Investment and the Cost of Capital in the Cross-Section: The Term Spread Predicts the Duration of Investment*

Ian Dew-Becker

Federal Reserve Bank of San Francisco

November 26, 2012

Abstract

I study the determinants of investment in assets with different depreciation rates. When physical capital is discounted like a bond with a similar duration, a high term spread is associated with low average duration for investment. I document a strong negative correlation between the term spread and the duration of investment, implying an important role for the cost of capital in determining the composition of aggregate investment. The results are robust to including a variety of controls. Consumer durable goods purchases display similar behavior.

JEL Codes: E22, E43, G31

Keywords: Investment, cost of capital, term spread

1 Introduction

This paper studies the cross-section of investment. While there is an enormous amount of work studying the aggregate level of investment and the determinants of firm-level investment, there is

*Corresponding address: 101 Market St. San Francisco, CA 94105. email: ian.dewbecker@gmail.com. I thank Effi Benmelech, John Campbell, Malcolm Baker, John Beshears, Jan Eberly, Emmanuel Farhi, Ben Friedman, Bob Gordon, Robin Greenwood, Dale Jorgenson, Loukas Karabarbounis, David Laibson, Greg Mankiw, Owen Lamont, Kelly Shue, Jeremy Stein, Karl Walentin, and Eric Zwick and seminar participants at Harvard and Duke for helpful comments and discussions.

essentially no analysis of the determinants of investment in different types of assets. This paper begins that task by analyzing the distribution of investment across assets according to their depreciation rates. I show that when interest rates for long-duration assets are higher than those for short-duration assets, aggregate investment shifts relatively towards high-depreciation assets.

The response of investment to the cost of capital is a key mechanism in macroeconomics and finance. It is a primary feedback mechanism in standard general-equilibrium models; one of the key drivers for the response of the economy to monetary policy shocks; the source of the classical crowding-out effect of government spending; an important determinant of the size of distortions from taxes, and central to production-based asset pricing theories (e.g. Cochrane 1991, 1996). This paper considers a novel method for uncovering an empirical relationship between investment and the cost of capital.

There is a long literature that studies the effect of the cost of capital on investment. Simple methods have, in general, failed to find important effects.[1] Bernanke and Gertler (1995) find that nonresidential investment seems to respond only weakly to shocks to the Federal funds rate.[2] The discount rate is also a determinant of Tobin's Q, but estimates of the impact of Q on investment tend to be small (Summers, 1981; Eberly, Rebelo, and Vincent, 2009, give a recent review). The primary contribution of this paper is to show that interest rates affect what assets firms invest in at the aggregate level. Furthermore, the effect is relevant at the cyclical frequency: it is neither centered around discrete (and somewhat rare) policy changes, such as tax changes, or dependent on very long-term effects.[3]

The basic idea here is to forecast the cross-section of investment using the cross-section of interest rates, instead of forecasting the level of investment with the level of interest rates. Long-term assets are discounted with long-term interest rates, and short-term assets with short rates. When long

[1] See Chirinko, 1993, for an extensive review.

[2] However, in recent unpublished papers, Gilchrist and Zakrajsek (2008) and Guiso et al. (2002) find a relationship in micro data between investment and interest rates.

[3] Caballero (1994) and Schaller (2006) use cointegration methods to show that in the long run the cost of capital is meaningfully related to the size of the capital stock (and hence the level of investment). A number of researchers have also focused on high-frequency changes in taxes which produce large movements in the cost of capital and investment (Hassett and Hubbard, 2002, provide an extensive review).

rates are higher than short rates—the term spread is high—a cost-of-capital effect implies investment should shift towards short-duration assets. The negative relationship holds strongly in the data: it explains one third of the cross-sectional variation in investment by duration, and the effect holds both within and across industries.

Standard regressions of aggregate investment on the level of interest rates have the fundamental identification problem that periods of high interest rates may also be periods when investment demand is high, so the correlation between investment and interest rates could be zero or even positive. By studying the cross-section, I abstract from aggregate shocks, hopefully reducing this endogeneity problem. The strong empirical results suggest that in fact endogeneity is less of an issue in the cross-section.

The data is simple to construct. I obtain nominal investment by asset and year from the Bureau of Economic Analysis. I study an index of average duration defined as the average the of the assets' economic life-spans, weighted by their share in aggregate investment in each year.[4] Figure 1 shows that this index of average duration is highly negatively correlated with the spread between interest rates on ten and one-year nominal Treasury bonds (note that the axis for average duration is reversed for the sake of clarity). When interest rates are relatively high for long-duration assets, investment shifts towards short-duration assets, creating a strong negative correlation between average duration and the term spread.

A negative raw correlation between investment and interest rates suggests that the cost of capital has an important role in determining the cross-sectional distribution of investment, but there are alternative mechanisms that could produce this result. I therefore build a simple Q-theory model to help elucidate the possible sources of bias in the basic result in figure 1 and try to account for them in subsequent regressions. I control for the level of productivity and expected productivity growth in a variety of ways and find that they do not eliminate the basic effect. More importantly, I find that the term spread–average duration relationship is not driven by changes in demand across industries. When the term spread is high, investment shifts towards low-duration assets within

[4]Specifically, "lifespan" is measured as a Macaulay duration using data on economic depreciation rates.

individual industries, in addition to shifting from industries that use more long-duration assets to ones that use more short-duration assets. The basic results are also robust to controlling for measures of volatility and bank lending.

The structure of the main analysis is to document the simple duration/term-spread correlation and then ask whether it is causal by trying to reject potential non-causal explanations. As an alternative strategy, I use a standard recursively identified VAR to ask whether shocks to monetary policy, which affect short-term interest rates and hence the term spread, affect the average duration of investment. I find that there is a substantial and immediate response (raising short-term interest rates increases the average duration of investment), a notable difference from aggregate output and investment, which respond only sluggishly. The VAR thus provides additional evidence that the composition of investment responds quickly and strongly to shifts in the cross-section of the cost of capital.

In addition to contributing to the literature on the determinants of the level of investment, this paper is related to the recent literature on production-based asset pricing with projects that have differing characteristics (e.g. Berk, Green, and Naik, 1999, and Gomes, Kogan, and Yogo, 2009). While those papers show that variation in the types of capital owned by firms can lead to differences in their stock prices, I find that variation in the cross-section of asset prices can affect the types of investment that firms undertake.

