Has the Response of Investment to Financial Market Signals Changed?

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Introduction

A prominent factor in many popular accounts of the fluctuations of business fixed investment is the gyrations in financial markets, particularly the stock market. For example, the behavior of the stock market is given a prominent role for the boom and bust of investment in the late 1990s and early 2000s. With stock prices rising strongly and IPOs relatively easy during the "Internet bubble" of the late 1990s, many firms found it easy to raise funds for capital expenditures. When stock prices collapsed beginning in 2000, funds were harder to obtain and firms found that they had "too much" capital.[2] Consequently, investment collapsed during this period, and remained sluggish until stock prices began to recover in 2003.

<Figure 1 about here.>

Beyond these casual observations, a slightly more systematic examination indicates that stock prices and fixed investment appear to have a tight link over recent years. Figure 1 shows the year-over-year percentage change of the Wilshire 5000, the broadest index of US stock prices, and private real nonresidential fixed investment from the national income accounts over the past 11 years. The behavior of these two series is in accord with the story in the previous paragraph, and there is a high correlation between the two of 0.73.[3]

Of course, equity prices and investment should be related to each other to the extent that equity prices reflect the "fundamentals" of investment for firms, which underlies the *q* model of investment introduced by Brainard and Tobin (1968) and Tobin (1969).[4] If the fluctuations discussed in the first paragraph are the result of changing evaluations of fundamentals over time, then they may be in some sense "optimal" and of lesser concern for possible policy intervention. However, what underlies the concerns of the public and policymakers is that investment, at least in this instance, may have responded to nonfundamental fluctuations in the stock market, leading to "excessive" volatility of investment.

A number of stories could explain why there now may be a tighter link between stock prices and fixed investment. For example, the development of the US financial system toward a capital markets-based system from a bank-based system could be one factor. In this case, higher stock prices signal to capital markets that the prospects for firms have improved, which lead capital markets to provide more funds at better terms for firms and then allow (capital-constrained) firms to invest more than they had previously.

Furthermore, some recent studies have provided an intellectual basis for a link between investment and non-fundamental equity price movements. Baker, Stein and Wurgler (2003) develop a model where stock prices have a stronger impact on the investment of "equity-dependent" firms. Their empirical results indicate that such firms' investment is much more sensitive to their stock price movements than is the investment of other firms. Gilchrist, Himmelberg, and Huberman (2005) develop a model where the combination of short-selling constraints and dispersion of investor beliefs drive a firm's stock price above its fundamental value, leading to greater equity issuance, reduced capital costs, and higher real investment. They find some empirical evidence of such a relationship between investor dispersion, equity issuance, Tobin's Q, and real investment.

These recent studies stand in contrast to previous empirical work, such as Morck, Shleifer, and Vishny (1990), Blanchard, Rhee, and Summers (1993), and Chirinko and Schaller (1996), which have not found much effect of nonfundamental stock price movements on aggregate fixed investment.[5] There could be at least a couple of reasons for these differences. First, there could have been a significant change in investment behavior such that investment has become more responsive to nonfundamental stock price movements in the last ten years. Second, the models cited in the previous paragraph are more explicitly microeconomic. As such, they suggest that the relationship between real investment and stock price movements at the aggregate level may change over time, depending upon how nonfundamental equity price movements are distributed across firms as well as firms' characteristics over time. In either case, this suggests that the relationship between aggregate equity price movements and fixed investment may vary over time, which is not fully explored in these earlier studies.

In this paper, I take a small step to examine whether the links between financial market signals and aggregate business equipment investment has changed over the past 45 years. I do this using three reduced-form “forecasting” models of investment. The first is a simple model that relates equipment investment growth with stock price appreciation. The second has the flavor of the Jorgenson (1963) neoclassical model with stock price appreciation included as an additional regressor to examine the effects of “nonfundamental” stock price movements in a simple way. The third is a version of the q model. Each is put through a variety of specification tests to investigate whether the relationship between equity price fluctuations and equipment investment may have changed over this period.

To preview the results, I find evidence of parameter instability in each of these models, much of which is consistent with changing coefficients on stock price appreciation over time. However, much of the evidence suggests that the relationship between equity price movements and investment has been weaker over much of the past decade, in contrast to the picture in Figure 1. There is a recent period where the relationship appears to have been stronger, but it was short-lasting. In sum, it is not clear that aggregate investment has become unduly sensitive to nonfundamental equity price movements.

The rest of the paper is organized as follows. The next section presents the results of the simple model of stock price appreciation on the growth of fixed investment for various categories of equipment. The following two sections present a similar analysis for a version of the neoclassical model and a version of the *q* model. The last section provides some concluding remarks.

Investment and stock price appreciation

The first model provides a simple examination of the changes in the correlation between stock price appreciation and fixed investment apparent in Figure 1. Specifically, we estimate the following reduced form regression.

(1) $$\Delta i_t = \alpha_0 + \sum_{j=1}^{N} \alpha_j \Delta s_{t-j} + \rho \Delta i_{t-1} + \varepsilon_t$$

In equation (1), Δi_t is the growth rate of aggregate nonresidential real equipment and software investment, or some category within it, from the US national income accounts, and Δs_t is the appreciation of real equity prices as measured by the Standard and Poor's 500 price index (S&P 500) relative to the price index for GDP of the nonfarm business sector.[6] The S&P 500 is chosen for this exercise because it is the broadest price index that encompasses the period since 1960.[7] Growth rates and price appreciation are measured by 400 times the log difference (i.e., we annualize growth rates). Lagged investment growth is included as a dependent variable in these regressions to account for the properties of the error term in the regression: preliminary results show considerable serial correlation in the error term; nevertheless, the results for the coefficient(s) on stock price appreciation are not unduly sensitive to it. We let N=4 as a simple device to allow for the possibility of "time-to-build" for fixed investment.

The plan in this section is to begin by estimating equation (1) across various "exogenous" splits of the sample, based on previous studies that have identified possible structural shifts of the aggregate economy. We then test for general parameter instability in the model, and also test for a single structural break at an unknown date. Finally, we estimate rolling regressions as a simple way to allow for the relationship to vary over time and examine the possible changes in the relationship.[8]

Changes across "exogenous"' eras

In this subsection, we examine how the relationship between stock price appreciation and fixed investment may have changed across different eras based on changes in the behavior of real aggregate output growth that has been identified by previous studies. The first split of the data is based on changes in productivity growth during the post-World War II period. The reasoning behind this split is that changes in trend productivity reflect possible changes in the return on fixed investment. As such, the incentives for investment in different eras for productivity growth could be markedly different, which may lead to different responsiveness to financial market signals.

As many authors have observed and shown, trend productivity growth slowed notably after 1973; for example, see Kahn and Rich (2004). Also, some studies as well as observations from some economic policymakers (e.g., Federal Reserve Board Chairman Greenspan) have found that trend productivity apparently has increased since the mid-1990s. Because it has occurred relatively recently, the date for this shift is less certain; Kahn and Rich (2004) date it more toward the latter part of the decade, while others would place it a little earlier. For our purposes, to ensure sufficient observations in the latter period, we will date the new high productivity period beginning in 1994; somewhat later dates have little qualitative effect on the results. Thus, in this split, we define three eras: 1960-1973, 1974-93, and 1994-2004.

The second split of the data is based on changes in the volatility of GDP growth during the post-World War II period. McConnell and Perez-Quiros (2000) found a structural break in GDP growth with significantly lower volatility beginning in 1984. A number of subsequent studies have confirmed their basic result as well as finding similar declines in the volatility of many macroeconomic variables; for example, see Stock and Watson (2002) and Ahmed, Levin, and Wilson (2004). As such, in this split, we define two eras: 1960-1983 and 1984-2004. The reasoning behind this split is that changes in volatility of macroeconomic variables may reflect changes in the uncertainty of the returns to investment projects. This in turn may influence investment incentives and thus the responsiveness to financial market signals.

<Table 1 about here.>

Table 1 presents the p-values from structural stability tests assuming that the dates for the productivity and volatility splits were chosen “exogenously.” For the productivity split, the p-values are for the hypothesis that the coefficients estimated for the 1974-93 and 1994-2004 periods are not different from those estimated for the 1960-73 period. For the volatility split, the null hypothesis is that the coefficients estimated for the 1984-2004 period are not different from those estimated in the 1960-83 period. For each split, we test for structural stability for all coefficients as well as for the equity price appreciation coefficients only.

