta\ \Delta\mathrm{RD}_{t-1}$$

$$E_t[\Delta\mathrm{RD}_t] = b + \gamma\ \Delta\mathrm{RD}_{t-1}$$

Thus,

$$E_t\left[x^{\mathrm{a}}_{t+2}\right] = x^{\mathrm{a}}_{t+1} + a + \theta\Delta\mathrm{RD}_{t+1} = x^{\mathrm{a}}_t + 2a + \theta b + \theta\Delta\mathrm{RD}_t[1+\gamma]$$

$$E_t\left[x^{\mathrm{a}}_{t+3}\right] = x^{\mathrm{a}}_{t+2} + a + \theta\Delta\mathrm{RD}_{t+2} = x^{\mathrm{a}}_t + 3a + 2\theta b + \theta\gamma b + \theta\Delta\mathrm{RD}_t\left[1+\gamma+\gamma^2\right]$$

$$E_t\left[x^{\mathrm{a}}_{t+4}\right] = x^{\mathrm{a}}_{t+3} + a + \theta\Delta\mathrm{RD}_{t+3} = x^{\mathrm{a}}_t + 4a + 3\theta b + 2\theta\gamma b + \theta\gamma^2 b + \theta\Delta\mathrm{RD}_t\left[1+\gamma+\gamma^2+\gamma^3\right]$$

$$E_t\left[x^{\mathrm{a}}_{t+5}\right] = x^{\mathrm{a}}_{t+4} + a + \theta\Delta\mathrm{RD}_{t+4} = x^{\mathrm{a}}_t + 5a + 4\theta b + 3\theta\gamma b + 2\theta\gamma^2 b + \theta\gamma^3 b + \theta\Delta\mathrm{RD}_t\left[1+\gamma+\gamma^2+\gamma^3+\gamma^4\right]$$

In general,

$$E_t\left[x^{\mathrm{a}}_{t+k}\right] = x^{\mathrm{a}}_t + ka + \theta b \sum_{j=1}^{k-1}\left[(k-j)\gamma^{j-i}\right] + \theta\Delta\mathrm{RD}_t\left[1-\gamma^k\right]/(1-\gamma)$$

Noting that

$$\sum_{k=1}^{\infty} k\ z^k = z/(1-z)^2$$

for $-1<z<1$, it can be shown that

$$P_t = \sum_{k=1}^{\infty} R_t^{-k} E_t\left[x_{t+k}^{\mathrm{a}}\right] = \frac{a\ R_t}{(R_t-1)^2} + \frac{\theta\ b\ R_t}{(1-\gamma)(R_t-1)^2} - \frac{\theta\ b\ R_t}{(1-\gamma)\left[(R_t-(1-\gamma)^2\right]} + \mathrm{bv}_t + \frac{1}{(R_t-1)} x_t^{\mathrm{a}} + \frac{\theta\ R_t}{(R_t-1)(R_t-\gamma)} \Delta \mathrm{RD}_t$$

Using the Clean Surplus relationship, it can be shown in a straightforward fashion that both modified Ohlson valuation models satisfy the transversality condition: $\lim\ k \rightarrow \infty R^{-k}\ \mathrm{bv}_{t+k}=0$ provided $1<R$.