Lastly, the findings here are relevant to understanding the relationship between interest rates and debt issues. The final section of the paper provides novel evidence that firms match the maturity of their debt issues to their physical investment, consistent with previous evidence in the finance literature (e.g. Stohs and Mauer, 1996). The results suggest that the timing of debt issues to the term spread documented by Baker, Greenwood, and Wurgler (2003) could be explained by the dynamics of physical investment and the fact that firms match the maturity of their debt to their assets.

The remainder of the paper is organized as follows. Section 2 describes the data and section 3 reports the main result. Next, I outline in section 4 a simple model that justifies the regression of the average duration of investment on the term spread. Section 5 controls for a number of possible biases suggested by the investment model and shows that the term spread is the single most powerful predictor of the average duration of investment, while section 6 considers an alternative VAR-based identification strategy. In section 7 I show that the relationship between duration and the term spread also appears in purchases of consumer durable goods. Section 8 examines the relationship between the type of debt that firms sell and the duration of their assets. I find a positive relationship (consistent with maturity-matching theories), which gives added support for the idea that long-term interest rates are the relevant cost of capital for long-duration assets and short rates for short-term assets. Finally, section 9 concludes.

2 Data

To study the relationship between investment and the cost of capital in the cross-section, we need a relevant measure of the cost of capital that differs across assets. The duration of assets is a natural source of variation because it is easy to quantify for both physical assets (through their depreciation rates) and bonds (through maturities). Of course, the cost of capital depends on more than simply the level of interest rates: the equity premium is large and variable (e.g. Lettau and Ludvigson, 2001). The advantage of focusing on interest rates here is that we can directly observe the cost of capital for assets of different durations. While there have been studies of the term structure of equity (Lettau and Wachter, 2007), there is no simple way to actually measure the term structure of expected returns on equity, let alone the variation in the slope of that term structure.

I obtain data on Treasury yields measured at year-end from the Federal Reserve. Treasury data has the advantage of including bonds with a large variety of maturities over a long period of time. However, firms do not in general borrow at the Treasury yield. I therefore also study the spread between yields on 3-month commercial paper and the Moody's seasoned Baa corporate bond yield (from *Global Financial Data* and the Federal Reserve, respectively). The Moody's index is meant to measure bonds with remaining maturities near 30 years. The main results focus on the Treasury yield spread.[5]

A potential concern is that the relevant discount rate for investment is the real interest rate, not the nominal rate. One method for obtaining the real interest rate would be to subtract an inflation forecast from the nominal rate. In general, random-walk inflation forecasts are competitive with more sophisticated methods (Atkeson and Ohanian, 2001). With a random-walk forecast, the nominal term spread and the spread obtained after subtracting expected inflation will be identical, which suggests that there is little to be gained by forecasting inflation here.[6]

Another option is to look at yields on inflation-protected bonds. The time series of inflation-protected bonds in the United States is relatively short, but inflation protected bonds have been sold in the United Kingdom since the 1980's. Figure 2 plots the 10/5 year term spread in the UK for both nominal and inflation-protected bonds since 1985. Over the sample, the two series move together closely, even through the financial crisis. Their variances differ, but they are over 70 percent correlated. This result suggests that by studying the nominal term spread, we will obtain results that are similar to what we would obtain with the unobservable real term spread.

Data on capital stocks and investment come from the Bureau of Economic Analysis's (BEA) fixed asset tables. The main results focus on aggregate investment by asset, but the BEA also reports data at the asset$\times$industry level. Data on depreciation rates is from Fraumeni (1997), the source for current depreciation rates used by the BEA.[7] The BEA uses geometric (declining balance) depreciation for nearly all assets.[8] Depreciation rates are estimated primarily from data on service lives and sales of vintage assets. Given the resale value of an asset for each age along with a service life, one can estimate an approximate geometric depreciation rate.[9] These depreciation rates are

[5]Ideally, we would measure the true cost of capital for each asset, including the cost of capital for equity, in particular. While there is research on the term structure for equity (Lettau and Wachter, 2007), it is not obvious how to construct an equity cost of capital for each asset simply by looking at its depreciation rate.

[6]Furthermore, we would need to estimate a 10-year inflation forecast, which would be difficult even if inflation were relatively easy to forecast at short horizons. Another option would be to use survey data on inflation forecasts, but this would substantially limit the available time series.

[7]Her depreciation rates closely match depreciation obtained by simply diving BEA reported depreciation by the capital stock.

[8]Missiles and nuclear fuel rods, for example, are modeled with straight-line depreciation.

[9]The BEA's current estimates are a combination of data from a variety of studies on resale values reviewed in Fraumeni, 1997.

closer to economic depreciation than the straight-line method used for accounting purposes by many firms (Hulten and Wykoff, 1981).

I use 36 asset classes from the BEA tables, excluding household and government assets and educational, health, and religion-related structures. The majority of the analysis focuses on equipment investment. The investment literature generally finds that models have substantial trouble explaining structures investment (Oliner, Rudebusch, and Sichel, 1995). This may be partly caused by the fact that nonresidential building projects take fourteen months to complete on average (Edge, 2000).[10] The main results below go through when structures are included, but the relationships are far less clear. I therefore leave the analysis of structures to future work so as not to distract from a complete analysis of equipment investment.

For each asset class, the BEA reports total stocks (on a current-cost basis) and investment for the private nonresidential economy. The asset classes accounting for the most nominal investment in 2007 were software (16 percent of total investment), petroleum and natural gas exploration and wells (8 percent), communication equipment (7 percent), and computers and peripheral equipment (6 percent). Except for oil and gas, these assets all have high depreciation rates, and substantial investment is necessary just to keep the stocks at constant levels.

For an asset with geometric depreciation rate δ_i, if we assume that productivity is constant and there is a fixed discount rate r^*, Macaulay's duration, D_i, will be

$$D_i = \sum_{j=1}^{\infty} j \frac{(1-\delta_i)^{j-1}}{(1+r^*)^j} = \frac{1+r^*}{r^*+\delta_i} \qquad (1)$$

When measuring durations I fix $r^* = 0.03$.[11] Table 1 lists the assets used in this study along with their depreciation rates and durations. Software, computers, and office and accounting equipment have the highest depreciation rates, all above 20 percent per year. Types of heavy industrial machinery tend to have lower depreciation rates, as low as 5 percent.

[10] See Edge (2000) for an empirical model of residential and nonresidential structures investment that takes into account building lags.

[11] Allowing for a constant rate of productivity growth would be the equivalent of choosing a lower value of r^*. The results are not sensitive to the choice of r^*.

