Noisy Share Prices and the Q Model of Investment

Stephen Bond
Nuffield College, Oxford University and Institute for Fiscal Studies
steve.bond@nuf.ox.ac.uk

Jason G. Cummins
New York University and Institute for Fiscal Studies
jason.cummins@nyu.edu

First Draft: September 27, 1999

Abstract

We consider to what extent the empirical failings of the Q model of investment can be accounted for by the failure of the assumption that share prices are strongly efficient. We characterise the implications of different types of 'measurement error' in stock market valuations, considered as a measure of the present value of expected future profits, for consistent estimation of the Q model. We show that the model can be identified when we use a measure of fundamentals based on securities analysts' earnings forecasts *in place of* the conventional measure of average q based on share price data. In this case we find more reasonable estimates of the size of adjustment costs and the elasticity of investment with respect to fundamentals. Perhaps most surprisingly, we find that conditional on our measure, there is no additional information relevant for investment in the conventional share price based measure of average q. In addition, neither cash flow nor non-linear terms are found to be significant conditional on our constructed measure of average q. Taken together these results provide the first evidence that there is a measure of fundamentals that is a sufficient statistic for investment.

JEL Classification: D92, E22.
Keywords: Investment; Tobin's Q.

We thank seminar participants at Bergamo and the Institute for Fiscal Studies for helpful comments and suggestions. Haibin Jiu elastically supplied super research assistance. Cummins gratefully acknowledges financial support from the C. V. Starr Center for Applied Economics. The data on earnings expectations are provided by I/B/E/S International Inc.

Preliminary and Incomplete: Do Not Circulate or Quote

> "Perhaps no single empirical issue is of more fundamental importance to both the fields of financial economics and macroeconomics than the question of whether or not stock prices are a well-informed and rational assessment of the value of future earnings available to stockholders"
>
> Fischer and Merton (1984), p.94

1 Introduction

The Q model of investment has proved to be a popular and powerful framework for analysing the investment decisions of firms, linking the firm's optimal investment decisions to expected future profitability via the observable stock market valuation of the firm. Despite this close connection between theory and data, the empirical performance of the Q model has generally been disappointing, at both the macro and micro levels and across countries. Most empirical estimates imply that investment is insensitive to changes in average q, defined, in its simplest formulation, as the ratio of the stock market value of the firm to the replacement cost of its property, plant and equipment. Perhaps more importantly, most studies have rejected the prediction that average q is a sufficient statistic for investment.[1] These results have striking and, perhaps, counterintuitive implications for understanding the determinants of investment spending, which typically drives business cycles. Essentially they suggest that businesses ignore changes in their expected future profitability when making capital investment decisions.

There have been many attempts to salvage the Q model by enriching its theoretical or empirical foundation: for example, by incorporating imperfect competition (Schiantarelli and Georgoutsos, 1988), multiple capital inputs (Hayashi and Inoue, 1991) or autocorrelated adjustment cost shocks (Blundell, Bond, Devereux and Schiantarelli, 1992). Another approach has focussed on periods when variation in average q is dominated by exogenous changes in tax parameters, finding more reasonable estimates of the structural parameters in these periods (Cummins, Hassett and Hubbard, 1994, 1996). This is consistent with the possibility that the variation in share prices, which normally dominates the variation in average q measures, contains excessive 'noise' that

[1] See, for example, Fazzari, Hubbard and Petersen (1988); Hayashi and Inoue (1991); Blundell, Bond, Devereux and Schiantarelli (1992); Barnett and Sakellaris (1995); Abel and Eberly (1996); Eberly (1997).

is at best uninformative about company investment. However, given the large literature on the effects of capital market imperfections (see, for example, the surveys in Schiantarelli, 1996, and Hubbard, 1998) and the growing literature that emphasizes non-convex adjustment costs and option value of waiting to invest (see, for example, Caballero, 1998 and Dixit and Pindyck, 1994), the consensus view seems to be that the standard Q model is itself seriously misspecified.

In this paper we consider to what extent these empirical failings of the Q model can be accounted for by failure of the assumption that share prices are strongly efficient. This assumption — that stock market valuations equal the present value of expected future net distributions to shareholders — is crucial to the conventional measurement of average q. However this strong form of market efficiency is not implied by the extensive evidence consistent with weak market efficiency, or the requirement that excess returns cannot systematically be made by trading on the basis of publicly available information. Several models of asset pricing have been proposed that are consistent with weak efficiency but allow large and persistent departures from strong efficiency; see, for example, the rational bubbles models of Blanchard and Watson (1982) and Froot and Obstfeld (1991), and the noise trader model of Campbell and Kyle (1993).

The main empirical novelty in our work is the use of data on securities analysts' earnings forecasts. We use these forecasts to construct an alternative estimate of the present value of expected future profits, and input this into an alternative measure of average q that does not rely at all on share price information. We consider using this constructed measure both as an instrumental variable for the conventional measure of average q based on equity valuations, and as an alternative to the conventional measure in an otherwise standard Q model of investment. In contrast to the consensus view that the Q model is misspecified, in our approach we maintain the basic theoretical setup Hayashi (1982) introduced to equate average and marginal q and relax only the assumption of strong stock market efficiency. We are certainly not, however, the first to investigate whether deviations from strong efficiency help account for the dismal performance of empirical investment equations.[2] In particular, we discuss how

[2]Previous related literature includes Abel and Blanchard (1986), Mørck, Schleifer and Vishny (1990), and Blanchard, Rhee and Summers (1993).

our approach relates to that of Abel and Blanchard (1986), who relied on econometric forecasts of marginal q, rather than a stock market based measure of average q.

Our main analytical contribution is to characterise the implications of different types of 'measurement error' in stock market valuations, considered as a measure of the present value of expected future profits, for consistent estimation of the Q model. This measurement error may be serially uncorrelated or persistent, and may be correlated or uncorrelated with the present value of expected future profits itself. In each case we propose a test of the null hypothesis of strong stock market efficiency, and consider identification of the Q model under the alternative.

Our empirical results, using panel data for US companies that are publicly traded, are unequivocal. Using the conventional measure of average q, based on stock market valuations, we replicate the usual empirical findings: the average q model yields implausible estimates of adjustment costs; cash flow terms are significant conditional on average q; and there are significant non-linearities in the relationship between investment rates and average q.

Using alternative instrument sets, and using our constructed measure as an instrument for the usual measure of average q, has little effect on these results. However, we obtain strikingly different results when we use our measure of average q based on analysts' earnings forecasts *in place of* the conventional measure of average q based on share price data. In this case we find more reasonable estimates of the size of adjustment costs, and neither cash flow nor non-linear terms are found to be significant conditional on our constructed measure of average q. Perhaps most surprisingly, we find that conditional on our measure, there is no additional information relevant for investment in the conventional share price based measure of average q.

Conditional on the structure of the Q model of investment, these results reject the null hypothesis of strong stock market efficiency, and indicate that the deviations of equity valuations from the firm's 'fundamental' value (i.e., the present value of expected future net distributions to shareholders) are both persistent and themselves correlated with fundamental values. We discuss models of rational bubbles and noise traders that are consistent with these results. Our results also suggest that company investment is consistent with a model in which firms seek to maximise the present value of their expected future profits rather than their stock market capitalisations, which are not necessarily the same objective once we recognise that share prices violate the strong form of market efficiency.[3]

2 The Q model

2.1 Basic model

The model we consider is standard in the investment literature. The objective of the firm when choosing investment at time t is to maximise the present value of the stream of current and expected future net distributions to its existing shareholders. Assuming, for simplicity, no taxes and no debt finance, the net distribution to shareholders (i.e. dividends paid minus the value of new shares issued) coincides with the net revenue generated by the firm in each period. Thus the firm's objective is to maximise:[4]

$$V_t = E_t \left[\sum_{s=0}^{\infty} \beta_{t+s} \Pi_{t+s} \right], \tag{1}$$

where Π_{t+s} denotes net revenue generated in period $t+s$; β_{t+s} is the discount factor used in period t to discount expected revenue in period $t+s$, with $\beta_t = 1$, and $E_t[.]$ denotes an expectation conditioned on information available in period t.

We specify the net revenue function to have the form

$$\Pi_t \left(K_t, L_t, I_t\right) = p_t \left[F(K_t, L_t) - G(I_t, K_t)\right] - w_t L_t - p_t^K I_t \tag{2}$$

where K_t is the stock of capital in period t, L_t denotes a vector of variable inputs used in period t, I_t is gross investment in period t, p_t is the price of the firm's output, w_t is a vector of prices/wage rates for the variable inputs, and p_t^K is the price of capital goods in period t. $F(K_t, L_t)$ is the production function for gross output, and $G(I_t, K_t)$ is an adjustment cost function, with costs of adjusting the capital stock specified to take the form of lost output. Our timing assumption is that current investment is immediately

[3] See Stein (1996) for conditions under which this remains an appropriate objective for firms in the absence of strong efficiency.

[4] The firm index i is suppressed except when needed for clarification.

productive, and the stock of capital evolves according to

$$K_{t+s} = (1 - \delta)K_{t+s-1} + I_{t+s}, \tag{3}$$

where δ is the rate of economic depreciation. We also assume that current prices and the realisations of current technology shocks are known to the firm when choosing current investment. The expected value in equation (1) is taken over the distribution of future prices and technology shocks. Other timing conventions are certainly possible, but would not affect the substance of our analysis in the following sections.

The firm chooses investment to maximise V_t subject to the capital accumulation constraint in equation (3). The first order conditions for this problem give

$$-\left(\frac{\partial \Pi_t}{\partial I_t}\right) = \lambda_t, \tag{4}$$

and

$$\lambda_t = E_t\left[\sum_{s=0}^{\infty} \beta_{t+s}(1-\delta)^s \left(\frac{\partial \Pi_{t+s}}{\partial K_{t+s}}\right)\right], \tag{5}$$

where λ_t is the shadow value of an additional unit of installed capital in period t.

Given equation (2) and price-taking behaviour, the first order condition (4) can be rearranged as

$$\left(\frac{\partial G_t}{\partial I_t}\right) = (q_t - 1)\,\frac{p_t^K}{p_t} \tag{6}$$

where $q_t = \lambda_t / p_t^K$ is marginal q, or the ratio of the shadow value of an additional unit of capital to its purchase cost. In the absence of adjustment costs, investment is chosen such that marginal q is unity, and in the presence of strictly convex adjustment costs investment is an increasing function of marginal q.