For both splits there appear to be some evidence of differences across the eras. For the productivity split, there is evidence that the coefficients in the 1994-2004 period are different from those in 1960-73, although the evidence is weaker when we consider only the stock price appreciation coefficients. In the volatility split, there is stronger evidence of differences across the two eras, at least outside of information equipment and software and its various subcomponents. At this point, let us also note that our results generally will tend to be weaker for information equipment and its subcomponents, reflecting the difficulty of estimating these components of investment (which have generally grown rapidly throughout our sample) using these models.

However, when we examine the sum of the coefficients on the lags of equity price appreciation as a measure of the responsiveness of equipment investment to stock prices, we find a surprising result in light of the picture seen in Figure 1. As shown in Table 2, the coefficient estimates in the latter period of productivity and volatility splits are generally smaller than they are in earlier periods; this is especially evident in the volatility split. These estimates thus imply that real equipment investment has become less responsive to equity price fluctuations in these later periods.

<Table 2 about here.>

What accounts for this pattern? Much like many other real economic variables, real equipment investment has become less volatile over the past twenty years. In contrast, equity prices have not experienced such a decline in volatility. As such, this would imply that investment should have a smaller coefficient in the regression for the later periods. Of course, this still leaves the question of the observed high correlation during the late 1990s and early 2000s seen in Figure 1. We defer further discussion of this until later.

General parameter instability

We now move away from the "exogenously determined" splits of the data and consider the evidence of general instability of the parameters in the estimates of equation (1). Although we argued that split dates used in the previous section were exogenous and thus we could use standard Chow-type statistics to determine whether there were structural breaks at those dates, it is still true that some prior data analysis had gone into picking those dates. Therefore, the standard statistics may be biased toward finding structural breaks at those dates. We address this issue in two ways. In this section, we test for general parameter instability using a test statistic developed in Hansen (1992). In the next section, we test for and date endogenously determined structural breaks, using statistics originally developed by Andrews (1993).

The Hansen (1992) test statistic is approximately a Lagrange multiplier test of the null of constant parameters against the alternative that the parameters follow some sort of martingale process. Such an alternative incorporates the possibilities of structural breaks as well as the parameters following random walks. It thus has greater power than the CUSUM statistic (see Brown, Durbin, and Evans, 1975), which primarily tests for constancy in the intercept of a regression (see Kramer, Ploberger, and Alt, 1988). However, this statistic does not provide a date for a structural break or some other type of nonconstancy of the parameters. We address this in the subsequent sections.

The Hansen (1992) test statistics for the model described by equation (1) are presented in Table 3. Three statistics are presented. The first is that for testing the stability of all parameters: the coefficients on the dependent variables as well as the variance of the error term of the regression. The second statistic is a test for the stability of only the coefficients on the lags of equity price appreciation. The third is the test statistic for the stability of the variance of the error term.

<Table 3 about here.>

The statistics in the first column of Table 3 provide evidence of instability in some of the parameters of the model for equipment investment and its components. The statistic is above the

5% critical value for most categories of equipment investment and is above the 10% critical value for the aggregate.[9] In the two categories where the statistic is not above the 10% critical value, they are close to exceeding it.

With regard to the instability of the coefficients on lags of stock price appreciation, the evidence is mixed.[10] The test statistic for this case in the second column of Table 3 is above its 5% critical value for aggregate equipment and software investment expenditures as well as for the industrial and transportation equipment components. For the other components, the test statistic is well below its critical values, which on the face of it suggests that we cannot reject the hypothesis that these coefficients are constant.

However, as seen in the third column of Table 3, the test statistic for the variance of the error term indicates strong evidence that it is not constant in most of these categories. As discussed in Hansen (1992), instability in the error term variance reduces the power of the test for the constancy of the coefficients. We would thus state that at this point the test does not provide conclusive evidence concerning the constancy of the equity price coefficients in the information equipment and software categories. Still, we have found at least some evidence that the responses of equipment investment expenditures to equity price fluctuations has changed over the 1960-2004 period.

Endogenous structural break

With additional evidence of instability in the model represented in equation (1), we turn to a further examination of its nature. In this section, we test for a possible structural break in the regression using the *sup F* statistic discussed in Andrews (1993) as well as estimating a date for any such break.[11]

Table 4 presents the results of this exercise. The first three columns of the table relate to the null hypothesis that there is no structural break in any of the coefficients of the model. The first column displays the *sup F* statistic and the second column presents its asymptotic p-value, calculated according to the method of Hansen (1997). The third column presents the estimated structural break, calculated as that break date that minimizes residual variance (see Hansen [2001] concerning this). The last two columns relate to the coefficients on the lags of equity price appreciation given the estimated structural break date. The fourth column displays the test statistic of the null hypothesis that these coefficients are the same across the estimated structural break, and the fifth column provides the standard p-values of the statistic.

<Table 4 about here.>

The test statistics generally point to a structural break in the regression, although the estimated dates differ across the various components of equipment and software investment expenditures. In six of the eight categories, including the aggregate, the test statistic and its associated p-values indicate a rejection of no structural break at the 5% level or better. For aggregate equipment and software expenditures and transportation equipment, the estimated break date is close to that associated with the GDP volatility break documented by McConnell and Perez-Quiros (2000). The estimated break dates for most of the other categories are in the early- to mid-1970s, which is reasonably close to the date associated with a decline in trend productivity growth: the one exception is “other” equipment where the estimated date is in the early 1990s.

For the most part, the test statistics also indicate that the coefficients on lagged stock price appreciation differ across the estimated structural break for the associated category. As in the exogenous structural breaks, the weaker results occur for information equipment and software and its subcomponents, which again probably reflect the difficulty of estimating investment behavior in these sectors. Also, because the estimated break dates are not all that different from the exogenous break dates discussed in the first subsection, the sum of the coefficients on equity price appreciation (not presented here) display a similar pattern to that in the previous subsection: the sum is smaller in the later period of the split, suggesting that investment expenditures are less responsive to equity price fluctuations in the later period. This may be contrary to the popular presupposition that stock price fluctuations have been important in the recent fluctuations of equipment investment, although consistent with the decline in real macroeconomic volatility since the mid-1980s. The next subsection provides a higher frequency analysis of possible changes in the relationship between stock prices and investment to examine the late 1990s more closely.

Rolling regressions

Structural breaks are only one type of parameter instability that can occur for regression models. As a simple method to examine more general forms of instability as well as to provide further analysis of possible changes in the relationship between stock prices and investment, we estimate the regression model (1) over a fixed window that we roll through the sample. To balance having sufficient degrees of freedom in the regression with having a compact period for analysis, we decided to fix the window at 24 quarters (six years).[12]

<Figure 2 about here.>

To summarize the results of this exercise, Figure 2 displays for aggregate equipment and software investment the sum of the coefficients on the lags of stock price appreciation in each of the rolling samples. The horizontal axis of the graph corresponds to the last period of the rolling sample. Two standard error confidence bands are placed around the rolling estimates, and a horizontal line conforming to the full sample estimate is included as reference for the rolling estimates.

From this figure, we see some results that are consistent with our previous analysis. For example, the sum of the coefficients is generally larger and usually significantly positive through the mid-1980s. Afterwards, the estimates are generally smaller and statistically insignificant with a number of cases of negative point estimates. These patterns are consistent with our prior results finding a break in the estimates around the GDP volatility break of the mid-1980s and a smaller response of investment to stock market fluctuations after that break.

However, there is one major exception to this pattern. For samples that end in 2001 and 2002, there is a sharp rise in the estimated coefficient sum to levels seen in the early part of the sample. These particular samples correspond to the period of the late 1990s-early 2000s investment boom and bust as well as the Internet stock price “bubble.” After these two years, the coefficient estimate drops sharply and again becomes statistically insignificant.

<Figure 3 about here.>

Figure 3 presents the results for this exercise for the high-tech category of information equipment and software. These results have patterns that are similar to those for the aggregate equipment and software. Table 5 present a summary of the results of this rolling regression exercise for the other components of equipment investment. The rough patterns in the table are similar across components: with the exception of information equipment and software (whose peak estimate occurs during the 2001-02 “bump” as seen in Figure 3), the maximum estimate of the coefficient sum occurs before 1985, and the minimum estimate generally occurs after that date. As far as the “bump” in the estimates seen in the aggregate and information equipment, it is apparent in industrial equipment (although it is more subdued than seen in Figures 2 and 3) but not in transportation and “other” equipment.