Finally, for the purpose of summarizing the cross-section of investment, I define an index measuring the average duration of investment,

$$\bar{D}_t \equiv \sum_i \frac{I_{it}}{\sum_i I_{it}} D_i \tag{2}$$

$\bar{D}_t$ is simply a weighted average of the durations of the assets, where the weights are the assets' shares in aggregate nominal investment. When investment shifts relatively towards short-duration assets, e.g. computers or software, $\bar{D}_t$ falls. Furthermore, $\bar{D}_t$ is constructed so that it is not mechanically related to the level of investment. There is no particular reason why there need be a positive or negative relationship between the level of investment (or the state of the business cycle) and $\bar{D}_t$.[12]

Figure 3 plots $\bar{D}_t$ for 1948–2011. As might be expected, average duration has been falling over time. The fastest rate of decline appears in the late 1980's, and the series flattens out after 1994. We should not expect transitory changes in the term spread to explain the long-term changes in the duration of investment; long run changes are driven by technological shifts, e.g. the introduction of computers, software, and other electronic equipment. Instead, the term spread will explain the year-to-year variation in $\bar{D}_t$.[13]

Table 1 shows that computers have a depreciation rate of 25 percent, and software 40 percent. Their combined share of nominal investment rises from 5.4 percent in 1978 to 25.5 percent in 2011. Figure 3 also includes a version of $\bar{D}_t$ that excludes investment in computers and software, and we can see that if not for computers and software, there is no decline in the average duration of investment over time. Over the sample, though, the correlation of the first differences of the two versions of $\bar{D}_t$ is over 90 percent. For the main regressions, I detrend all of the variables using the Hodrick–Prescott (HP) filter with a smoothing parameter of 25. I obtain similar results when I use a polynomial trend or take first differences (see table 2 for results in first differences).

[12] Rather than using an index of average duration, which involves a discount rate, we could also simply use an index of the average depreciation rate of investment. All of the results below go through with this alternative measure.

[13] Tevlin and Whelan (2003) give a more extensive discussion of the recent decrease in the duration of the capital stock.

3 Results

Figure 1 plots HP-detrended $\bar{D}_t$ and the 10/1 year term spread at the end of the previous year (with the axis for $\bar{D}_t$ reversed). The negative relationship is immediately apparent. The term spread and average duration have a correlation of -57 percent. Gray bars indicate NBER-dated recessions. In most recessions, the term spread rises due to the Fed cutting interest rates, and the duration of investment falls. Duration is often high just prior to recessions, e.g. 1970, 1990, 2001, and 2007, when the yield curve is inverted. Looking more closely, we can see that over time the term spread has become more volatile while $\bar{D}_t$ has become somewhat less volatile, which is a common finding: the real economy has become less volatile (the great moderation), while Federal Reserve policy has become more aggressive, causing higher volatility in interest rates.

Table 2 reports results of regressions of $\bar{D}_t$ on the first lag of the term spread. All of the variables in table 2 are standardized to have unit variance so that the regression coefficients indicate how a one standard deviation increase in the independent variables affects $\bar{D}_t$ in terms of its own standard deviation. The units of $\bar{D}_t$ have no deep economic meaning on their own.

As expected, in the first column we find a highly significant negative coefficient on the term spread and an R^2 of 0.33. This is a high value; Oliner, Rudebusch, and Sichel (1995), when forecasting the level of aggregate investment using models with as many as 11 lags of quarterly data, obtain at best an R^2 of 0.34. With a single variable, I am able to get an R^2 nearly as high for $\bar{D}_t$. Column two uses the term spread on corporate bonds instead of Treasuries and finds a nearly identical coefficient and R^2.

The third column of table 2 controls for the lagged level of $\bar{D}_t$. The coefficient is only marginally significant and the coefficient on the term spread is essentially unchanged. Column 4 reports a simple Granger-causality test, showing that leading values of the term spread have no explanatory power for average duration, which is consistent with the theory that firms are responding to the cost of capital, rather than $\bar{D}$ driving the term spread or there being some underlying variable that causes the term spread and $\bar{D}$ to generally move together.

Finally, the fifth column runs the basic regression using investment in all assets instead of equipment alone. The results still go through. The symmetrical regression using only structures investment is unenlightening because there is not enough variation in duration within structures to provide reasonable statistical power.

To test for a break in the relationship between $\bar{D}_t$ and the term spread, I use the sup-F test (also known as the Quandt likelihood ratio test). We might expect that the break in this relationship would have appeared following the great moderation, when monetary policy became more aggressive and the economy less volatile. The F-test for a break, though, is maximized in 1958. Looking at figure 1, it is clear that after 1958 the volatility of $\bar{D}_t$ fell and the volatility of the term spread rose. The F-statistic for a break is never above the critical value reported in Andrews (1993) except for in 1958 and 1959. The highest value outside those two years is 4.56 in 1992, well below the 10 percent critical value of 5.00. There is thus evidence for a structural break, but not where we might have thought. For the period since 1960, we cannot reject the hypothesis that the relationship between $\bar{D}_t$ and the term spread has been stable.

4 Model

With the basic result in hand, it is useful to build a simple and stylized model to help understand where this correlation might come from. It is tempting to immediately jump to the conclusion that there is variation in the cost of capital (i.e. shocks to the supply of investment goods), which drives the result in figure 1. The model helps identify what other factors might induce a similar correlation.

I consider a standard infinite-horizon setup with a few simplifications for analytic tractability. Firms face a linear production function in each type of capital, where the current level of productivity for asset i is $\exp(b_{it})$. That is, revenue is equal to

$$\sum_i \exp(b_{it}) K_{it} \tag{3}$$

where K_{it} is the stock of asset i at date t. Note that this revenue function ignores complementarities between types of assets. In general, if a decline in the term spread is expected to shift investment towards long-duration assets, complementarity across assets will attenuate this effect (in the limit of a Leontief production function, firms would never vary the composition of the capital stock).

I follow Baxter and Crucini (1993) and Jermann (1998) in specifying the (continuous-time) update process for capital as

$$\dot{K}_{it} = -\delta_i K_{it} + \phi\left(I_{it}\right) \tag{4}$$

where δ_i is asset i's depreciation rate. The adjustment-cost function ϕ takes the form

$$\phi\left(I_{it}\right) = \frac{\eta}{1-1/\gamma} I_{it}^{1-1/\gamma} + \eta_2 \tag{5}$$

ϕ has the useful property that the elasticity of investment with respect to Tobin's Q will equal the constant γ.[14]

Denoting the instantaneous discount rate at time $t+k$ from the perspective of date t as $f_{t,t+k}$, the firm maximizes the discounted value of its revenue net of investment costs,

$$\Pi_t = \max_{I_{it}} \int_{j=0}^{\infty} \sum_i \left[\exp\left(-\int_{k=0}^{j} f_{t,t+k} \right) E_t \exp\left(b_{i,t+j}\right) K_{it+j} - I_{it+j} \right] dj \tag{6}$$

where E_t denotes the expectation operator conditional on information available at date t.