The average q model requires that $\Pi_t\,(K_t, L_t, I_t)$ is homogeneous of degree one in (K_t, L_t, I_t), sufficient conditions for which are that both the gross production function and the adjustment cost function exhibit constant returns to scale, and the firm is a price-taker in all markets. Given this linear homogeneity, Hayashi (1982) proved the equality of marginal q and average q, which with our timing convention yields

$$q_t = \frac{V_t}{p_t^K(1-\delta)K_{t-1}}. \tag{7}$$

Average q is the ratio of the value of a firm entering period t with a capital stock of $(1-\delta)K_{t-1}$ inherited from the past, to the replacement cost value of that capital in period t. Notice that the numerator of average q in (7) is the present value of current and expected future net revenues, as in equation (1). This will only be measured by the firm's equity valuation if stock market prices are strongly efficient.

Further assuming that adjustment costs have the symmetric, quadratic form

$$G(I_t, K_t) = \frac{b}{2}\left[\left(\frac{I_t}{K_t}\right) - c - e_t\right]^2 K_t, \tag{8}$$

then gives the convenient linear model

$$\begin{aligned}\left(\frac{I_t}{K_t}\right) &= c + \frac{1}{b}\left(\frac{V_t}{p_t^K(1-\delta)K_{t-1}} - 1\right)\frac{p_t^K}{p_t} + e_t, \\ &= c + \frac{1}{b}Q_t + e_t\end{aligned} \tag{9}$$

in which the error term e_t is an adjustment cost shock, observed by the firm but not by the econometrician, which may be serially correlated. [5]

2.2 Measurement error in share prices

Under the assumption that stock market prices are strongly efficient, the firm's equity valuation (V_t^E) coincides with its 'fundamental' value (V_t), and the empirical investment equation (9) can be estimated consistently by using the equity valuation to measure the numerator of average q. We relax this strong efficiency assumption to allow for the possibility that $V_t^E \neq V_t$, and consider the implications of the resulting measurement error in average q for the estimation of the Q investment model (9).

[5] It is well known that the Q model can be extended to allow for debt finance and the presence of taxes. See, for example, Summers (1981) and Hayashi (1982, 1985). We incorporate the standard adjustment for debt finance and tax in the empirical measures of Q_t used in section 4.

We first write

$$Q_t = \frac{V_t}{p_t(1-\delta)K_{t-1}} - \frac{p_t^K}{p_t} \tag{10}$$

and

$$V_t^E = V_t + m_t, \tag{11}$$

so that the measure of Q_t that uses the firm's equity valuation has the form

$$\begin{aligned} Q_t^E &= \frac{V_t + m_t}{p_t(1-\delta)K_{t-1}} - \frac{p_t^K}{p_t} \\ &= Q_t + \frac{m_t}{p_t(1-\delta)K_{t-1}} \\ &= Q_t + \mu_t. \end{aligned} \tag{12}$$

Substituting Q_t^E for Q_t in the investment model (9) then gives

$$\left(\frac{I_t}{K_t}\right) = c + \frac{1}{b}Q_t^E + \left(e_t - \frac{\mu_t}{b}\right). \tag{13}$$

It is useful to distinguish among three forms that the measurement error μ_t may take. The first is where μ_t is serially uncorrelated. In this case it is possible to obtain consistent parameter estimates from (13), using Q_{t-1}^E as an instrumental variable for Q_t^E.[6] The second form generalizes μ_t as a kth-order moving average process. Then Q_{t-k-1}^E is a valid instrument, and it should be possible to obtain consistent parameter estimates when the time dimension of the panel exceeds k. However, previous research suggests that allowing for this type of measurement error in the Q model does not have a major impact on the empirical results.[7]

Several models of share price bubbles and noise trading would predict highly persistent deviations of equity valuations from 'fundamental' values. In this third form, the measurement error is highly persistent. Two sub-cases can be distinguished, depending on whether μ_t is correlated or uncorrelated with the firm's fundamental value

[6]We discuss here the case where adjustment cost shocks (e_t) are serially uncorrelated, but relax this assumption later.

[7]See, for example, Hayashi and Inoue (1991) and Blundell *et al.* (1992).

V_t. In the latter case, the persistent serial correlation in μ_t will rule out the use of lagged Q^E_{t-s} as instruments for Q^E_t, but the orthogonality between μ_t and V_t allows the use of lagged determinants of V_t as instrumental variables. Thus it should be possible to obtain consistent estimates from the model in equation (13), using lagged values of sales, profits or investment, for example, as instruments.[8] The key to identification in this case would be the exclusion of lagged values of conventionally-measured Q^E_t itself from the instrument set.

In the second sub-case, where the measurement error μ_t is both highly persistent and correlated with V_t, it appears that the adjustment cost parameter $(\frac{1}{b})$ is not identified from the model in equation (13). The current error μ_t is correlated with μ_{t-s}, which in turn is correlated with observable influences on V_{t-s}. This rules out using lagged sales, profits or investment as valid instruments. Hence it is unclear that there are any valid instruments for conventionally-measured Q^E_t in this case. It is worth emphasising that this form of the measurement error is consistent with both rational bubbles and noise trader models.[9]

To test the null hypothesis that stock market valuations are strongly efficient against the alternative that share valuations deviate from fundamental values (V_t) in a way that is both highly persistent and correlated with V_t itself, we propose to use securities analysts' forecasts of future earnings to construct an alternative estimate of the present value of current and future net revenues. Under the null hypothesis of strong efficiency, and the assumptions used to obtain the Q model, the conventional measure of Q^E_t using stock market valuations should be a sufficient statistic for investment. Under the alternative, there is relevant information about expected future profitability that is not summarised in the conventional measure of Q^E_t, and an alternative measure based on analysts' forecasts of profits should be informative.

To implement this test we use analysts' consensus forecasts of future profits as a measure of $E_t\,[\Pi_{t+s}]$. Combining these forecasts with a simple assumption about the discount rates β_{t+s}, we can construct an alternative estimate of the present value of

[8] Current values of these variables will not be valid instruments if they are correlated with e_t.

[9] See, for example, Blanchard and Watson (1982), Froot and Obstfeld (1991) and Campbell and Kyle (1993).

current and future net revenues as

$$\widehat{V_t} = E_t \left(\Pi_t + \beta_{t+1}\Pi_{t+1} + \ldots + \beta_{t+s}^{s}\Pi_{t+s}\right). \tag{14}$$

We then use this estimate in place of the firm's stock market valuation to obtain an alternative estimate of average q, and hence

$$\widehat{Q_t} = \left[\frac{\widehat{V_t}}{p_t^K(1-\delta)K_{t-1}} - 1\right]\frac{p_t^K}{p_t}. \tag{15}$$

Including $\widehat{Q_t}$ as an additional regressor in equation (13) tests the null of strong efficiency, conditional on the structure of the Q model.

Finally we consider identification of the Q model under the alternative that μ_t, the measurement error in Q_t^E is highly persistent and correlated with V_t. This *may* be possible if we use $\widehat{Q_t}$ *in place of* the conventional measure Q_t^E. Clearly our estimate of $\widehat{V_t}$ will also measure the firm's fundamental value V_t with error. The sources of measurement error include truncating the series after a finite number of future periods, using an incorrect discount rate, and the fact that analysts forecast net profits rather than net revenues. Letting $\nu_t = \widehat{Q_t} - Q_t$ denote the resulting measurement error in our estimate of Q_t, the econometric model is then

$$\left(\frac{I_t}{K_t}\right) = c + \frac{1}{b}\widehat{Q_t} + \left(e_t - \frac{\nu_t}{b}\right). \tag{16}$$

The measurement error ν_t may also be persistent. Identification will depend on whether this measurement error is uncorrelated with suitably lagged values of observable instruments, for example sales, profits or investment. We regard this as an empirical question that will be investigated using tests of overidentifying restrictions in the context of model (16).

2.3 Relation to Abel and Blanchard (1986)

To implement our approach, we construct an approximation to

$$\text{average } q_t = \frac{E_t\left[\sum_{s=0}^{\infty}\beta_{t+s}\Pi_{t+s}\right]}{p_t^K(1-\delta)K_{t-1}} \tag{17}$$

Abel and Blanchard (1986) proposed instead to econometrically forecast using vector autoregressions

$$\text{marginal } q_t = \left(\frac{1}{p_t^K}\right) E_t \left[\sum_{s=0}^{\infty} \beta_{t+s}(1-\delta)^s \left(\frac{\partial \Pi_{t+s}}{\partial K_{t+s}}\right)\right]. \tag{18}$$

Our approach relies on the assumption that Π_t is homogeneous of degree one in (K_t, L_t, I_t), but avoids the need to specify a functional form for the marginal revenue product of capital. The practical appeal is that we can use published profit forecasts based on the information set available to professional securities analysts, which is likely to be richer than that available to the econometrician specifying the auxiliary forecasting model needed to implement the Abel-Blanchard approach.

When implementing their procedure, Abel and Blanchard (1986) and subsequent researchers (see, for example, Gilchrist and Himmelberg, 1995) assumed that Π_t is homogeneous of degree one in K_t *alone*. This is strictly inconsistent with the structure of the Q model outlined in section 2.1, and likely to result in biased estimates of the adjustment cost parameter. Given the assumption that Π_t is homogeneous of degree one in (K_t, L_t, I_t), we have[10]

$$\Pi_t = \left(\frac{\partial \Pi_t}{\partial K_t}\right) K_t + \left(\frac{\partial \Pi_t}{\partial I_t}\right) I_t \tag{19}$$

or

$$\frac{\partial \Pi_t}{\partial K_t} = \frac{\Pi_t}{K_t} - \left(\frac{\partial \Pi_t}{\partial I_t}\right)\left(\frac{I_t}{K_t}\right). \tag{20}$$

Thus the approximation $\left(\frac{\partial \Pi_t}{\partial K_t}\right) \approx \left(\frac{\Pi_t}{K_t}\right)$ omits terms in the rate of investment (and, for the adjustment cost function in equation (8), also terms in the square of the rate of investment) that will result in omitted variable bias.[11] Moreover, given the structure of adjustment costs assumed in equation (8), that forms the basis for a linear relationship between the investment rate and Q, it is difficult to see how net revenue Π_t could be homogeneous of degree one in K_t alone.