<Table 5 about here.>

Returning to the simple picture in Figure 1, the results of these rolling regressions point to the period of the late 1990s and early 2000s as a special period in regard to the relationship between stock prices and equipment investment. This is especially true for high-tech information equipment and software. Given the behavior of high-tech stocks and investment during this period, these results would be consistent with stories that emphasize the unique role of the Internet stock price “bubble” in determining investment during this period, which would include the story behind the model of Gilchrist, Himmelberg, and Huberman (2005). However, to this point we have not differentiated between “fundamental” and “nonfundamental” equity price fluctuations. To make the case for the unique behavior during this period more solid, we need to begin to control for some fundamental movements in equity prices and investment.

Investment, “fundamentals,” and stock price appreciation

To account for fundamentals that drive fixed business investment, we derive a model based on the principles of the neoclassical model developed by Jorgenson (1963).[13] In the model, investment is a function of expected revenue, which we will proxy using output, and investment user costs, which we will proxy using real interest rates. We can then describe investment based on “fundamentals” in the following manner.

(2) $$i_t = f(E_t(y_{t+1}), r_{t-1})$$

To derive the model of fundamentals that is the basis of the estimates in this section, we make two further assumptions. First, we assume that $E_t(y_{t+1})$ can be estimated as a linear projection of past values of output.

(3) $$E_t(y_{t+1}) = \beta_0{}' + \sum_{i=1}^{N} \beta_i{}' y_{t=i}$$

Second, we assume that the function in the right hand side of equation (2) is a linear function of its arguments.

(4) $$f(E_t(y_{t+1}), r_{t-1}) = a_0 + a_1 E_t(y_{t+1}) + \sum_{i=1}^{N} \gamma_i r_{t-i}$$

Combining equations (2), (3), and (4), we then have an empirical model of “fundamental” investment.

(5) $$i_t = \alpha_0' + \sum_{i=1}^{N} \beta_i y_{t-i} + \sum_{i=1}^{N} \gamma_i r_{t-i}$$

To this “fundamental” model, we make the following modifications to derive the model we estimate and test for the role of “nonfundamental” equity price movements in equipment and software investment. First, we take first differences of the model (5) to account for the fact that the variables in the model have unit roots. Second, as in the model of the previous section, we add a lag of the dependent variable to the right hand side to account for possible serial correlation in the error term of the regression. Finally, we add lags of equity price appreciation to the model, which, given the other fundamental variables, should account for the nonfundamental equity price movements. Therefore, the form of the model we estimate and test in this section is:

(6) $$\Delta i_t = \alpha_0 + \sum_{i=1}^{N} \alpha_i \Delta s_{t-i} + \sum_{i=1}^{N} \beta_i \Delta y_{t-i} + \sum_{i=1}^{N} \gamma_i \Delta r_{t-i} + \rho \Delta i_{t-1} + \varepsilon_t$$

The analysis for this model is similar to that of the simple model. We first estimate and examine equation (6) across the exogenous splits of the sample defined in the previous section. We then test for general parameter uncertainty as well as for a single structural break at an unknown date. However, given the number of parameters in this model—we again assume that $N=4$ in the model, so that there are 14 parameters—we do not estimate rolling regressions because of the size of the sample needed to provide sufficient degrees of freedom.

<Table 6 about here.>

The tests of structural stability across the productivity and volatility eras presented in Table 6 provide similar conclusions to the corresponding tests for the simple model. For the productivity split, there is pervasive evidence that at least some coefficients display significant differences across the different periods, with particularly strong evidence that the 1994-2004 period is different from the 1960-73 period. Concentrating on the equity price appreciation coefficients only, there is less evidence of a difference between the 1960-73 period and the 1974-93 period, but there is stronger evidence of a difference between the 1960-73 period and the 1994-2004 period. For the volatility split, there is strong evidence that at least some of the coefficients differ across the two eras. In the cases of equipment outside of information equipment and software, the tests point to changes in the equity price appreciation coefficients across the two eras.

<Table 7 about here.>

The pattern of the coefficients on equity price appreciation across the various eras, whose sums are presented in Table 7, is quite similar to the patterns seen for the simple model. In this model, the response to nonfundamental equity price fluctuations generally is less in the later periods. This is most evident in the volatility split, but is also apparent in the 1994-2004 period of the productivity split. Again, these patterns are consistent with the declining volatility of investment spending since the mid-1980s.

<Table 8 about here.>

Turning to tests of structural changes without assuming break dates, the Hansen tests for the "neoclassical" model point to parameter instability in the model, with the statistic testing for all parameters in the model rejecting stability at the 10 percent level or less in most categories of investment (Table 8). However, there is little direct evidence of instability in the equity price appreciation coefficients, with the test statistic being statistically significant in only two investment categories. As in the simple model, much of the evidence of instability is in the estimate of error variance, which reduces the power of the test to find instability in the other parameters of the model. Therefore, this test does not preclude changes in the response of investment to nonfundamental fluctuations of equity prices.

<Table 9 about here.>

We next turn to tests of the structural stability of the model with an unknown breakpoint. These tests overwhelmingly indicate that there is a break, which may not be surprising given the large number of parameters there are in this model (Table 9). For aggregate equipment spending, the estimated break date is consistent with the GDP volatility break, as in the simple model. The estimated break dates for the other investment categories generally are similar to those from the simple model; the one exception being “other” equipment, where the estimated break date occurs before the 1980s in the “neoclassical” model whereas it occurred after the 1980s in the simple model. Also note that this category is one prominent case where test statistics suggest that there is not a significant change in the coefficients on equity price appreciation. For most other categories, the estimated break date is associated with significant differences in the equity price appreciation coefficients across the two periods.

Overall, the conclusions from the “neoclassical” model are similar to those of the simple model. There is evidence that the response of investment to changes in equity price appreciation, controlling for fundamental factors influencing investment spending, has changed over the period since 1960. However, as in the simple model, it appears that this response has become smaller since the mid-1980s. We next turn to a model where financial market fluctuations are a measure of fundamental influences on investment, the *q* model.

Investment responsiveness to *q*

In this section, we move away from an *ad hoc* inclusion of equity prices in an investment model to estimating a model where financial variables have an explicit role in determining investment: the *q* model. The derivation of the theoretical model is similar to that of Chirinko (1993). Suppose a representative firm maximizes discounted flow of profits up to some horizon T (which could be infinity).

$$\text{(7)} \qquad \begin{aligned} &\max E_0 \sum_{t=0}^{T} \beta^t \left[f(k_{t-1}, l_t) - w_t l_t - p_t i_t - a(i_t, k_{t-1}) \right] \\ &s.t. \quad k_t = (1-\delta) k_{t-1} + i_t \end{aligned}$$

Here k_t is the capital stock at the end of period t, l_t is labor input, w_t is the wage, i_t is investment, p_t is the price of capital goods in period t, $f(.,.)$ is the production function, and $a(.,.)$ is the capital adjustment cost function. The first order condition for investment at period t is the following.

$$\text{(8)} \qquad E_t \left[\beta \left[f_k(k_t, l_{t+1}) - a_k(i_{t+1}, k_t) \right] - \left[p_t - \beta(1-\delta) p_{t+1} \right] - \left[a_i(i_t, k_{t-1}) - \beta(1-\delta) a_i(i_{t+1}, k_t) \right] \right] = 0$$

Let $\lambda_t = f_k(k_t, l_{t+1}) - a_k(i_{t+1}, k_t)$ denote the marginal cash flow (net of adjustment costs) derived from an additional unit of capital. Using this and repeated substitution (along with the transversality condition), equation (8) can be written as:

$$\text{(9)} \qquad E_t \left[\sum_{s=0}^{T-t} \beta^s (1-\delta)^s \lambda_{t+s} - p_t - a_i(i_t, k_{t-1}) \right] = 0$$

To derive the q model from equation (9), define $q_t'=V_t/p_tk_t$ as the ratio of the value of the market value of the firm to the value of its capital stock. As discussed in Hayashi (1982), under certain conditions (constant returns to scale technology and perfect competition) the value of the firm can be written as $V_t = E_t(\Sigma_{s=0}^{T-t}\beta^s(1-\delta)^s\lambda_{t+s})K_t$, so that (9) can be written as:

$$E_t\left[p_t q_t' - p_t - a_i(i_t, k_{t-1}) = 0\right]$$

or letting $q_t = p_t\, q_t' - p_t$,

(10) $$E_t\left[q_t - a_i(i_t, k_{t-1}) = 0\right]$$

In standard estimation of the q model, a form of quadratic adjustment costs are assumed such that the derivative of the adjustment cost function with respect to investment is $a_i(i_t,k_{t-1}) = \acute{\alpha}(i_t/k_{t-1}) + \acute{\varepsilon}_t$, which then implies the regression q model (assuming no lags).