I assume discount rates follow the process,

$$f_{t,t+j} = \bar{r} + z_t^r + \exp\left(-\phi_r j\right) x_t^r - \frac{\bar{\delta} + \bar{r}}{\left(\phi_r + \bar{\delta} + \bar{r}\right)} x_t^r$$

where z_t^r is a level factor and x_t^r a slope factor. Level and slope factors are generally found to explain 95 percent or more of the variation in U.S. interest rates (e.g. Litterman and Scheinkman, 1991). It is not a priori obvious whether we should think of an increase in the slope of the term structure as coming from a decline in short-term interest rates, an increase in long-term interest

[14] This functional form has the drawback that it is not necessarily consistent with negative investment. However, asset-level investment is always positive in the data, so this is not a practical concern here.

rates, or something in between. Here, a shock to x_t^r represents a rotation of the forward curve with the property that it has no first-order effect on the price of capital with depreciation rate $\bar{\delta}$. the parameter ϕ_r represents how rapidly rotation x^r dies out as the time horizon gets longer.

For productivity growth, I assume that different assets may have different current levels of productivity, but expected productivity growth in the future is the same for all assets, $E_t \dot{b}_{t+j} = \mu_{t,t+j}$, where

$$\mu_{t,t+j} = \bar{\mu} + z_t^b + \exp\left(-\phi_r j\right) x_t^b - \frac{\bar{\delta} + \bar{r}}{\left(\phi_b + \bar{\delta} + \bar{r}\right)} x_t^b$$

As above, z_t^b and x_t^b are assumed to have mean zero and their interpretation is the same as that for z_t^r and x_t^r.

Taking the first-order condition for I_{it} yields the standard Tobin's Q type solution

$$I_{it}^{1/\gamma} = Q_{i,t} \tag{7}$$

$$Q_{i,t} \equiv \left(\delta_i + \bar{r}\right) \int_{j=0}^{\infty} \exp\left(-\delta j\right) \left[\exp\left(-\int_{k=0}^{j} f_{t,t+k}\right) E_t \exp\left(b_{i,t+j}\right)\right] dj \tag{8}$$

where the normalization $(\delta_i + \bar{r})$ ensures that $Q_{i,t}$ is equal to 1 in steady state. The appendix shows that, using a first-order approximation, we can derive an approximate expression for the index of average duration, $\bar{D}_t$,

$$\bar{D}_t = \frac{\sum_i I_{it} D_i}{\sum_i I_{it}} \approx d_0 + k_r x_t^r - k_b x_t^b + k_{zr} z_t^r - k_{zb} z_t^b + k_d \sum_i D_i b_{it} \tag{9}$$

for positive constants $d_0, k_r, k_b, k_{zr}, k_{zb}$, and k_d that depend on the fundamental parameters of the model.

The previous section considered a simple regression of $\bar{D}_t$ on the term spread, which is driven here by x_t^r. Holding all else equal, equation (9) confirms the simple intuition that this relationship should be negative. Equation (9) shows, however, that there are at least four potential omitted variables in this regression: long-run expected productivity growth and discount rates, z_t^b and z_t^r; the productivity growth spread, x_t^b, and the covariance of the levels of idiosyncratic productivity,

b_{it}, with durations D_i.

First, holding the term spread and the productivity spread fixed, an increase in productivity growth, z_t^b, or a decrease in discount rates z_t^r, will tilt the distribution of investment towards long-duration assets. This effect is the primary feature of duration: long-duration assets gain more value from a permanent decline in interest rates or increase in expected productivity growth than do short-duration assets. To the extent that the term spread is correlated with long-term average productivity growth and interest rates, then, a regression of the average duration of investment on the term spread will be biased.

Specifically, we could spuriously find a negative relationship between the term spread and $\bar{D}_t$ if expected long-term productivity growth is low in periods when the term spread is high. The term spread is countercyclical, so this would correspond to a situation in which expected long-term productivity growth z_t^b is low during recessions. I will try to control for these effects by controlling for the level of aggregate investment and various other indicators of the state of the business cycle.

The second source of bias is that the productivity spread, x_t^b, could be correlated with the term spread. In particular, if productivity growth is expected to slow down in the same periods that the term spread is high, we would find a spurious negative relationship between average duration and the term spread. In this case, recessions would have to be periods in which productivity growth is expected to decelerate in the future, which seems unlikely given that recessions are periods when growth is already slow in the first place (by definition).

Finally, the levels of productivity across assets could be related to duration, affecting $\bar{D}_t$ through the covariance term, which can be thought of as the covariance between duration and productivity across assets. If this covariance changes over time and is systematically related to the level of the term spread, then omitting it from the regression would bias the coefficient on the term spread.

Over long horizons, investment and productivity shift substantially across different assets. The most notable of these changes is the long-run decline in prices and increase in investment in computers and software (Tevlin and Whelan, 2003).[15] The model would interpret this phenomenon as

[15] See also Caballero, 1994, and Schaller, 2006, for studies of the relationship between investment and the cost of capital in the long-run.

an increase in b_{it} for low-duration assets, which drives $\bar{D}_t$ downward. A simple way to control for those movements is to detrend $\bar{D}_t$.

Short-run movements in idiosyncratic productivity are more difficult to account for, though. If changes in the term spread are correlated with shifts in productivity that favor certain assets, then the regression of $\bar{D}_t$ on the term spread will be biased. In the empirical analysis below, I discuss and control for some specific mechanisms, most importantly industry demand shifts, that could drive high-frequency movements in $\sum_i D_i b_{it}$.

Instead of running a regression of average duration on investment, it would be nice to estimate a more fundamental parameter, such as the coefficient on marginal Q, which tells us about the size of adjustment costs in investment. One way to do that would be to calculate Tobin's Q for each asset individually, as in Abel and Blanchard (1986), by discounting expected future marginal products using the full term structure of real discount rates. The problem is that we do not actually directly measure the marginal product of any individual asset at any point in time. Moreover, we do not measure anything like the true discount rate for each asset. Rather, the term spread in this paper is measured using Treasury yields and is taken as an indicator of differences in discount rates across assets. A deeper problem is that Abel and Blanchard's method would also require forecasting inflation at very long horizons, when the literature generally finds that inflation is difficult to forecast even at quarterly and annual horizons (e.g. Atkeson and Ohanian, 2001).[16]

What the regression of average duration on the term spread is useful for is testing whether the

[16] Euler equation estimation is also an option. In a pair of papers, Oliner, Rudebusch, and Sichel (1995, 1996) study the effectiveness and internal consistency of Euler equation models for investment. They obtain parameter estimates that are somewhat difficult to reconcile with economic theory, find that supposedly "structural" parameters are unstable over time, and that the models have little forecasting power. There are also legitimate concerns about the validity and relevance of the instruments used in these models (especially when extended to asset-level data).