[10] Since $\left(\frac{\partial \Pi_t}{\partial L_t}\right) = 0$ for the variable inputs.

[11] Abel and Blanchard (1986) themselves noted this point in their footnote 5 but ignored it in their empirical work.

3 Data

The Compustat dataset is an unbalanced panel of firms from the industrial, full coverage, and research files. The variables we use are defined as follows. The replacement value of the capital stock is calculated using the standard perpetual inventory method with the initial observation set equal to the book value of the firm's first reported net stock of property, plant, and equipment (data item 8) and an industry-level rate of economic depreciation constructed from Hulten and Wykoff (1981). Gross investment is defined as the direct measure of capital expenditures in Compustat (data item 30). Cash flow is the sum of net income (data item 18) and depreciation (data item 14). Both gross investment and cash flow are divided by the current period replacement value of the capital stock. The construction of Q^E and $\hat{Q}$ is discussed in detail in appendix A (to be written). The implicit price deflator (IPD) for total investment for the firm's three-digit SIC code is used to deflate the investment and cash flow variables and in the perpetual inventory calculation of the replacement value of the firm's capital stock. The three-digit IPD for gross output is used to form the relative price of capital goods. These price deflators are obtained from the NBER/Census database (http://www.nber.org/nberprod). We use Compustat data on the firms' dividend payout and S&P bond rating to split the sample.

We employ data on expected earnings from I/B/E/S International Inc., a private company that has been collecting earnings forecasts from securities analysts since 1971. To be included in the I/B/E/S database, a company must be actively followed by at least one securities analyst, who agrees to provide I/B/E/S with timely earnings estimates. According to I/B/E/S, an analyst actively follows a company if he or she produces research reports on the company, speaks to company management, and issues regular earnings forecasts. These criteria ensure that I/B/E/S data come from well-informed sources. The I/B/E/S earnings forecasts refer to net income from continuing operations as defined by the consensus of securities analysts following the firm. Typically, this consensus measure removes from earnings a wider range of non-recurring charges than the "extraordinary items" reported on firms' financial statements.

For each company in the database, I/B/E/S asks analysts to provide forecasts of earnings per share over the next four quarters and each of the next five years. We focus on the annual forecasts to match the frequency of our Compustat data. In practice, few analysts provide annual forecasts beyond two years ahead. I/B/E/S also obtains a separate forecast of the average annual growth of the firm's net income over the next three to five years — the so-called "long-term growth forecast". To conform with the timing of the stock market valuation we use to construct Q^E, we construct $\hat{Q}$ using the last reported analysts' forecasts before the beginning of the fiscal year.

We abstract from any heterogeneity in analyst expectations for a given firm-year by using the mean across analysts for each earnings measure (which I/B/E/S terms the "consensus" estimate). We multiply the one-year-ahead and two-year-ahead forecasts of earnings per share by the number of shares outstanding to yield forecasts of future earnings levels.

The sample we use for estimation includes all firms with at least four consecutive years of complete Compustat and I/B/E/S data. We require four years of data to allow for first-differencing and the use of lagged variables as instruments. We determine whether the firm satisfies the four-year requirement after deleting observations that fail to meet a standard set of criteria for data quality (described below).

We deleted observations for the following reasons: (1) q^E is less than 0, its theoretical minimum, or greater than 40; (2) $\hat{q}$ is less than 0 or greater than 40. These types of rules are common in the literature and we employ them to maintain comparability to previous studies.

3.1 Empirical specification

Following Blundell et al. (1992), our empirical specification also allows for the adjustment cost shock (e_{it}) for firm i in period t to have the first-order autoregressive structure

$$e_{it} = \rho e_{i,t-1} + \varepsilon_{it} \tag{21}$$

where ε_{it} can further be allowed to have firm-specific and time-specific components. Allowing for this form of serial correlation in equation (13) gives the dynamic specification

$$\begin{aligned}\frac{I_{it}}{K_{it}} &= c(1-\rho) + \frac{1}{b}Q^E_{it} - \frac{\rho}{b}Q^E_{i,t-1} + \rho\left(\frac{I_{i,t-1}}{K_{i,t-1}}\right) \\ &\quad + \left(\varepsilon_{it} - \frac{1}{b}\left(\mu_{it} - \rho\mu_{i,t-1}\right)\right)\end{aligned} \tag{22}$$

and a similar dynamic specification based on the model defined by equation (16), where $\hat{Q}$ replaces Q^E. We allow for time effects by including year dummies in the estimated specifications. Estimation allows for unobserved firm-specific effects by using first-differenced GMM estimators with instruments dated $t-3$ and earlier. This is implemented using DPD98 for GAUSS.[12] The common factor restriction is tested and imposed in the results reported below, using the minimum distance procedure described in Blundell *et al.* (1992).

4 Empirical results

In our results we use the full sample of firms that meet our data requirements and two subsamples of firms, those that pay dividends and those that have a bond rating from Standard and Poor's at the beginning of the year. We focus on these two sub-samples because they contain large, well-established firms that have very liquid markets for their equity; which are arguably the conditions that are least favorable to our conjecture that there are deviations from strong efficiency.

Table 1 presents the GMM estimates of the first-differenced investment equations using our different controls for fundamentals. We implement GMM with an instrument set that contains the period $t-3$ and $t-4$ values of I/K and CF/K, as well as a full set of year dummies. We do not present results from other instrument sets in this preliminary draft. In particular, we do not use an instrument set containing lags of Q^E, which would distinguish between the first and second cases discussed above where measurement error is serially uncorrelated or serially correlated but uncorrelated with

[12] See Arellano and Bond (1991, 1998).

the firm's fundamental value V_t. However, in the empirical work we have done the results when using lags of Q^E in the instrument set are qualitatively similar to those we discuss below.

The coefficient on q^E (shown in column 1) is small and statistically insignificant from zero. The p-value of the Sargan test, reported with the other diagnostic tests below the estimate, strongly rejects the joint test of the model and instrument validity. In contrast, the coefficient on $\hat{q}$ (shown in column 2) is two orders of magnitude greater than that on q^E and precisely estimated. Moreover, when we use both measures of fundamentals in the investment equation (column 3) the estimate on $\hat{q}$ is about the same as when q^E is not included, while the estimate on q^E remains insignificant. In both cases when $\hat{q}$ is included in the model the Sargan test is not rejected, nor are the other diagnostic tests. Taken together, these results imply that we reject strong efficiency of the stock market when using the Q model.

We can use the estimates on q^E and $\hat{q}$ to calculate the implied elasticities of the investment-capital ratio with respect to the fundamental variable. As shown in the bottom of the table, the elasticities from using $\hat{q}$ are more than twenty-five times that when q^E is used. In contrast to many previous studies, these estimates indicate that investment spending is quite sensitive to fundamentals. The estimates also imply that when $\hat{q}$ is used marginal adjustment costs for a \$1 investment are all less than \$1, evaluated at either the means or medians of the sample variables.

In the remaining columns of the table we perform the same analysis using the two subsamples of firms. The results are qualitatively identical, although the point estimates on $\hat{q}$ are smaller in the dividend paying sample and larger in the bond rated sample.

In table 2 we perform the identical exercises as in table 1, replacing q^E and $\hat{q}$ with their tax adjusted variants. While in the full sample the share priced based measure of fundamentals is now statistically significant, when $\hat{Q}$ is included in the regression it is not. In the subsamples, the results mirror those in table 1. Hence, regardless of whether we use the tax-adjusted or unadjusted measures we find similar results.

In tables 3 through 6 we examine the robustness of our results. In table 3 we introduce cash flow as an additional regressor in the investment equations. In all other respects, the estimation method and data are identical to those used to generate the results in table 1. In this framework, the coefficient on cash flow measures its influence after controlling for expected future returns, and it should be zero if there are no binding financial constraints and the Q model is otherwise correctly specified. The coefficient on q^E in column 1 is little affected but, as many studies have found, the coefficient on cash flow is large and statistically significant. In columns 2 and 3 when we use $\hat{q}$ as a control for fundamentals we find that investment is insensitive to cash flow. Moreover, there is no evidence that the model is misspecified based on the diagnostic tests, and the economic implications of the results are similar to those in table 1.

In the subsamples, the estimates on cash flow are statistically insignificant regardless of which measure is used. Considering just the results using q^E, this evidence would seem to be consistent with earlier studies: cash matters for the firms that are most likely to face liquidity constraints, not the large, liquid firms we have isolated in our two subsamples. But this conclusion is premature when we consider the results using $\hat{q}$. Here regardless of the sample of firms, cash does not matter for investment. We come to the same conclusion when we repeat the exercise in table 4 using the tax-adjusted variables.

Finally, in tables 5 and 6 we introduce non-linear terms in the measures of fundamentals. Again, the estimation method and data are identical to those used to generate the results in table 1. In this framework, the coefficient on the squared-term measures the extent to which investment responds nonlinearly to fundamentals. The coefficient on the squared terms should be zero if adjustment costs take the symmetric, quadratic form of equation 8. However, significant non-linearities are consistent with a model of non-convex adjustment costs.

The coefficient on q^E in column 1 of table 5 is substantially larger than in table 1 and is precisely estimated. The coefficient on the square of q^E is negative and statistically significant, indicating that the investment rate is concave in q^E. In particular, the elasticity is much larger than in table 1, compare 0.410 to 0.030, but tails off rapidly, becoming negative at values of q^E greater than seven. There is cause for concern about the specification based on the Sargan test, which is rejected at nearly the five percent level. But the result would be very encouraging in isolation. Indeed, there appears to be some hope of salvaging the model when non-linearities are introduced. The relevant issue then is whether the non-linearities are a primitive feature of the structural model, as emphasized by Abel and Eberly (1996), or whether measurement error is responsible. After all if q^E is likely to be more mismeasured for larger values than for smaller.