(11) $$i_t / k_{t-1} = \alpha q_t + \varepsilon_t$$

Note that the coefficient on q in equation (11) is a function of a parameter of the adjustment cost function. Therefore, if that coefficient changes over time it would imply changing adjustment technology (costs).

In estimating this model, we make a number of modifications to the theoretical model with quadratic adjustment costs. First, because a possible unit root in the variables of (11), we first difference the variables. Second, we approximate $\Delta(i_t/k_{t-1})$ with the growth rate of investment, which avoids the problems of calculating an aggregate real capital stock and makes this model more comparable to the models in the previous sections. Finally, although the theoretical model implies that only the contemporaneous value of q_t should affect investment growth in period t, previous empirical studies have found that the empirical fit of the model improves by including lags of q_t in the regression.[14] Preliminary estimates of this model indicate a similar pattern, so we include the lags rather than the contemporaneous value, which then leads to the following form of the model we estimate.[15]

$$(12) \qquad \Delta i_t = \alpha_0 + \sum_{i=1}^{N} \alpha_i \Delta q_{t-i} + \varepsilon_t$$

We measure *q* in a similar manner as Oliner, Rudebusch, and Sichel (1995); details on the calculation can be found in that study and the working paper version of it. The analysis for this model then proceeds along similar lines as in the previous two sections.

<Table 10 about here.>

The tests for a structural break across the productivity and volatility splits presented in Table 10 provide weaker evidence of a change in the response to changes in *q* than was the case for equity price appreciation in the two previous models. Concentrating on the coefficients on Δq_{t-i}, there is no evidence of a change in the coefficients for aggregate investment, although there is some evidence of a break for some of the components of investment spending. For the productivity split, there appears to be statistically significant changes in these coefficients for information equipment and software, industrial equipment, and transportation equipment: both the 1974-93 and 1994-2004 periods differ from the 1960-73 period. The evidence is weaker for the volatility split, where there are statistically significant results for industrial, transportation equipment, and software.

<Table 11 about here.>

The sums of the coefficients on Δq_{t-i} presented in Table 11 are consistent with the weaker evidence of a structural break across these splits. For aggregate investment, the estimates are similar for the periods across the two splits. For information equipment and software, the estimates indicate, compared to the 1960-73 period, a weaker response to *q* fluctuations in the low productivity 1974-93 period and a stronger response in the 1994-2004 period. There is a less clear pattern for industrial equipment across the productivity eras, although there is a somewhat weaker response in the low volatility period than in the high volatility period. For transportation equipment, consistent with the stronger evidence in this component of a structural break in both splits, the response to *q* fluctuations is weaker in the later periods.

<Table 12 about here.>

Perhaps surprisingly, the Hansen parameter stability tests provide weaker evidence of instability than in the cases of the other models. There is evidence of instability in the variance of the error term for information equipment and software and some of its components, but there is little other evidence otherwise (Table 12). Given the results from the exogenous splits, this may reflect a power issue related to the general nature of the Hansen test and the possibility of misspecification and less precise estimation of *q*-type models. Nevertheless, we move on to consider some more specific forms of parameter instability in the model, although some caution is required in interpreting any such evidence against stability.

<Table 13 about here.>

Allowing for the possibility of a structural break at an endogenously determined date, the statistical tests indicate that we can reject no break in all of the categories of investment at the 10 percent level or better (Table 13). However, the estimated break date differs notably from the previous models for aggregate investment, industrial equipment, and transportation equipment. In addition, the estimates suggest that the Δq_{t-i} coefficients are not statistically different across the endogenously determined break for aggregate investment and “other” equipment. In contrast, they are statistically significantly different for information equipment and software, industrial equipment, and transportation equipment. In sum, there is evidence of a structural break in the model but it is less clear that the break is related to changes in the response of investment to q.

<Figure 4 about here.>

<Figure 5 about here.>

<Table 14 about here.>

Turning to the rolling regressions, the pattern of the sum of coefficients on Δq_{t-i} bears some similarity to those for the sum of the coefficients on equity price appreciation in the simple model. For both aggregate investment and information equipment, there is the sharp rise in this sum for periods that include the Internet “bubble” era and its aftermath (Figures 4 and 5). The peak also occurs around the bubble era for industrial equipment, but occurs earlier for transportation and other equipment (Table 14). Also, as in the simple model, there was rise in the sum of the coefficients in the mid-1980s that was less extreme although longer-lasting. One difference from the simple model is that the sum of coefficients are not as consistently low in the 1984-2000 period as in that model, even though the minimum value of the sum for aggregate investment does occur just before the rise to the peak value (Table 14).

Overall, our analysis of this "*q*" model provides somewhat weaker evidence of a change in the responsiveness of investment to changes in financial variables than did our two previous models. Nevertheless, it still displays a general pattern similar to the earlier analysis: the response has been weaker since the mid-1980s with the exception of the late 1990s and early 2000s when both equity markets and investment showed exceptional behavior.

Concluding remarks

This paper has examined the role of equity price fluctuations in the behavior of aggregate investment and whether this role has changed recently. The popular view is that the Internet equity price boom and bust had an outsized role in the investment boom and bust of the late 1990s and early 2000s, even though previous economic studies have found nonfundamental stock price movements to have little effect on aggregate investment. One way to reconcile these two viewpoints is that there has been a change in the relationship between investment and equity prices.

Using a series of models, we find evidence that there has been a change in the response of investment to equity price fluctuations, to their "nonfundamental" component, and to fluctuations in q. However, much of our evidence points to equity price fluctuations having a smaller effect on investment since the mid-1980s. This has been a period of low macroeconomic volatility, of which less volatility of investment has been a part. As the volatility of financial markets have changed little through this period, estimates of their effect on investment should be smaller.

There is one notable exception to this pattern. Estimating the relationship over shorter periods indicates that the association of equity prices and investment rose significantly during the late 1990s and early 2000s. Of course, this pattern would be consistent with the view that firms took advantage of cheap financial capital from an overpriced stock market to “overinvest” in real capital during the late 1990s, and then cut back real capital spending drastically when the end of the stock market boom raised the cost of financial capital. This would also be consistent with some recent research finding a relationship between nonfundamental equity price movements and real investment during “unusual” periods such as the Internet equity price boom. However, because this relationship appears to be such a temporary and exceptional phenomenon, more research into the period is needed.

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Endnotes

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[1]I would like to thank John Roberts (my discussant), Per Berglund and Leanne Ussher (the editors), and the other conference participants for their comments. All remaining errors reflect upon me. Views and opinions presented in this paper are solely the responsibility of the author and do not represent official views of the Federal Reserve Bank of New York or the Federal Reserve System.

[2] The extent of any capital "overhang" in the late 1990s and early 2000s remains an open question. Using a neoclassical model as a basis, McCarthy (2003) found overhangs to be relatively contained during this period. Still, other aspects of investment behavior at the industry level during this period were consistent with there being sizable overhangs; e.g. see McCarthy (2004).

[3] Because the observations are not independent when using year-over-year changes, the correlations may be overstated. Using quarterly changes, the correlation drops to 0.30 in this case. However, the qualitative points that are made in the text remain valid if quarterly changes are used instead.

[4] Hayashi (1982) would formalize the relationship between Tobin's q and investment within a dynamic optimization model of the firm as well as provide the conditions under which average and marginal q are equivalent.

[5] However, Chirinko and Schaller (2001) did find evidence that the Japanese equity price "bubble" affected Japanese fixed investment.

[6] Preliminary work indicated that for nonresidential structures investment, it was rare to find any cases of significant coefficients. This is another reflection of the difficulty of estimating standard investment models for nonresidential structures relative to that for equipment; see Oliner, Rudebusch, and Sichel (1995). As such, we concentrate on equipment investment in this paper.

[7] Data on the Wilshire 5000 is available only from 1972. For such a period, the results are similar when using the Wilshire or the S&P 500.

[8] In all regressions in this paper, the coefficient standard errors are calculated using the Newey and West (1987) covariance matrix estimate that is consistent under heteroskedasticity and serial correlation (up to four lags in the moving average term).

[9] This test statistic has a nonstandard distribution. The critical values come from Table 1 in Hansen (1992).

[10] Statistics for each of the parameters of the model, including the coefficient on each separate lag of stock price appreciation, are in a separate appendix available from the author.