I attempted to estimate an Euler equation using the panel of data on asset-level investment. Between two-stage least squares, LIML, and GMM methods, there were substantial differences in results indicating that the model is misspecified or there are problems with the instruments. I also replicated some of the troubling results found by Oliner, Rudebusch, and Sichel. Furthermore, Euler equations are clearly difficult to estimate even with quarterly data, and I only have annual data on asset-level investment.

The Euler-equation method is also more restrictive than the methods used in this paper because it is difficult or impossible to incorporate all of the controls that I consider. Euler equations are useful for estimating specific parameters in tightly theorized models. The regressions used here are meant to test a broader range of possible explanations for the correlation between average duration and the term spread and to measure the explanatory power of the term spread. I therefore leave the Euler equation analysis of this panel dataset for future work.

term spread drives investment in the direction that we would expect and how much explanatory power the term spread has for the cross-section of investment. A high R^2 in a regression of average duration on the term spread is evidence that the cross-section of interest rates is an important determinant of the cross-sectional distribution of investment.

5 Alternative explanations

The working hypothesis is that the negative relationship between average duration and the term spread is a simple cost-of-capital effect. The model in the previous section shows that there are a number of other factors that could cause us to find the correlation we observe in figure 1. This section considers a range of possible alternative explanations. I find that the correlation is driven to some extent by these other factors, but that the cost of capital retains a substantial amount of explanatory power and is generally the most powerful variable for explaining average duration.

5.1 Correlations by asset and industry

One possible explanation for the correlation between the term spread and $\bar{D}$ is that demand for the products of different industries depends on the term spread. For example, suppose when the term spread is high consumers demand fewer durable goods (the term spread tends to be countercyclical, as are durables purchases; Yogo, 2006). If durable goods industries tend to use relatively more long-duration capital than services providers (for example, a car manufacturer may use more heavy machinery than a barber shop), then we would see investment shift towards low-duration assets. In the terms of the model, this is a story about the covariance term $\sum_i D(\delta_i)\left[\log(B_{i0}) - N^{-1}\sum_i \log(B_{i0})\right]$. The correlation between $\bar{D}$ and the term spread then would be driven by consumer demand (and hence the variation in the marginal product across assets) instead of the cost of capital. We can test this hypothesis by decomposing $\bar{D}$ into components driven by within-industry reallocation and changes in the composition of investment across industries.

As noted above, the BEA not only reports data on aggregate investment; it also gives levels of investment at the asset×industry level. Denoting the first difference of $\bar{D}_t$ as $\Delta\bar{D}_t$, we can decompose $\Delta\bar{D}_t$ following van Ark and Inklaar (2006) using the industry-level data as

$$\begin{aligned}\Delta\bar{D}_t &= \sum_j \left[\frac{1}{2}\left(\frac{I_{j,t}}{\bar{I}_t} - \frac{I_{j,t-1}}{\bar{I}_{t-1}}\right)\left(\bar{D}_{j,t} + \bar{D}_{j,t-1}\right)\right] \\ &\quad + \sum_j \left[\frac{1}{2}\left(\frac{I_{j,t}}{\bar{I}_t} + \frac{I_{j,t-1}}{\bar{I}_{t-1}}\right)\left(\bar{D}_{j,t} - \bar{D}_{j,t-1}\right)\right] \qquad (10)\end{aligned}$$

where $\bar{D}_{j,t} \equiv \sum_i \frac{I_{j,i,t}}{\bar{I}_{j,t}} D_i$ is the average duration of industry j at time t. The first part of equation (10) can be thought of as a cross-industry reallocation effect. It sums the changes in the industry investment shares weighting by their average depreciation rates at dates t and $t-1$. The second term is the within-industry reallocation term. It represents the effects of industries changing their mix of investment among different assets. I refer to the two effects as the between and within-industry effects, respectively.

The final three columns of table 2 report results from first-differenced regressions of $\Delta\bar{D}$ and its decomposition (10) on the change in the term spread. $\Delta\bar{D}$ and ΔTS are standardized to have unit variance as in the remainder of the table. The three columns report results from regressions with different dependent variables. The first column uses $\Delta\bar{D}$. The coefficient on the term spread is similar to though somewhat smaller than the coefficient in column 1. In other words, the relationship between $\bar{D}$ and the term spread is somewhat weaker in high frequency data, which is perhaps not surprising considering the effects of planning, ordering, and building lags. The coefficients in columns 7 and 8 by definition sum to the coefficient in column 6. The within-industry coefficient is twice the size of the between-industry coefficient; in other words, two thirds of the aggregate effect comes from reallocation within industries. The hypothesis that industry demand is correlated with the term spread seems to be true, but it explains only a minority of the variation in average duration over time.

To analyze how the relationship in figure 1 and table 2 differs across assets, I run a regression of each asset's share of aggregate investment on the term spread.[17] Specifically, for each asset we

[17] To control for long-term changes in the composition of investment I first detrend the dependent variable and the

run the regression

$$\frac{I_{it}}{\sum_i I_{it}} = \alpha_i + \beta_i TS_t + \varepsilon_{it} \tag{11}$$

It is straightforward to show that if β_i is negatively related to each asset's duration, then there will be a negative relationship between the term spread and $\bar{D}_t$. This is a way of asking whether the relationship we observe at the aggregate level is pervasive across assets, or is driven by a few outlier assets.

Figure 4 plots the coefficients β_i against duration. The black boxes are for equipment, grey diamonds structures. Regression lines are included for the sample of all assets and for equipment only. The correlations between β_i and D_i are -0.42 and -0.31 for equipment only and all assets, respectively. Looking across equipment, the relationship between the composition of investment and the term spread is broadly based not driven by a few outliers.

The plot includes labels for the assets that make up the largest part of investment over the last 15 years. Numbers in parentheses represent their percentage shares over that period. Within equipment, auto purchases as a share of total investment are far more positively correlated with the term spread than any other asset, though they represent a relatively small part of aggregate investment. Software is the single largest component of investment and it is well above the best fit line. Communication equipment and computers are next in the rankings and are somewhat closer to the regression line.