The results in column 2 where we perform the analogous experiment using $\hat{q}$ support, rather strongly, the latter interpretation. In this case, we find no evidence of non-linearity or model misspecification, indicating that measurement error in share prices, rather than non-convex adjustment costs, are responsible for the results when using q^E. The results in the subsamples and when using the tax-adjusted variants, in table 6, lead to the same conclusion.

5 Implications

[To Be Written]

6 Conclusion

The empirical failure of the Q model has led to a vibrant research agenda focusing on different ways the model might be salvaged. The two most persuasive criticisms of the theoretical setup of the model are that it ignores the role of capital market imperfections and non-convex adjustment costs. Many empirical studies are supportive of these lines of inquiry, having rejected the basic model in ways that are consistent with these proffered explanations. However, all these studies take as a given that the stock market is strongly efficient.

We show the conditions under which it is possible to identify the Q model when stock prices are not strongly efficient. We find empirically that the model cannot be identified using share prices, but that it can be using a measure of fundamentals that relies on securities analysts' forecasts of future profits. Using the share price measure of fundamentals we replicate the results from earlier research. But using our new measure we find more reasonable estimates of the size of adjustment costs and the elasticity of investment with respect to fundamentals. Perhaps most surprisingly, we find that conditional on our measure, there is no additional information relevant for investment in the conventional share price based measure of average q. In addition, neither cash flow nor non-linear terms are found to be significant conditional on our constructed measure of average q. Taken together these results provide the first evidence that there is a measure of fundamentals that is a sufficient statistic for investment.

References

Abel, Andrew B. and Olivier J. Blanchard (1986). The present value of profits and cyclical movements in investment. *Econometrica* 54(2): 249–273.

Abel, Andrew B. and Janice C. Eberly (1996). Investment and q with fixed costs: An empirical analysis. Mimeograph, University of Pennsylvania.

Arellano, Manuel and Stephen Bond (1991). Some tests of specification for panel data: Monte carlo evidence and an application to employment equations. *Review of Economic Studies* 58(2): 277–297.

Blanchard, Olivier J., Changyong Rhee, and Lawrence H. Summers (1993). The stock market, profit, and investment. *Quarterly Journal of Economics* 108(1): 115–36.

Blanchard, Olivier J. and Mark W. Watson (1982). Bubbles, rational expectations, and financial markets. In P. Wachtel (Ed.), *Crises in the Economic and Financial Structure*. Lexington: Lexington Books.

Blundell, Richard, Stephen Bond, Michael Devereux, and Fabio Schiantarelli (1992). Investment and Tobin's q: Evidence from company panel data. *Journal of Econometrics* 51(1/2): 233–258.

Caballero, Ricardo J. (1997). Aggregate investment: A 90's view. Mimeograph, MIT.

Campbell, John Y. and Albert S. Kyle (1993). Smart money, noise trading and stock price behaviour. *Review of Economic Studies* 60(1): 1–34.

Cummins, Jason G., Kevin A. Hassett, and R. Glenn Hubbard (1994). A reconsideration of investment behavior using tax reforms as natural experiments. *Brookings Papers on Economic Activity* 1994(2): 1–74.

Cummins, Jason G., Kevin A. Hassett, and R. Glenn Hubbard (1995). Tax reforms and investment: A cross-country comparison. *Journal of Public Economics* 62: 237–73.

Dixit, Avinash K. and Robert S. Pindyck (1994). *Investment Under Uncertainty*. Princeton: Princeton University Press.

Fisher, Stanley and Robert C. Merton (1984). Macroeconomics and finance: The role of the stock market. *Carnegie-Rochester Conference Series on Public Policy* 21(1): 57–108.

Froot, Kenneth A. and Maurice Obstfeld (1991). Intrinsic bubbles: The case of stock prices. *American Economic Review* 81(5): 1189–1214.

Gilchrist, Simon and Charles P. Himmelberg (1995). Evidence on the role of cash flow for investment. *Journal of Monetary Economics* 36(3): 541–72.

Hayashi, Fumio (1982). Tobin's marginal q and average Q: A neoclassical interpretation. *Econometrica* 50(1): 213–224.

Hayashi, Fumio (1985). Corporate finance side of the Q theory of investment. *Journal of Public Economics* 27(3): 261–80.

Hayashi, Fumio and Tohru Inoue (1991). The relation between firm growth and Q with multiple capital goods: Theory and evidence from panel data on Japanese firms. *Econometrica* 59(3): 731–753.

Hubbard, R. Glenn (1998). Capital-market imperfections and investment. *Journal of Economic Literature* 36(1): 193–225.

Hulten, Charles R. and Frank Wykoff (1981). Measurement of economic depreciation. In C. R. Hulten (Ed.), *Depreciation, Inflation, and the Taxation of Income from Capital*. Washington: Urban Institute.

Mørck, Randall, Andrei Shleifer, and Robert W. Vishny (1990). The stock market and investment: Is the market a sideshow? *Brookings Papers on Economic Activity* 1990(2): 157–215.

Schiantarelli, Fabio and D. Georgoutos (1990). Monopolistic competition and the q theory of investment. *European Economic Review* 34(5): 1061–1078.

Stein, Jeremy (1996). Rational capital budgeting in an irrational world. *Journal of Business* 69(4): 429–55.

Summers, Lawrence H. (1981). Taxation and corporate investment: A q-theory approach. *Brookings Papers on Economic Activity* 1981(1): 67–127.

Table 1: GMM Estimates of First-Differenced Dynamic Investment Equations: Comparing Market- and Analyst-Based Measures of Fundamentals

Parameter	Full Sample			Dividend Paying Sample			Bond Rated Sample		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
q_{it}^E	0.002	—	0.004	0.001	—	-0.001	0.002	—	-0.001
	(0.008)		(0.006)	(0.005)		(0.004)	(0.008)		(0.009)
$\hat{q}_{it}$	—	0.122	0.120	—	0.089	0.089	—	0.149	0.159
		(0.023)	(0.025)		(0.034)	(0.032)		(0.039)	(0.037)
ρ	0.280	0.204	0.183	0.408	0.509	0.511	0.280	0.142	0.133
	(0.087)	(0.047)	(0.040)	(0.084)	(0.071)	(0.070)	(0.087)	(0.043)	(0.037)
	Diagnostic Tests (p-values)								
Second-Order Serial Correlation	0.061	0.878	0.745	0.096	0.122	0.129	0.233	0.566	0.636
Sargan Test	0.008	0.350	0.303	0.158	0.187	0.167	0.056	0.164	0.214
Common Factor Restriction	0.841	0.409	0.718	0.094	0.257	0.492	0.841	0.576	0.858
	Implied Elasticities								
	0.030	0.780	0.760	0.020	0.550	0.550	0.030	1.04	1.11

The dependent variable is the first difference of the ratio of investment to capital, I_{it}/K_{it}. Year dummies and an intercept are included (but not reported) in all regressions. Robust standard errors on coefficients are in parentheses.

The full sample contains the firms with at least four years of complete Compustat and I/B/E/S data. The number of firms in this sample is 961, for a total of 6144 observations, and the estimation period is 1986–97. The dividend paying sample contains the firms with at least four years of complete Compustat and I/B/E/S data for those firms that pay common dividends. The number of firms in this sample is 650, for a total of 4363 observations, and the estimation period is 1986-97. The bond rated sample contains firms with at least four years of complete Compustat and I/B/E/S data for those firms that have bond ratings from Standard & Poor's at the beginning of the year. The number of firms in the sample is 399, for a total of 2113 observations, and the estimation period is 1990-97.

Instrumental variables are the period $t-3$ and $t-4$ values of I/K and CF/K. The instrument sets also contain an intercept and year dummies.

The test of the overidentifying restrictions, called a Sargan test, is asymptotically distributed $\chi^2_{(n-p)}$, where n is the number of instruments and p is the number of parameters. The test for second-order serial correlation in the residuals is asymptotically distributed as N(0,1) under the null of no serial correlation.

Table 2: GMM Estimates of First-Differenced Dynamic Investment Equations: Comparing Market- and Analyst-Based Measures of Fundamentals

Parameter	Full Sample			Dividend Paying Sample			Bond Rated Sample		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Q_{it}^{E}	0.009	—	0.005	0.003	—	0.001	0.001	—	-0.000
	(0.003)		(0.003)	(0.003)		(0.003)	(0.004)		(0.005)
$\hat{Q}_{it}$	—	0.092	0.082	—	0.067	0.075	—	0.101	0.110
		(0.015)	(0.015)		(0.025)	(0.024)		(0.026)	(0.025)
ρ	0.397	0.058	0.127	0.541	0.489	0.525	0.274	0.095	0.088
	(0.050)	(0.012)	(0.024)	(0.067)	(0.097)	(0.073)	(0.089)	(0.030)	(0.025)
	Diagnostic Tests (p-values)								
Second-Order Serial Correlation	0.096	0.307	0.436	0.112	0.128	0.153	0.234	0.728	0.803
Sargan Test	0.041	0.733	0.907	0.220	0.196	0.281	0.045	0.181	0.246
Common Factor Restriction	0.018	0.812	0.761	0.020	0.705	0.363	0.955	0.706	0.935

See notes to Table 1.

Table 3: GMM Estimates of First-Differenced Dynamic Investment Equations: Comparing Excess Sensitivity to Cash Flow

Parameter	Full Sample (1)	(2)	(3)	Dividend Paying Sample (4)	(5)	(6)	Bond Rated Sample (7)	(8)	(9)
q_{it}^E	0.004	—	0.002	0.002	—	-0.004	0.008	—	0.004
	(0.006)		(0.006)	(0.005)		(0.005)	(0.009)		(0.010)
$\hat{q}_{it}$	—	0.102	0.089	—	0.101	0.111	—	0.123	0.120
		(0.023)	(0.025)		(0.041)	(0.041)		(0.054)	(0.049)
CF_{it}/K_{it}	0.165	0.106	0.131	0.058	0.107	0.141	0.070	0.204	0.202
	(0.070)	(0.068)	(0.074)	(0.098)	(0.097)	(0.102)	(0.141)	(0.145)	(0.125)
ρ	0.334	0.211	0.161	0.511	0.484	0.472	0.300	0.099	0.085
	(0.032)	(0.044)	(0.027)	(0.065)	(0.077)	(0.074)	(0.062)	(0.024)	(0.020)
	Diagnostic Tests (p-values)								
Second-Order Serial Correlation	0.474	0.945	0.809	0.156	0.215	0.204	0.639	0.874	0.820
Sargan Test	0.181	0.335	0.317	0.322	0.198	0.175	0.051	0.140	0.197
Common Factor Restriction	0.084	0.650	0.865	0.085	0.406	0.598	0.315	0.908	0.987
	Implied Elasticities								
	0.060	0.780	0.570	0.030	0.620	0.680	0.130	0.860	0.840

See notes to Table 1.