[11] Note that for now, we test for only a single break; see Hansen (2001) for a discussion of one strategy in estimating multiple structural breaks in a regression model. Also, we do not estimate a confidence interval for the estimated break date; methods of doing so are discussed in Bai (1997).

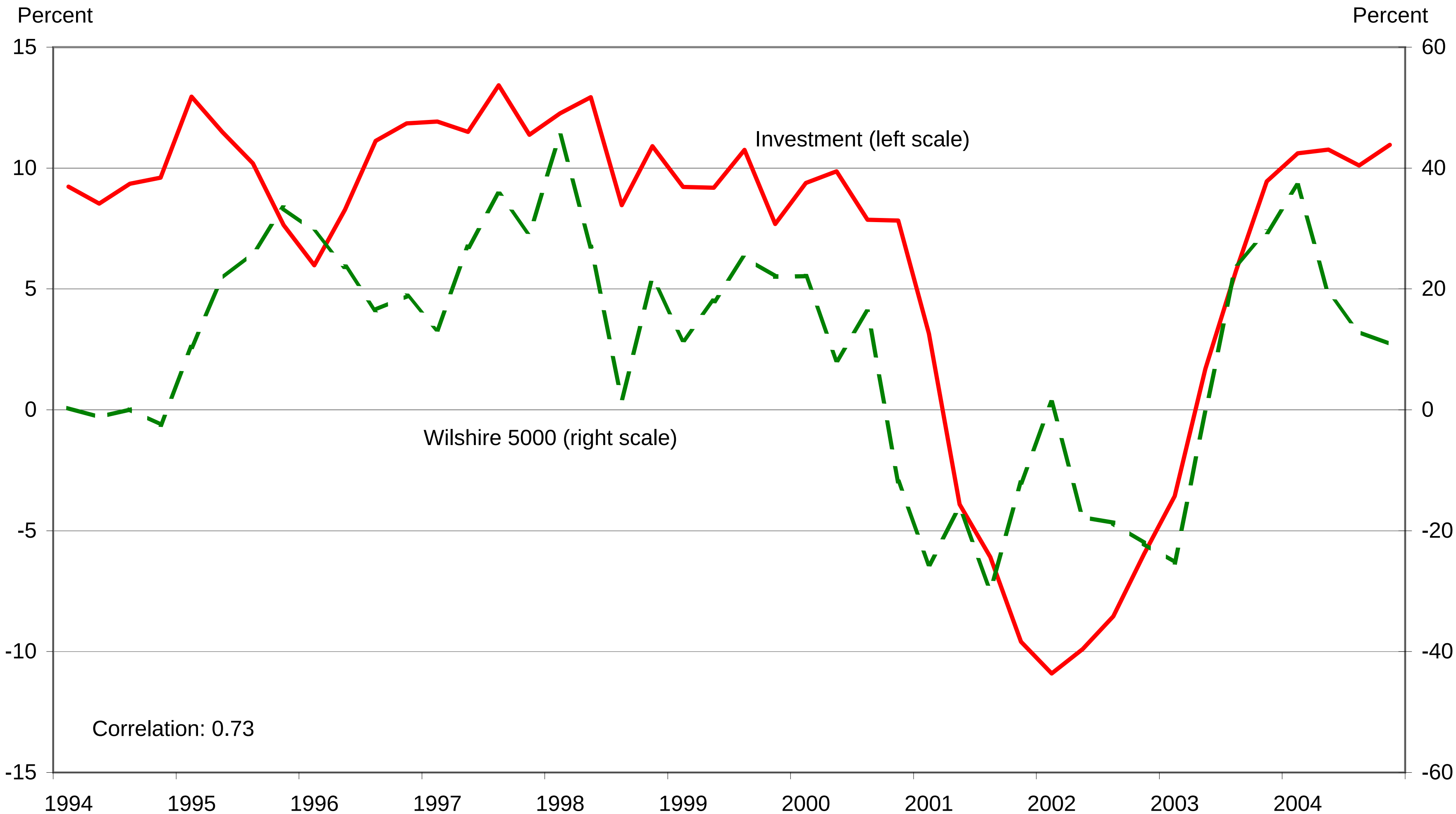
[12] Preliminary analysis indicates that the results are not particularly sensitive to small changes in the size of the window.

[13] This model has been the basis of many empirical studies of investment behavior; some examples include Hall and Jorgenson (1967), Clark (1979), Bernanke, Bohn, and Reiss (1988), Morck, Shleifer, and Vishny (1990), and Oliner, Rudebusch, and Sichel (1995).

[14] For example, see Clark (1979). A common justification for including lags in the regression is time-to-build; however, see Oliner, Rudebusch, and Sichel (1995) for a critique of such a justification.

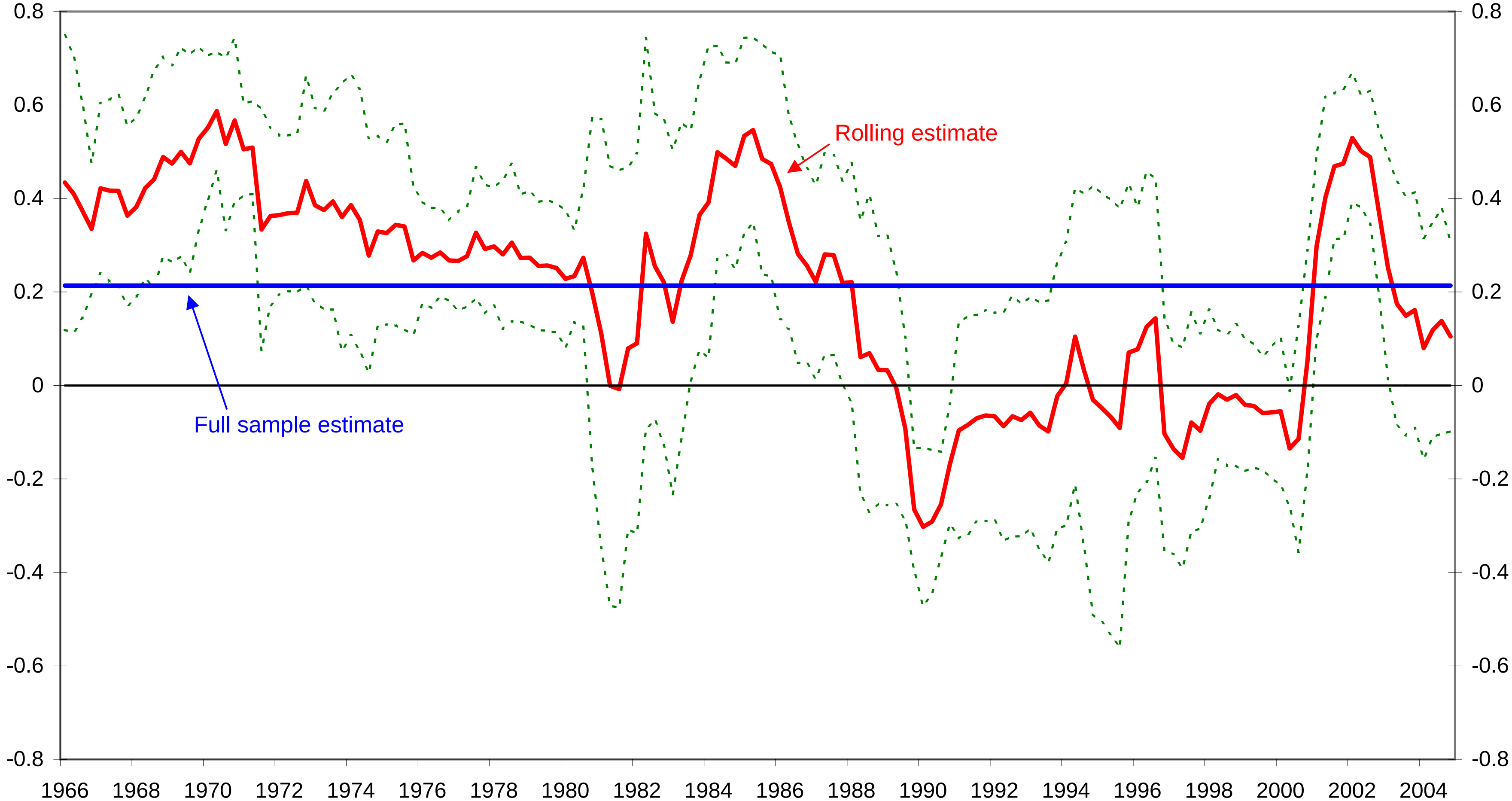
[15] Another complication concerns the incorporation of multiple capital inputs into the model; see the model of Chirinko (1993b) for a q model that allows for multiple capital inputs explicitly. Again to put our results on a common plane with previous aggregate studies, we keep the standard formulation generally used in macroeconomic analysis.