Structures do not match the results for equipment very well. While the shares of structures are generally negatively related to the term spread, they are not as negative as we would think from just looking at equipment. Electric-power plants, in particular, are a large positive outlier. As noted above, the fact that building lags average over a year (a time that does not take into account the time required for planning) is likely to distort the regressions for structures.

term spread using the HP filter with a smoothing parameter of 25 as above.

5.2 The business cycle, volatility, and other explanations

Table 3 explores a number of other mechanisms that could cause the observed correlation beyond changes in demand across industries. Columns 1 and 2 control for the business cycle with the lagged detrended unemployment rate and level of output. In both cases the coefficient on the term spread is smaller but still statistically and economically significant. This is perhaps not surprising: even if the term spread does represent a true cost-of-capital effect, it is also a proxy for the business cycle. Controlling for other business cycle indicators will probably lower its coefficient. Including the current value and longer lags of unemployment and output do not change the results of the regressions.

Another obvious question is whether there is a mechanical relationship between average duration and the level of investment. Suppose a firm has equal stocks of two assets, one with a depreciation rate of 1 percent, the other 10 percent. In a maintenance phase with no net capital growth, there will be 10 times as much investment in the high depreciation as the low depreciation asset. However, in an expansion phase, assuming both assets are expanded equally, investment will shift towards being equally balanced between the two assets. If the term spread is correlated with the level of investment, it might also then be correlated with average duration. Column 3 tests that hypothesis by including detrended aggregate equipment investment. Puzzlingly, unlike the example just given, when investment is high, duration actually tends to be low. However, the coefficient on the term spread is still large and significant. The term spread thus has explanatory power beyond its indication of either the business cycle of overall level of investment. Column 4 shows that if we include all three aggregate indicators, unemployment, GDP, and investment, the coefficient on the term spread is the highest, and has the highest t-statistic, of any of the variables (implying that the marginal R^2 of the term spread is higher than any of the business-cycle indicators).

Abel et al. (1996), among many others, study the effects of irreversibility on investment. With irreversibility, when idiosyncratic uncertainty is high, firms may be less willing to invest in long-duration assets. Intuitively, if it is more difficult to sell a long-duration asset (e.g. a large wind turbine) because it is more costly to disassemble than a short-duration investment, then there is option value to delaying investment which is increasing in uncertainty.[18] Campbell et al. (2001) and Bloom (2009) find that when the volatility of returns on the aggregate stock market is high, so is idiosyncratic firm volatility. If the term spread is partially driven by aggregate volatility (a finding of Bloom, 2009, and implied by many term structure models, e.g. Longstaff and Schwartz, 1992), and volatility drives $\bar{D}$, then we would find a spurious correlation between the term spread and $\bar{D}$.

I use two measures of cross-sectional volatility that are also used in Bloom (2009): the period-by-period cross-sectional standard deviations of firm quarterly profit growth and stock returns, including controls for 3-digit SIC industries.[19] Column 5 of table 3 reports results of a regression of $\bar{D}$ on the volatility indexes. Both measures of volatility are positively correlated with the next year's term spread, which is consistent with Bloom's (2009) results. He finds that volatility shocks lead to economic contractions and reductions in the short rate. Table 3 shows that conditional on the term spread and the state of the business cycle, high stock return volatility (though not profit growth volatility) in the following year is associated with low duration investment. This is consistent with the hypothesis that long-duration investment involves a bigger commitment for firms than short-duration investment. That is, the hypothesis that high volatility interacts with fixed costs of adjustment to decrease investment seems to apply more strongly to long than short-term assets. Note, though, that even when controlling for volatility, the term spread remains significant and has a large coefficient.

Another alternative hypothesis is that the term spread does not reflect the cost of capital but is simply an indicator of the stance of monetary policy. When the Federal Reserve contracts the money supply, this may inhibit bank lending, as in Kashyap and Stein (2000). If banks are more likely to finance projects of a certain duration (either high or low), then the term spread might simply be correlated with movements in $\bar{D}$ because it is correlated with bank lending standards. One way to test this hypothesis is to try to directly measure bank lending standards. The Federal

[18] House and Shapiro, 2008, discuss the relationship between real option-type effects and asset duration.

[19] The original data was retrieved from Compustat and CRSP. I obtained the data used here from Nick Bloom's website.

Reserve has administered a Survey of Senior Loan Officers since 1967 (with a gap between 1983 and 1989) that asks banks about the level of their lending standards.[20] Column 6 includes the tightness index from this survey in the regression. The coefficient on the term spread remains significant. When bank lending standards are relatively tight (a high value of the index), average duration is low. This is perhaps surprising, since banks are usually thought of as financing short-duration projects, while firms go to credit markets for longer-term financing. One possible explanation is that lending standards tend to be high when other factors are driving firms towards short-duration investment. In particular, standards might be high in times of high uncertainty.

The appendix includes further robustness tests. When all of the controls are included simultaneously, the term spread is the only significant variable and it has more explanatory power than any of the other variables individually.

Lettau and Wachter (2007) argue that the differences in returns between high and low book/market (B/M) stocks can be explained by differences in the duration of their cash flows (see also Hansen, Heaton, and Li, 2008). A high value spread is associated with a high valuation for growth stocks, or long-duration assets, which implies investment in long-duration assets should be high. Since stock prices represent claims on capital, whereas Treasury bonds are claims on currency, we might expect that the value spread would have more predictive power than the term spread. Column 7 of table 3 reports the results of a regression including the value spread. I measure the value spread here as the ratio of the book to market ratios for the top and bottom third of stocks sorted by book to market (as reported on Kenneth French's website).[21] The coefficient is significantly negative: the opposite of what the duration theory of the value spread would predict. One possible explanation for this result is that firms with growth stocks tend to have lower-duration assets—e.g. technology firms—so when their values are high average duration falls. To many readers, that may have been the obvious result all along. Nevertheless, it runs against Lettau and Wachter's theory.

[20] I obtain data from Lown and Morgan, 2006.

[21] Specifically, French reports value spreads for small and large stocks, split at the median of market capitalization. I average these two value spreads. Furthermore, I detrend the value spread using the HP filter with a smoothing parameter of 100.

6 VAR evidence

The analysis thus far proceeded by documenting the raw correlation between the term spread and average duration and then tried to establish a causal relationship from a cost-of-capital effect by systematically rejecting other possible mechanisms that could induce the observed correlation. This section uses a different approach. I estimate a standard VAR in basic macro variables (as in, e.g., Christiano, Eichenbaum, and Evans, 1999). I show that shocks to monetary policy that increase the Fed Funds rate significantly reduce the term spread and raise the average duration of investment. Moreover, the average duration of investment responds to monetary policy shocks faster than other variables, such as output and consumption.