Table 4: GMM Estimates of First-Differenced Dynamic Investment Equations: Comparing Excess Sensitivity to Cash Flow

Parameter	Full Sample			Dividend Paying Sample			Bond Rated Sample		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Q_{it}^E	0.005	—	0.005	0.003	—	0.001	0.001	—	-0.000
	(0.003)		(0.003)	(0.003)		(0.003)	(0.004)		(0.005)
$\hat{Q}_{it}$	—	0.084	0.075	—	0.067	0.075	—	0.101	0.110
		(0.014)	(0.014)		(0.025)	(0.024)		(0.026)	(0.025)
CF_{it}/K_{it}	0.125	0.070	0.012	0.058	0.107	0.141	0.070	0.204	0.202
	(0.062)	(0.074)	(0.068)	(0.098)	(0.097)	(0.102)	(0.141)	(0.145)	(0.125)
ρ	0.332	0.086	0.138	0.541	0.489	0.525	0.274	0.095	0.088
	(0.032)	(0.018)	(0.024)	(0.067)	(0.097)	(0.073)	(0.089)	(0.030)	(0.025)
	Diagnostic Tests (p-values)								
Second-Order Serial Correlation	0.362	0.400	0.616	0.112	0.128	0.153	0.234	0.728	0.803
Sargan Test	0.180	0.698	0.898	0.220	0.196	0.281	0.045	0.181	0.246
Common Factor Restriction	0.089	0.932	0.881	0.020	0.705	0.363	0.955	0.706	0.935

See notes to Table 1.

Table 5: GMM Estimates of First-Differenced Dynamic Investment Equations: Comparing Non-linearity

Parameter	Full Sample			Dividend Paying Sample			Bond Rated Sample		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
q_{it}^E	0.041	—	0.002	0.049	—	0.015	0.051	—	-0.028
	(0.016)		(0.017)	(0.022)		(0.018)	(0.030)		(0.026)
$(q_{it}^E)^2$	-0.003	—	-0.000	-0.003	—	-0.001	-0.003	—	0.002
	(0.001)		(0.001)	(0.001)		(0.001)	(0.002)		(0.002)
$\hat{q}_{it}$	—	0.153	0.159	—	0.159	0.147	—	0.221	0.182
		(0.052)	(0.056)		(0.063)	(0.051)		(0.071)	(0.059)
$(\hat{q}_{it})^2$	—	-0.011	-0.013	—	-0.026	-0.016	—	-0.039	-0.030
		(0.014)	(0.014)		(0.017)	(0.013)		(0.023)	(0.016)
ρ	0.219	0.135	0.198	0.504	0.564	0.614	0.234	0.094	0.264
	(0.027)	(0.029)	(0.047)	(0.076)	(0.097)	(0.070)	(0.037)	(0.032)	(0.045)
	Diagnostic Tests (p-values)								
Second-Order Serial Correlation	0.695	0.480	0.987	0.136	0.105	0.134	0.375	0.918	0.349
Sargan Test	0.062	0.319	0.619	0.443	0.716	0.706	0.068	0.263	0.288
Common Factor Restriction	0.519	0.853	0.912	0.137	0.177	0.065	0.563	0.905	0.889
	Implied Elasticities								
	0.410	0.975	1.01	0.542	0.981	0.907	0.702	1.55	1.28

See notes to Table 1.

Table 6: GMM Estimates of First-Differenced Dynamic Investment Equations: Comparing Non-Linearity

Parameter	Full Sample			Dividend Paying Sample			Bond Rated Sample		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Q_{it}^E	0.018	—	0.005	0.024	—	0.011	0.027	—	-0.011
	(0.008)		(0.012)	(0.010)		(0.011)	(0.016)		(0.013)
$(Q_{it}^E)^2$	-0.001	—	0.000	-0.001	—	-0.000	-0.001	—	0.001
	(0.000)		(0.000)	(0.000)		(0.000)	(0.000)		(0.001)
$\hat{Q}_{it}$	—	0.096	0.088	—	0.084	0.086	—	0.096	0.082
		(0.017)	(0.022)		(0.027)	(0.024)		(0.020)	(0.023)
$(\hat{Q}_{it})^2$	—	-0.002	-0.002	—	-0.011	-0.013	—	-0.010	-0.009
		(0.006)	(0.007)		(0.006)	(0.007)		(0.007)	(0.006)
ρ	0.161	0.046	-0.142	0.525	0.550	0.499	0.204	-0.030	0.255
	(0.018)	(0.010)	(0.024)	(0.063)	(0.088)	(0.060)	(0.030)	(0.008)	(0.039)
	Diagnostic Tests (p-values)								
Second-Order Serial Correlation	0.889	0.282	0.102	0.156	0.135	0.277	0.419	0.652	0.358
Sargan Test	0.137	0.773	0.860	0.451	0.754	0.797	0.080	0.460	0.309
Common Factor Restriction	0.666	0.982	0.983	0.078	0.332	0.572	0.640	0.987	0.896

See notes to Table 1.

Figure 1: Kernel Regression Smoother of Real q as a Function of Tobin’s q

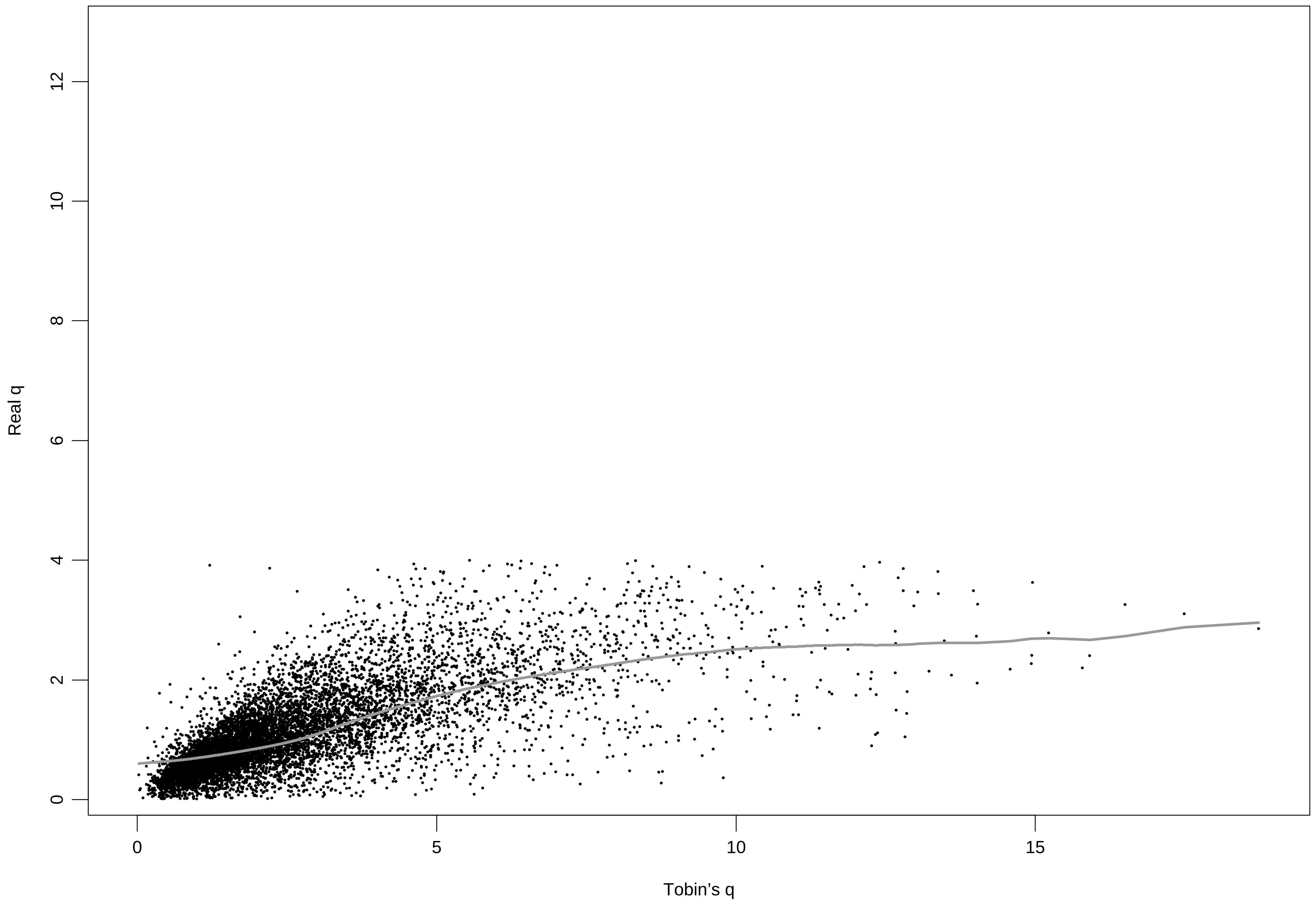

Figure 2: Kernel Regression Smoother of First Differences of Real q and Tobin's q