Figure 1.
Real investment fixed investment and the Wilshire 5000
(year-over-year percentage changes)



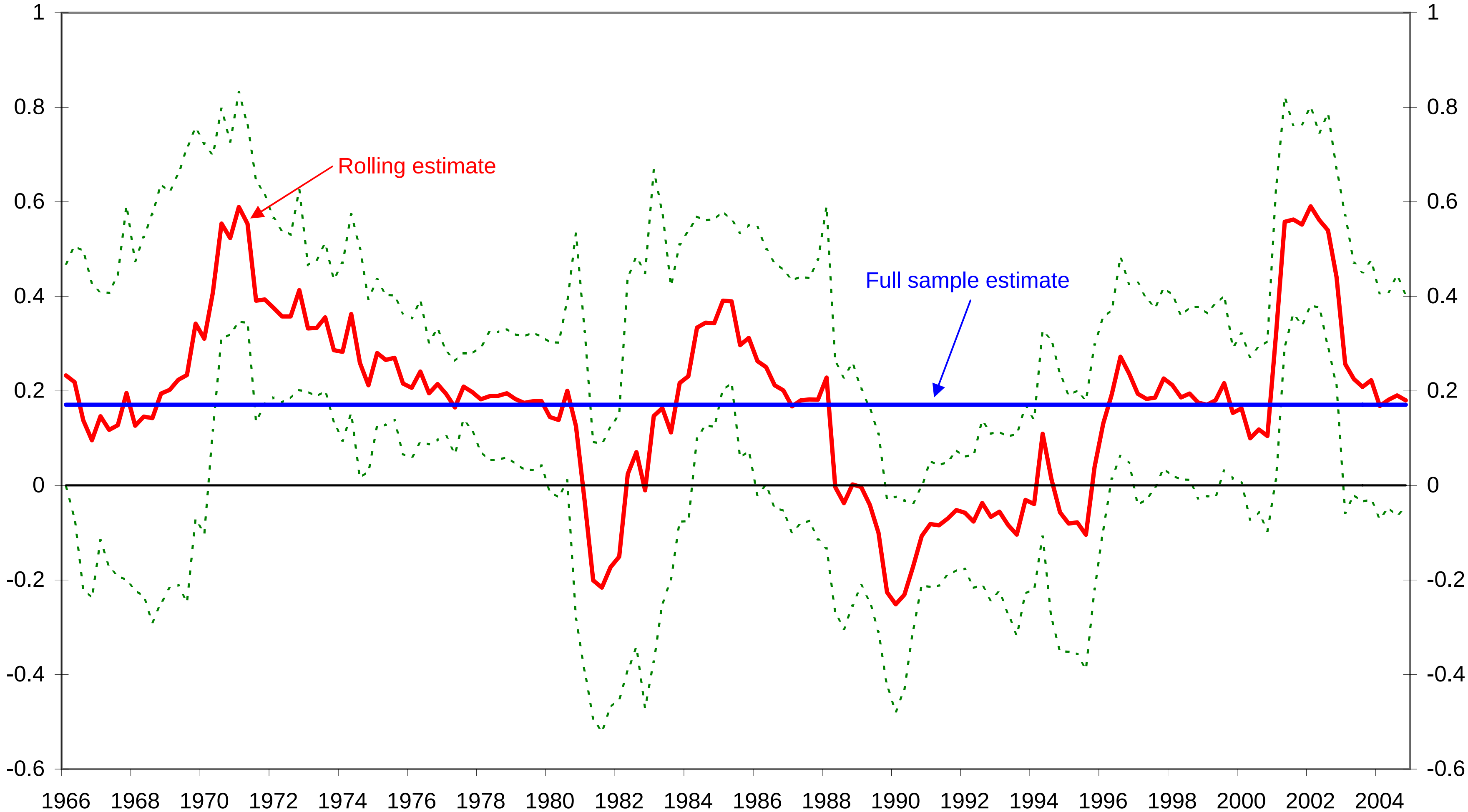
Sources: Bureau of Economic Analysis; Wall Street Journal; Haver Analytics

Figure 2.
Sum of coefficients on equity price appreciation: simple model
Equipment and software



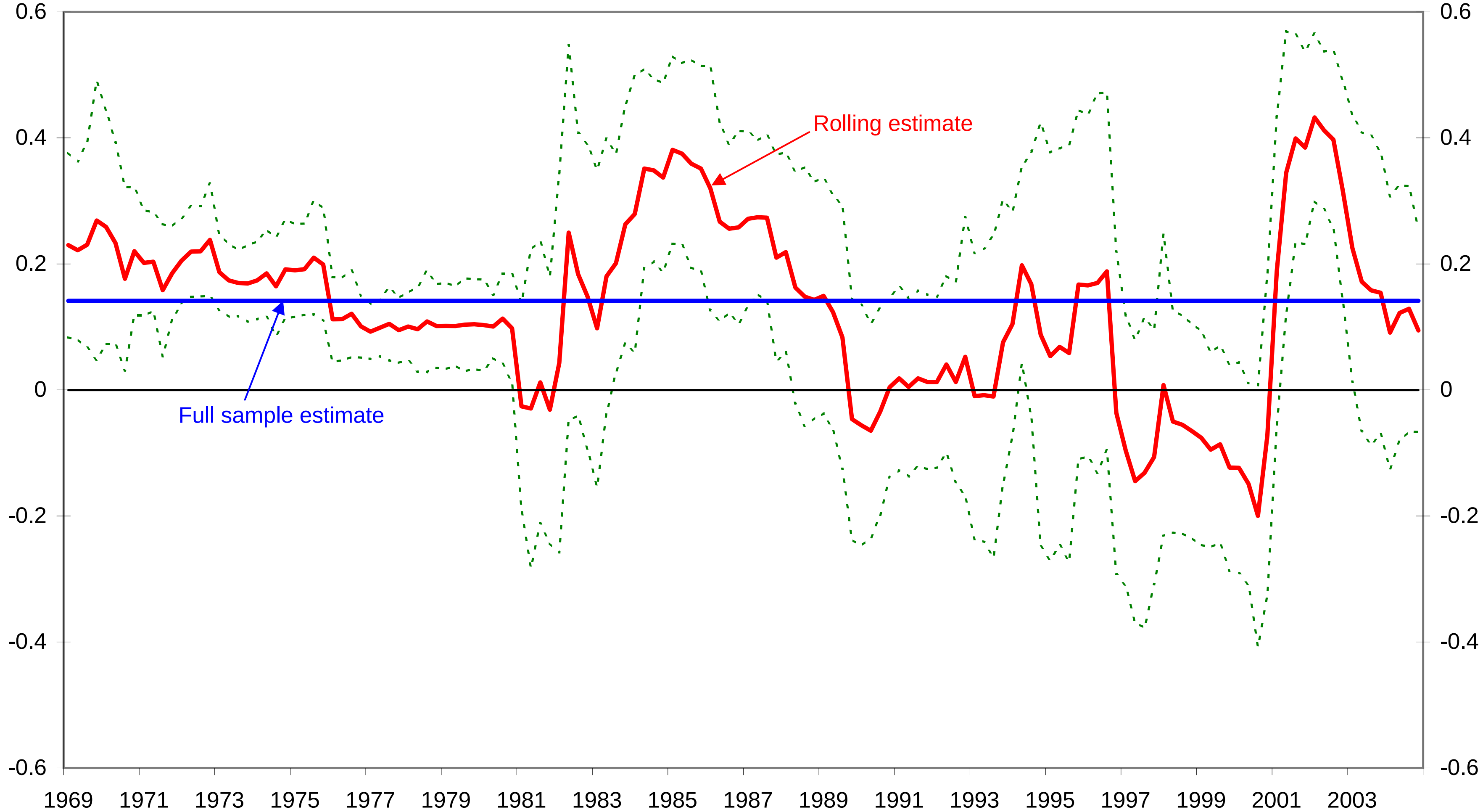
Notes: Green dashed lines denote ±2 standard deviation error bands. Rolling sample size is 24 quarters.
Source: Author's calculations

Figure 3.
Sum of coefficients on equity price appreciation: simple model
Information equipment and software