The data series included in the VAR are the annual logged levels of output, consumption, investment, the GDP deflator, and labor productivity, the level of the Fed Funds rate, $\bar{D}_t$ (detrended as above), and the term spread. The Fed funds rate and term spread are measured at the end of each year.

I identify the structural shock to the Fed Funds rate through the standard recursive scheme. Since the Fed Funds rate is measured at the end of the year, I assume that it moves last except for the term spread (also measured at the end of the year), i.e. it is allowed to respond to the shocks to all the other variables except for the term spread. I allow four years of lags in the VAR, as selected by the AIC.

The identifying timing assumption means that in measuring the shocks to the cost of capital at the end of year t (affecting investment in year $t+1$) we control for any factors that affect the other variables in year t. For example, if there is a change in the long-run level of real discount rates (z_t^r above) or long-run productivity growth (z_t^b) we will control for it as long as it has an effect on output, consumption, or any of the other endogenous variables in year t.

Figure 5 plots the responses of $\bar{D}_t$, output, consumption, and investment to a one-standard-deviation increase in the Fed Funds rate. On the impact of the shock, $\bar{D}_t$ immediately rises by 12 percent of its standard deviation. Output, consumption, and investment only display minimal responses in the first year following the shock. There is clearly a strong relationship between interest rates and the composition of investment. When the Fed cuts interest rates, short-term yields fall, while long-term yields are affected by relatively less. The dotted line in the top-left panel of figure 5 shows the response of the term spread to the monetary policy shock. The path is almost the mirror image of the response of $\bar{D}_t$ exactly as we would expect from the raw correlation between the term spread and $\bar{D}_t$.

The VAR results here show that when we attempt to identify exogenous shocks to the term spread, they have highly similar effects on the average duration of investment as we observe from simple raw correlations.

7 Consumer durables

If the term spread truly represents a cost of capital effect then we would expect household purchases of durable goods to respond to it in a manner similar to nonresidential investment. Households face some of the same choices as firms when deciding what types of durable goods to purchase. In particular, long-lasting durable goods may have financing arrangements with longer terms than those of shorter duration assets.[22]

Denoting the duration of durable good of type i as C_i and purchases as P_i, I define the average duration of consumer durables purchases as

$$\bar{C}_t \equiv \frac{\sum_i C_i P_{it}}{\sum_i P_{it}} \tag{12}$$

Table 4 lists the assets available from the BEA, along with their depreciation rates and durations. The two assets with the lowest depreciation rates are luggage and furniture at 13 percent. Computer software and motor vehicle parts have the highest rates at 76 and 90 percent, respectively. The assets are mostly clustered in a small range of depreciation rates, though: three fourths have depreciation rates between 16 and 25 percent.

[22] Attanasio, Goldberg, and Kyriazidou (2008) show that auto loan terms tend to be between three and five years, while home loans may be as long as 30 years.

Figure 6 plots HP-detrended $\bar{C}_t$ against the detrended term spread. As in figure 1, the axis for $\bar{C}_t$ is reversed so that a negative correlation in the data is an easier-to-read positive correlation in the figure. For most of the sample, there is a strong negative correlation, just as we observe for nonresidential investment. In a regression similar to those in table 2, consumer durables on the lagged term spread, the coefficient is -0.31 with a p-value of 0.008. There is thus a significant relationship over the full sample, though the correlation is somewhat weaker than what we observe for nonresidential investment. The correlation is clearest between 1965 and 1991. For nonresidential investment the correlation is more consistent over time, which explains why the QLR test in section 3 indicated a break point only in the very beginning of the sample.

The relationship between $\bar{C}_t$ and the term spread seems to abruptly break down after 1991. If we run a QLR test as before, we can reject the hypothesis of no break at the 1 percent level. The F-statistic is maximized in 1991, only one year different from the local maximum that is obtained in the F-statistic for nonresidential investment.[23] The fact that these two break tests are maximized around the same time suggests that the breakdown in the consumer durables plot is not due to a factor that is specific to consumers.

One possible consumer-specific explanation is that there was some sort of change in consumer credit markets around 1991. Perhaps easier access to credit cards made consumers less dependent on long-term financing for some durables purchases, which made them less sensitive to long-term credit conditions. The Flow of Funds accounts measure total credit card balances and household net worth. The ratio of consumer credit debt to net worth rises from 1.0 to 3.8 percent between 1945 and 1965, but then stays flat subsequently. While there were certainly changes in consumer credit markets following 1965, the total quantity of credit has remained in this sense stable.

8 The firm-level mechanism

The link between the term spread and the cost of capital will be most clear to managers if investment in long-duration assets is financed with long-duration debt. If, for example, firms always borrow

[23] Note, again, that the local maximum for nonresidential investment is not statistically significant.

at the same maturity and simply roll over their debt, then they might only pay attention to the interest rate for the maturity at which they borrow, instead of the full term structure.

Baker, Greenwood, and Wurgler (BGW, 2003) find that firms time the debt market when they sell bonds. In particular, when the term spread is high firms sell short-term debt. BGW argue that firms do this because when the term spread is high, the prices of short-term bonds are expected to fall in the future. Firms are selling expensive or overpriced debt, which BGW claim represents arbitrage.

But if it is true that firms try to match the maturity of their debt to the maturity of their investments, then the results in the previous sections could explain the BGW result. Matching the maturity of debt to assets reduces potential deadweight losses from bankruptcy (see, e.g., Stohs and Mauer, 1996). Graham and Harvey (2002) report evidence from surveys that maturity matching is the single most important determinant of debt maturity choice.[24]

Section 3 showed that when short-term yields are low, firms invest in short-duration assets. If the maturity-matching hypothesis is correct then those firms should also sell short-duration debt. That matches the Baker et al. result: low short yields are associated with short-duration investment, which is associated with sales of short-duration debt. BGW claim that firms are arbitraging debt markets; I claim they are managing risk through maturity-matching. The key to completing the argument is showing that firms actually do try to match the duration of their debt to that of their assets. In this section I provide evidence in support of this proposition.[25]

I obtain data from two sources. Data on capital stocks come from the BEA's detailed fixed asset

[24] See also Barclay and Smith, 1995, and Guedes and Opler, 1996, among many others.