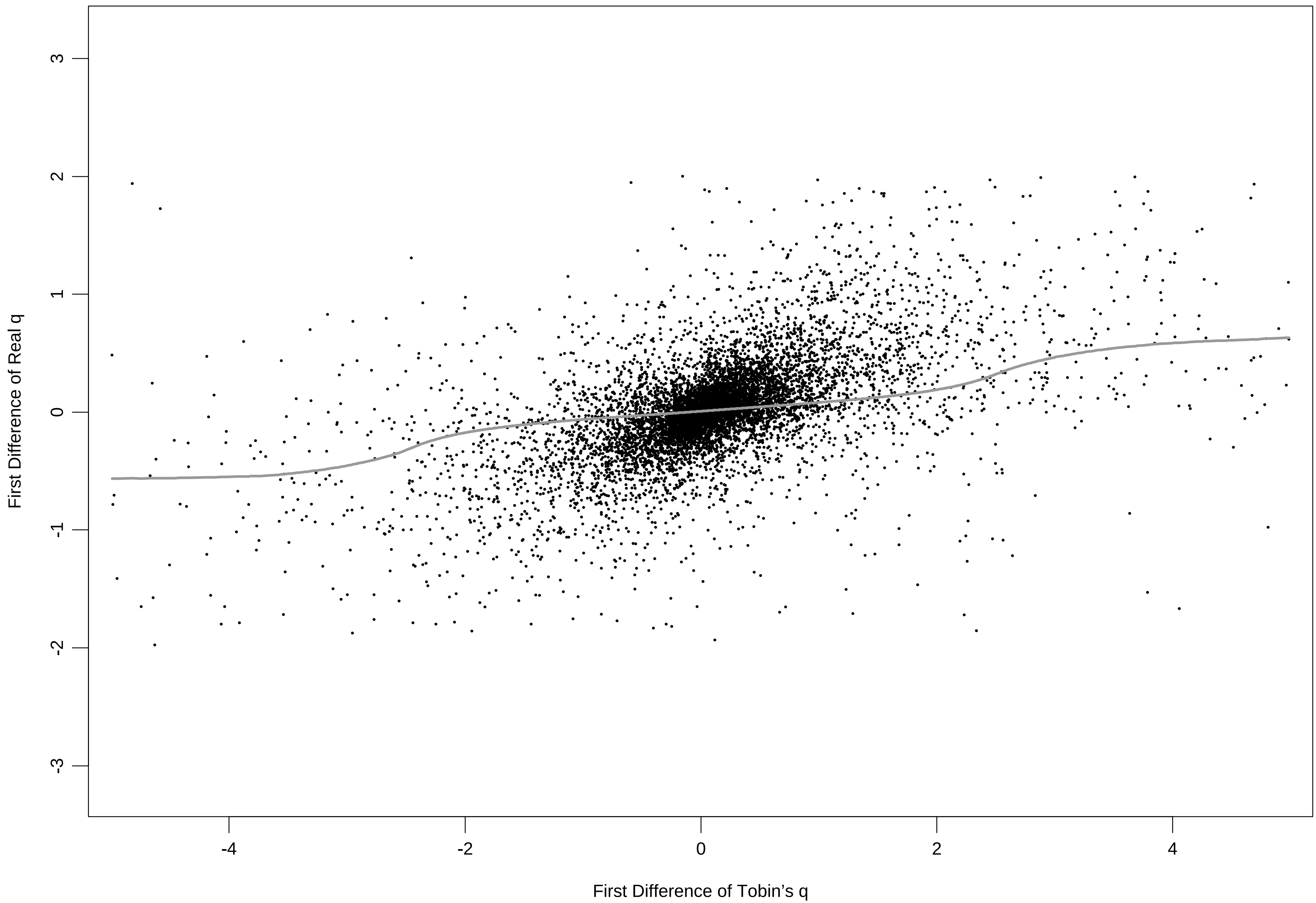

Figure 3: Distribution of Annual Tobin's q

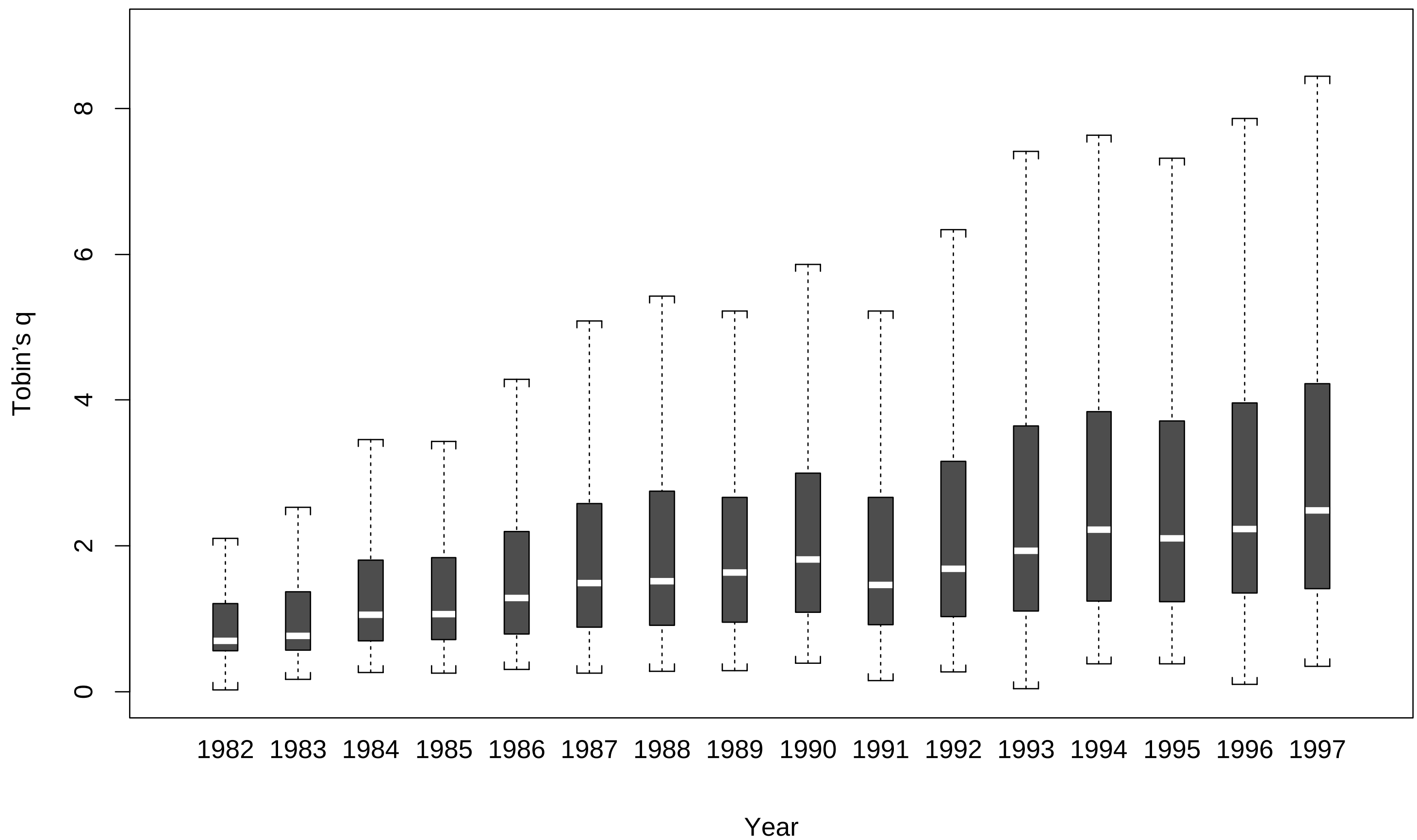

Figure 4: Distribution of Annual Real q

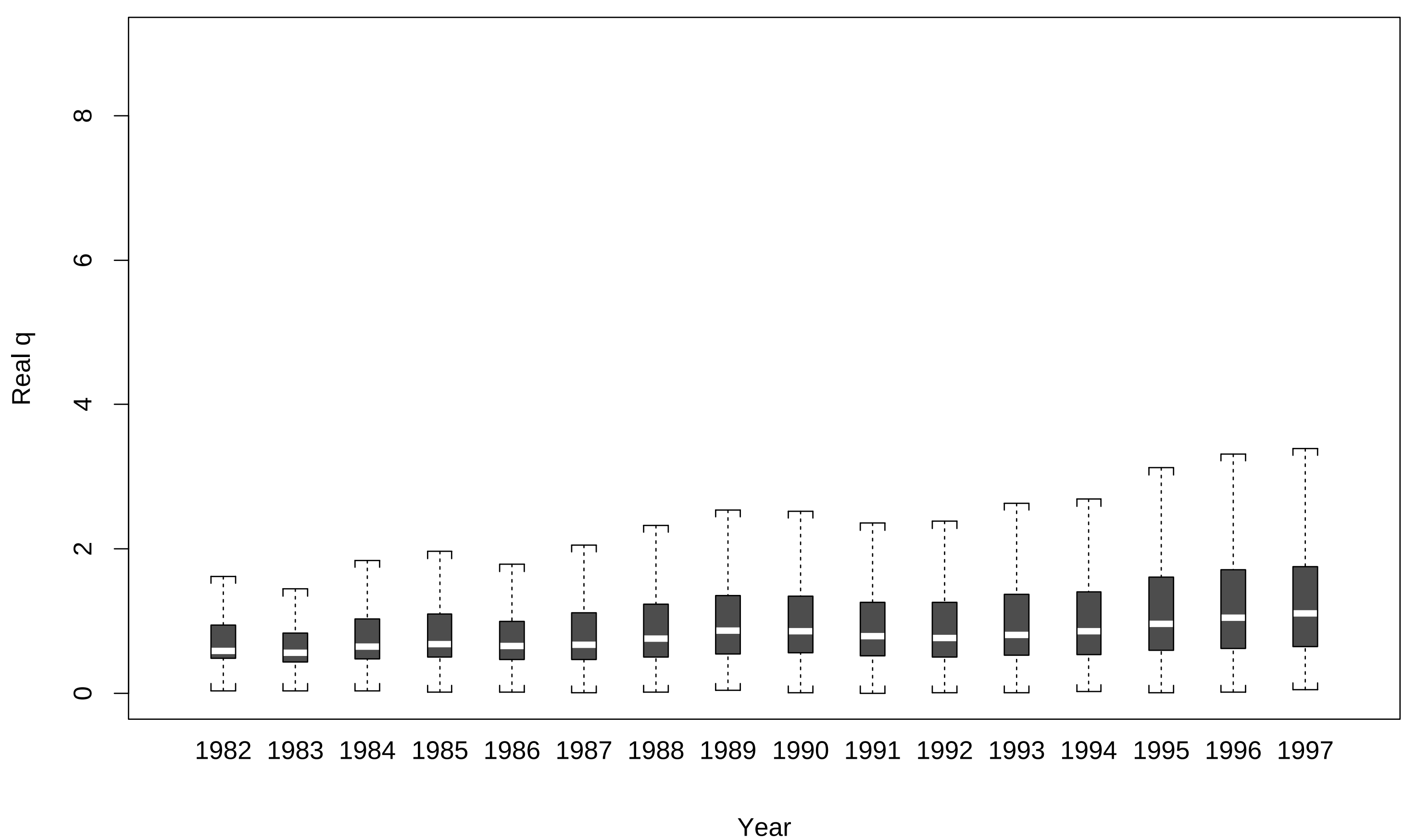

Figure 5: Annual Averages of Tobin's q and Real q (unweighted)