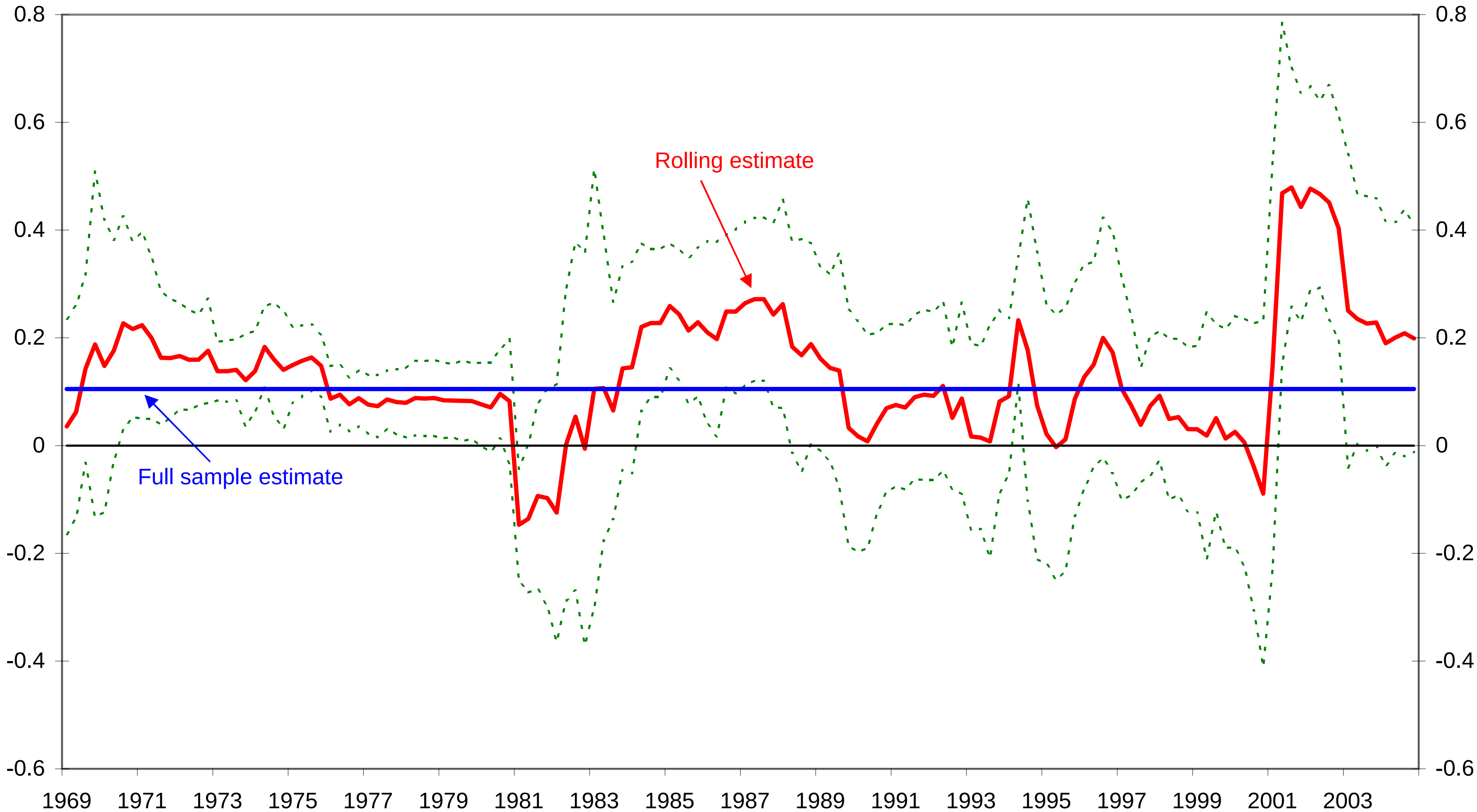
Notes: Green dashed lines denote ±2 standard deviation error bands. Rolling sample size is 24 quarters.
Source: Author's calculations

Figure 4.
Sum of coefficients on Δq_{t-i}: "Q" model
Equipment and software



Notes: Green dashed lines denote ±2 standard deviation error bands. Rolling sample size is 24 quarters.
Source: Author's calculations

Figure 5.
Sum of coefficients on Δq_{t-i}: "Q" model
Information equipment and software



Notes: Green dashed lines denote ±2 standard deviation error bands. Rolling sample size is 24 quarters.
Source: Author's calculations

Table 1: Structural stability tests--simple model

	Productivity split				Volatility split	
	All coefficients		Δs_{t-i} coefficients		All coefficients	Δs_{t-i} coefficients
Investment category	1974-93	1994-2004	1974-93	1994-2004		
Equipment & software	0.142	0.003	0.298	0.007	0.000	0.001
Information equip. & software	0.113	0.481	0.336	0.689	0.097	0.589
Computers	0.057	0.020	0.289	0.075	0.040	0.281
Software	0.491	0.022	0.776	0.083	0.300	0.370
Other information equipment	0.047	0.549	0.252	0.622	0.195	0.715
Industrial equipment	0.186	0.015	0.532	0.123	0.003	0.009
Transportation equipment	0.099	0.000	0.082	0.000	0.000	0.000
Other equipment	0.327	0.654	0.383	0.433	0.012	0.039

Notes: Entries in the table are the p-values from structural stability (Chow) tests of the corresponding coefficients. The reference period for the productivity split is 1960-73, and the reference period for the volatility split is 1960-83.

Table 2: Sum of coefficients on stock price appreciation--simple model

	Sample period	Productivity split			Volatility split	
Investment category	1960-2004	1960-73	1974-93	1994-2004	1960-83	1984-2004
Equipment & software	0.214***	0.408***	0.182**	0.138*	0.345***	0.079
Information equip. & software	0.171***	0.297**	0.076	0.212**	0.234***	0.125*
Computers	0.210	0.608	0.107	0.199	0.474*	0.025
Software	0.037	-0.008	-0.032	0.219***	0.021	0.085
Other information equipment	0.183***	0.359***	0.073	0.221*	0.239***	0.180*
Industrial equipment	0.148***	0.320***	0.130*	0.116	0.260***	0.030
Transportation equipment	0.468***	1.107***	0.455**	0.118	0.915***	0.049
Other equipment	0.200***	0.134	0.219**	0.162***	0.261***	0.124**

Notes: Entries in the table are the estimated sum of coefficients on Δs_{t-i}.

*** denotes sum of coefficients is statistically significant from zero at the 1 percent level.

** denotes sum of coefficients is statistically significant from zero at the 5 percent level.

* denotes sum of coefficients is statistically significant from zero at the 10 percent level.

Table 3: Hansen test statistics for parameter stability--simple model

Investment category	All parameters[a]	Δs_{t-i} coefficients[b]	σ^2 [c]
Equipment & software	1.707*	1.507**	0.136
Information equip. & software	3.190***	0.757	1.863***
Computers	2.002**	0.642	1.108***
Software	3.769***	0.577	2.388***
Other information equipment	1.973**	0.941	0.356*
Industrial equipment	2.583***	1.723***	0.848***
Transportation equipment	1.614	1.406**	0.064
Other equipment	1.604	0.742	0.362*

Notes: Entries in the table are the general parameter stability test statistics computed as in Hansen (1992), which have non standard distributions.

[a]Critical values for this column (7 parameters): 1%, 2.35; 5%, 1.90; 10%, 1.69.

[b]Critical values for this column (4 parameters): 1%, 1.60; 5%, 1.24; 10%, 1.07.

[c]Critical values for this column (1 parameter): 1%, 0.741; 5%, 0.470; 10%, 0.353.

Table 4: Structural stability tests with unknown breakpoint--simple model

	All coefficients[a]			Δs_{t-i} coefficients[b]	
Investment category	statistic	p-value	date	statistic	p-value
Equipment & software	29.44	0.001	1984:3	19.90	0.001
Information equip. & software	15.31	0.186	1969:1	6.01	0.198
Computers	27.03	0.003	1975:3	9.39	0.052
Software	23.72	0.011	1970:1	9.37	0.052
Other information equipment	16.05	0.150	1969:1	11.08	0.026
Industrial equipment	28.34	0.002	1975:4	14.61	0.006
Transportation equipment	34.32	0.000	1984:1	29.44	0.000
Other equipment	19.63	0.048	1991:2	17.53	0.025

[a]The statistic is the Andrews (1993) sup-F statistic. The p-values come from Hansen (1997).