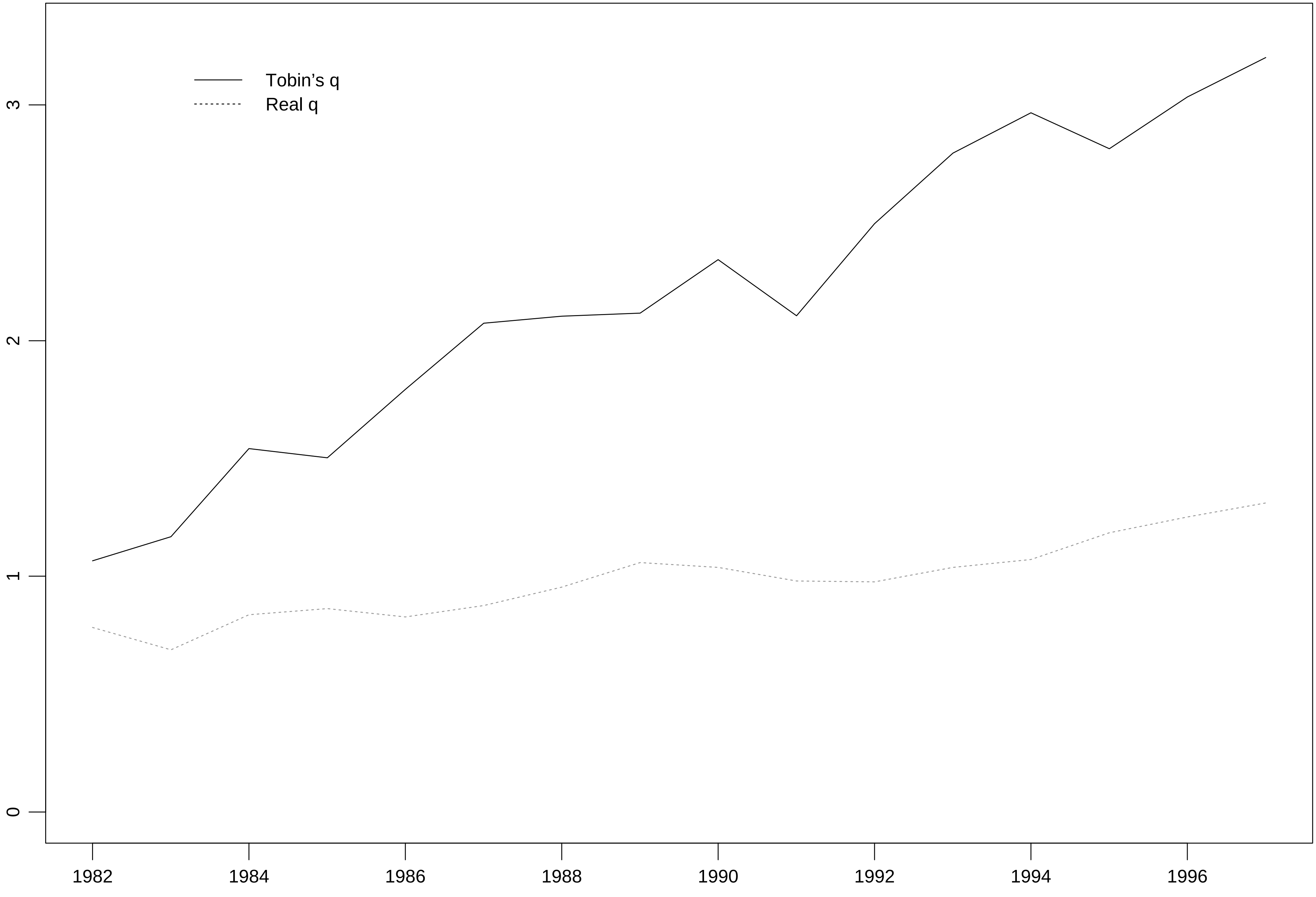

Figure 6: Annual Averages of Tobin’s q and Investment-Capital Ratio (unweighted)

Figure 7: Annual Growth Rates of Tobin’s q and Investment-Capital Ratio (unweighted)

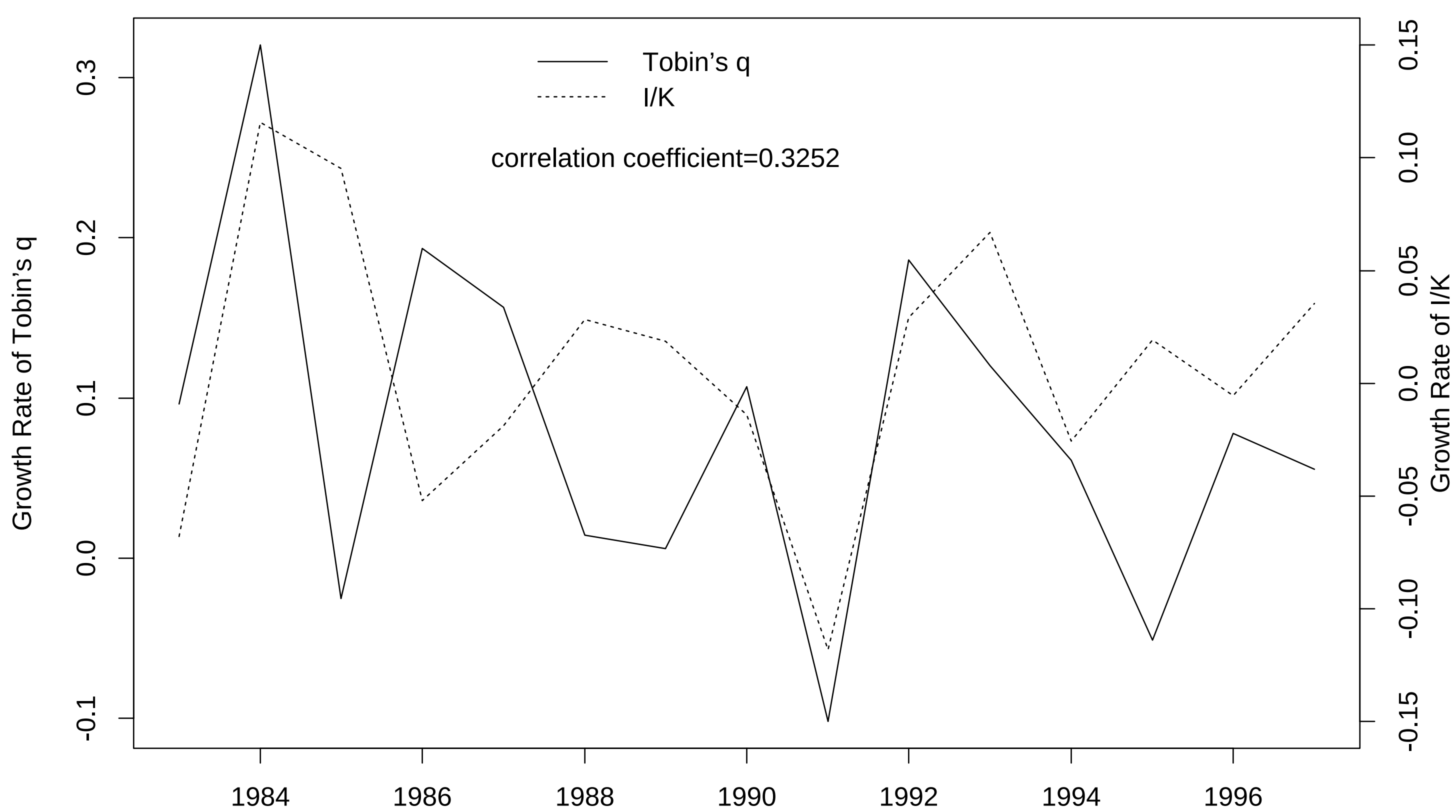

Figure 8: Annual Averages of Real q and Investment-Capital Ratio (unweighted)

Figure 9: Annual Growth Rates of Real q and Investment-Capital Ratio (unweighted)