[b]The statistic is the structural stability statistic given the estimated break date from the first part of the table.

Table 5: Rolling regressions summary, sum of Δs_{t-i} coefficients--simple model

Investment category	maximum	date	minimum	date	full sample estimate
Equipment & software	0.587	1970:2	-0.303	1990:1	0.214
Information equip. & software	0.590	2002:1	-0.251	1990:1	0.171
Computers	1.269	1965:4	-3.132	1966:3	0.210
Software	0.676	1970:4	-0.648	1966:2	0.037
Other information equipment	0.562	1966:1	-0.202	1990:1	0.183
Industrial equipment	0.567	1966:2	-0.377	1990:2	0.148
Transportation equipment	1.732	1970:2	-1.084	1966:4	0.468
Other equipment	0.784	1984:4	-0.189	1977:1	0.200

Notes: The size of the rolling sample window is 24 quarters (six years). The date of the maximum and minimum estimates is the last quarter of the relevant sample.

Table 6: Structural stability tests--"neoclassical" model

	Productivity split				Volatility split	
	All coefficients		Δs_{t-i} coefficients		All coefficients	Δs_{t-i} coefficients
Investment category	1974-93	1994-2004	1974-93	1994-2004		
Equipment & software	0.000	0.000	0.041	0.000	0.000	0.000
Information equip. & software	0.008	0.000	0.132	0.298	0.000	0.744
Computers	0.000	0.000	0.608	0.212	0.061	0.484
Software	0.004	0.000	0.770	0.048	0.001	0.172
Other information equipment	0.174	0.000	0.110	0.043	0.019	0.783
Industrial equipment	0.002	0.000	0.288	0.000	0.005	0.000
Transportation equipment	0.135	0.000	0.065	0.012	0.000	0.000
Other equipment	0.001	0.001	0.704	0.399	0.000	0.015

Notes: See Table 1.

Table 7: Sum of coefficients on stock price appreciation--"neoclassical" model

	Sample period	Productivity split			Volatility split	
Investment category	1960-2004	1960-73	1974-93	1994-2004	1960-83	1984-2004
Equipment & software	0.190***	0.429***	0.122*	0.042	0.324***	0.067
Information equip. & software	0.109**	0.277**	-0.012	0.045	0.152*	0.096
Computers	0.067	0.256	-0.029	-0.098	0.345	-0.089
Software	-0.040	-0.173	-0.117*	0.162**	-0.108	0.051
Other information equipment	0.131**	0.351***	0.004	-0.030	0.150*	0.137*
Industrial equipment	0.059	0.219**	0.044	0.002	0.175***	-0.037
Transportation equipment	0.393***	0.998***	0.323	-0.044	0.856***	0.035
Other equipment	0.140***	0.119	0.140*	0.195***	0.190*	0.048

Notes: See Table 2.

Table 8: Hansen test statistics for parameter stability--"neoclassical" model

Investment category	All parameters[a]	Δs_{t-i} coefficients[b]	σ^2 [c]
Equipment & software	2.741	1.058	0.185
Information equip. & software	3.750**	0.654	1.347***
Computers	3.815**	0.590	1.182***
Software	4.532***	0.693	2.537***
Other information equipment	3.116	0.777	0.282
Industrial equipment	3.297*	1.199*	1.059***
Transportation equipment	2.690	1.408**	0.055
Other equipment	3.716**	0.893	0.671**

Notes: Entries in the table are the general parameter stability test statistics computed as in Hansen (1992), which have non standard distributions.

[a]Critical values for this column (15 parameters): 1%, 4.07; 5%, 3.54; 10%, 3.26.

[b]Critical values for this column (4 parameters): 1%, 1.60; 5%, 1.24; 10%, 1.07.

[c]Critical values for this column (1 parameter): 1%, 0.741; 5%, 0.470; 10%, 0.353.

Table 9: Structural stability tests with unknown breakpoint--"neoclassical" model

	All coefficients[a]			Δs_{t-i} coefficients[b]	
Investment category	statistic	p-value	date	statistic	p-value
Equipment & software	155.35	0.000	1984:2	28.20	0.000
Information equip. & software	381.40	0.000	1969:1	12.92	0.012
Computers	94.78	0.000	1970:4	8.45	0.076
Software	104.86	0.000	1969:4	22.05	0.000
Other information equipment	279.96	0.000	1969:1	6.79	0.147
Industrial equipment	66.72	0.000	1971:4	13.12	0.011
Transportation equipment	106.22	0.000	1984:1	36.25	0.000
Other equipment	99.98	0.000	1979:2	5.83	0.212

Notes: See Table 4.

Table 10: Structural stability tests--"Q" model

	Productivity split				Volatility split	
	All coefficients		Δq_{t-i} coefficients		All coefficients	Δq_{t-i} coefficients
Investment category	1974-93	1994-2004	1974-93	1994-2004		
Equipment & software	0.053	0.032	0.462	0.114	0.756	0.610
Information equip. & software	0.011	0.039	0.007	0.012	0.303	0.600
Computers	0.206	0.045	0.886	0.896	0.050	0.314
Software	0.000	0.001	0.000	0.012	0.024	0.051
Other information equipment	0.000	0.011	0.000	0.007	0.224	0.737
Industrial equipment	0.000	0.004	0.000	0.014	0.013	0.053
Transportation equipment	0.012	0.001	0.004	0.002	0.091	0.031
Other equipment	0.388	0.620	0.938	0.408	0.152	0.147

Notes: See Table 1.

Table 11: Sum of coefficients on stock price appreciation--"Q" model

	Sample period	Productivity split			Volatility split	
Investment category	1960-2004	1960-73	1974-93	1994-2004	1960-83	1984-2004
Equipment & software	0.142***	0.195***	0.126***	0.139**	0.152***	0.102*
Information equip. & software	0.105***	0.131**	0.074**	0.219**	0.104***	0.154**
Computers	0.169*	0.237	0.145	0.163	0.198	0.098
Software	0.033	0.118**	-0.020	0.203***	0.032	0.083
Other information equipment	0.102***	0.090*	0.068**	0.291**	0.088***	0.224**
Industrial equipment	0.112***	0.090***	0.114***	0.149	0.122***	0.076
Transportation equipment	0.318***	0.527***	0.301***	0.092	0.396***	0.048
Other equipment	0.144***	0.111	0.142***	0.161***	0.146***	0.140***

Notes: See Table 2.

Table 12: Hansen test statistics for parameter stability--"Q" model

Investment category	All parameters[a]	Δq_{t-i} coefficients[b]	σ^2 [c]
Equipment & software	0.683	0.248	0.186
Information equip. & software	1.613	0.325	0.847***
Computers	1.686	0.260	1.093***
Software	1.893*	0.594	1.155***
Other information equipment	1.242	0.553	0.061
Industrial equipment	1.625	0.922	0.064
Transportation equipment	0.757	0.479	0.074
Other equipment	1.162	0.212	0.462*

Notes: See Table 3.

Table 13: Structural stability tests with unknown breakpoint--"Q" model

	All coefficients[a]			Δq_{t-i} coefficients[b]	
Investment category	statistic	p-value	date	statistic	p-value
Equipment & software	22.33	0.019	1971:3	5.12	0.275
Information equip. & software	30.12	0.001	1972:1	19.06	0.001
Computers	29.77	0.001	1975:3	9.50	0.050
Software	56.20	0.000	1972:1	44.30	0.000
Other information equipment	22.17	0.020	1980:2	6.69	0.153
Industrial equipment	45.25	0.000	1985:1	8.80	0.066
Transportation equipment	25.58	0.006	1975:1	20.93	0.000
Other equipment	17.33	0.089	1979:1	5.02	0.285

Notes: See Table 4.

Table 14: Rolling regressions summary, sum of Δq_{t-i} coefficients--"Q" model

Investment category	maximum	date	minimum	date	full sample estimate
Equipment & software	0.433	2002:1	-0.200	2000:3	0.142
Information equip. & software	0.479	2001:3	-0.147	1981:1	0.105
Computers	0.633	1971:1	-0.820	1969:1	0.169
Software	0.318	1970:3	-0.166	1982:2	0.033
Other information equipment	0.730	2002:1	-0.093	1981:1	0.102
Industrial equipment	0.518	2001:4	-0.345	1998:3	0.112
Transportation equipment	1.075	1970:1	-0.767	1997:4	0.318
Other equipment	0.569	1982:2	-0.154	1997:2	0.144

Notes: See Table 5.