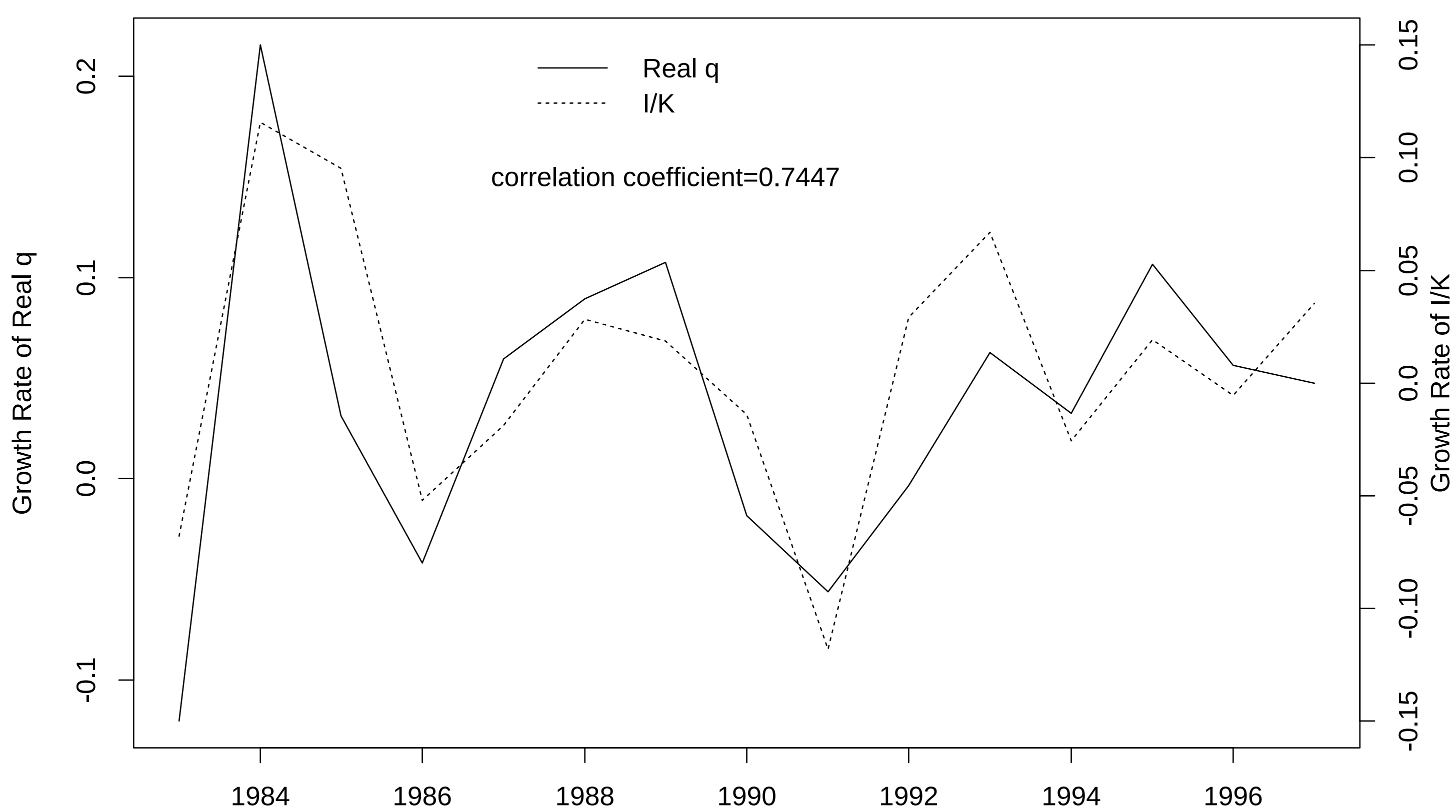

Figure 10: Annual Averages of Tobin’s q and Real q (weighted)

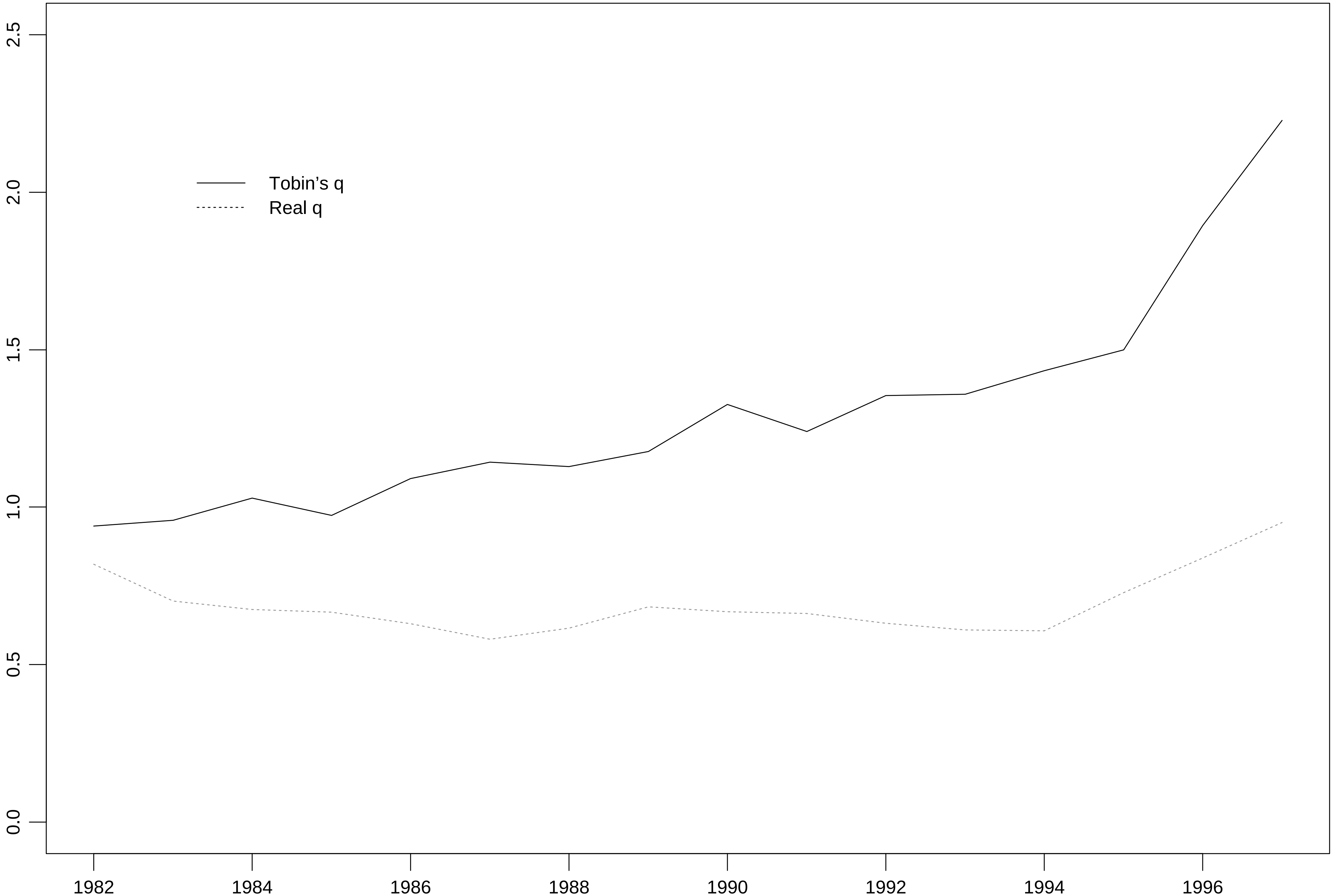

Figure 11: Annual Averages of Tobin's q and Investment-Capital Ratio (weighted)

Figure 12: Annual Growth Rates of Tobin's q and Investment-Capital Ratio (weighted)

Figure 13: Annual Averages of Real q and Investment-Capital Ratio (weighted)

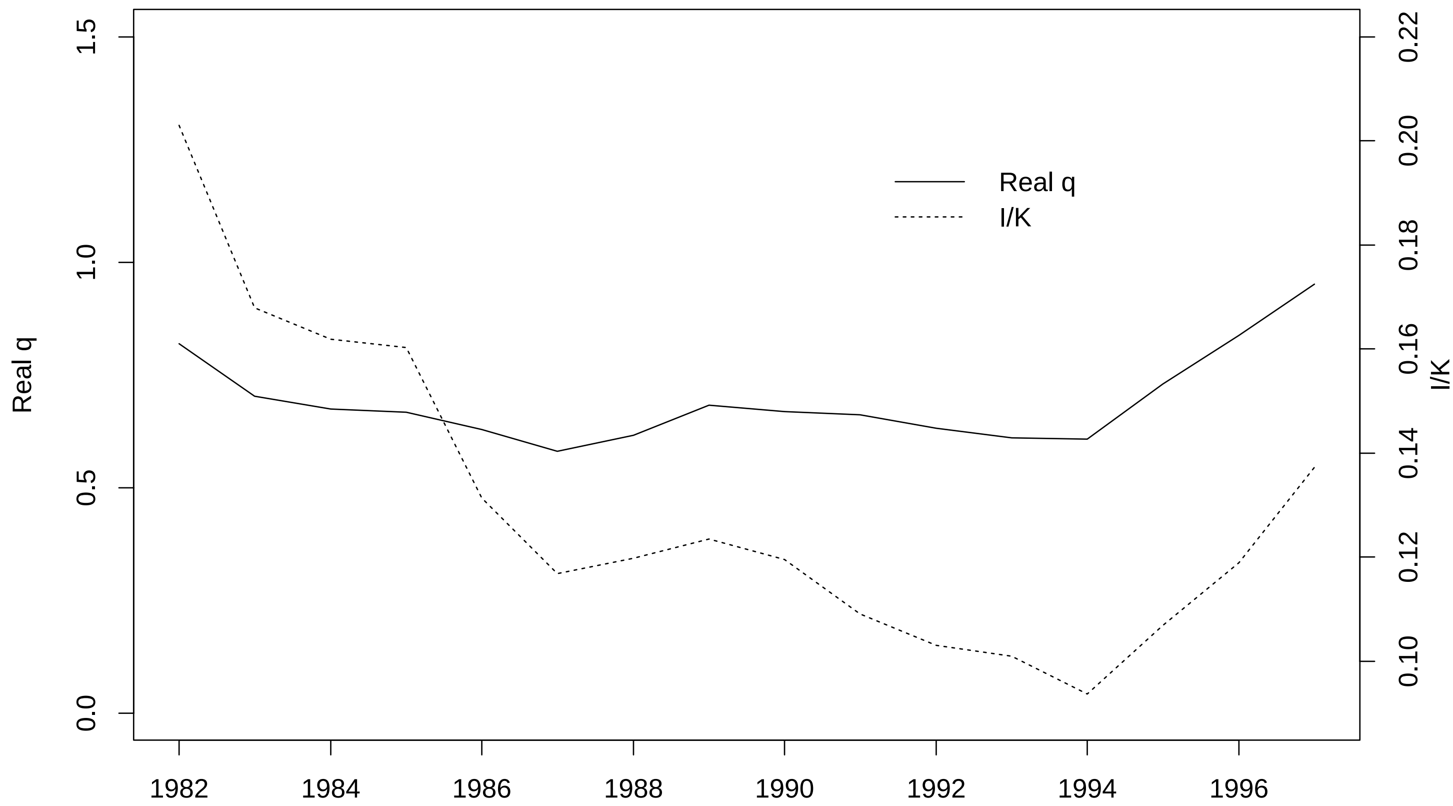

Figure 14: Annual Growth Rates of Real q and Investment-Capital Ratio (weighted)