[25] Baker at al. tried measuring the duration of assets with a similar strategy to mine. However, rather than using industry depreciation reported by the BEA, they used the amount of depreciation reported to the IRS by individual firms. Presumably this data was substantially more noisy than the BEA data, which caused them to find inconclusive results. Moreover, accounting depreciation is in general not the same as economic depreciation. The majority of firms use straight line depreciation, rather than the declining balance method found to better match the resale value of assets (Hulten and Wykoff, 1981).

tables as before.[26] I continue to measure average duration within industry j as

$$\bar{D}_{jt} = \frac{\sum_i D_i I_{ijt}}{\sum_i I_{ijt}} \tag{13}$$

where i indexes assets, j indexes industries, and I is investment

I obtain data on corporate debt from Compustat. Following Baker et al. (2003) and Greenwood et al. (2009), the long-term share in a given industry and year is the sum of all outstanding long-term debt reported by firms in that industry divided by all long and short-term debt.[27] I estimate issuance of long-term debt as the change in the level of long-term debt, and short-term issuance as simply the level of short-term debt (since short-term debt has, by definition, a maturity of less than one year). The long-term issuance share is then just the ratio of long-term issuance to total issuance.[28]

An important issue here is that Compustat only covers publicly traded firms, whereas the BEA's fixed-asset data covers all firms. To the extent that private firms have limited access to long-term credit markets, this will bias the level of the long-term share upwards.[29] It is less clear, though, that selection should cause us to spuriously find that high-depreciation industries have a low long-term share. The selection would need to occur in such a way that firms in high-depreciation industries are more likely to go public but are no more likely to have access to long-term credit markets.

Table 5 reports regressions of the long-term level and issuance shares on industry average duration. The first two columns use the level share, the second two the issue share. Columns 2 and 4 include industry fixed effects. Each regression includes year dummies and the standard errors are corrected for clustering within industries. Columns 1 and 3 show that there is a significant negative relationship between long-term debt levels and issuance and the depreciation rate of assets

[26] The BEA has its own industry classification which is slightly different from NAICS. I use industries that roughly correspond to a 2-digit NAICS classification, but I combine some industries to ensure that I have sufficient firm observations to get good financial data. I end up with 22 industries

[27] I measure long term debt as the sum of items 9 (long term borrowing) and 44 (long term debt about to retire), and short term debt as item 9 plus item 34 (current liabilities) minus long term debt.

[28] I drop firm observations if the level of long term debt drops by more than one half (as this amount of retirement is implausible). Industry-year observations are dropped if they have a negative level of long term debt issuance.

[29] For example, Titman and Wessels, 1988, find that small firms are less likely to use long-term debt financing.

in an industry. However, columns 2 and 4 show that when we include industry dummies the effect goes away. That is, there is not evidence that when an industry shifts towards higher-depreciation assets, it also changes the composition of its debt.

One reason I do not find within industry effects in table 5 could be that the data is not sufficiently precise. The median number of firms that is used to create the industry×year observations is only 148, and the 25th percentile is 30. Moreover, the measure of the duration of debt is extremely rough. Firms could easily be changing the maturity of their long-term issues, rather than substituting between long and short-term issues.[30]

9 Conclusion

This paper shows that there is a strong relationship in aggregate data between investment and the cost of capital. I find that the term spread can explain a third of the variation of the cross section of investment. While this relationship does not quantify the magnitude of internal adjustment costs facing firms, it does show that the cost of capital is a major factor driving the variation in the type of investment that firms do. The composition of investment changes meaningfully over the business cycle, and a substantial portion of these changes can be explained by the term spread alone.

The results are robust to including a variety of controls, including multiple indicators of the state of the business cycle. None of the controls eliminate the coefficient on the term spread. Moreover, when we include all of the controls at once, the term spread is the only variable that remains significant. Of all of the variables I study, the term spread is the most robust and powerful predictor of the distribution of investment. The dimension of investment studied here has not been examined before. The results extend also to consumer durables purchases: households tend to buy less-durable durables when the yield curve is steep.

Cochrane (2011) gives an extensive review of the literature on return predictability and variation in the price of risk, arguing that shifts in discount rates are part of "the central organizing question of

[30] While there is data with more detail on the duration of corporate debt, it does not have a long enough time series to be useful for finding the aggregate effects that I am looking for here.

asset pricing research." As Treasury bonds have (nominally) riskless payoffs, shifts in the term spread are purely driven by discount rates. The finding that the term spread determines the composition of investment is thus connected to Cochrane's organizing question by showing its relevance for the aggregate economy, and not just financial markets.

There are many other cross-sectional sources of variation in the cost of capital beyond differences in asset lives. Tax policies, e.g. R&D tax credits and bonus depreciation, distort the cost of capital, as will changes in the price of risk. The finding here that shifts in the term structure of interest rates affect the composition suggests that tax policy can succeed distorting investment choices. Similarly, to the extent that the price of risk varies over time, an interesting question is whether a high price of risk causes businesses to shift relatively towards low-risk/low-reward projects.

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., Avinash K. Dixit, Janice C. Eberly, and Robert S. Pindyck. 1996. "Options, the Value of Capital, and Investment." *Quarterly Journal of Economics*, *111(3)*, 753–777.

Andrews, Donald W.K. 1993. "Tests for Parameter Instability and Structural Change with Unknown Change Point." *Econometrica*, *61(4)*, 821–856.

Atkeson, Andrew and Lee E. Ohanian. 2001. "Are Phillips Curves Useful for Forecasting Inflation?" *Federal Reserve Bank of Minneapolis Quarterly Review*, *25* (1): 2–11.

Attanasio, Orazio P., Pinelopi Koujianou Goldberg, and Ekaterini Kyriazidou. 2008. "Credit Constraints in the Market for Consumer Durables: Evidence from Micro Data on Car Loans." *International Economic Review*, *49(2)*, 401–436.

Baker, Malcolm, Robin Greenwood, and Jeffrey Wurgler. 2003. "The Maturity of Debt Issues and Predictable Variation in Bond Returns." *Journal of Financial Economics*, *70* (2): 261–291.

Barclay, Michael J. and Jr. Clifford W. Smith. 1995. "The Maturity Structure of Corporate Debt." *Journal of Finance*, *50(2)*, 609–631.

Baxter, Marianne and Mario J. Crucini. 1993. "Explaining Saving–Investment Correlations." *American Economic Review*, *83(3)*, 416–436.

Berk, Jonathan B., Richard C. Green, and Vasant Naik. 1999. "Optimal Investment, Growth Options, and Security Returns." *Journal of Finance*, *54* (5): 1553–1607.

Bernanke, Ben S. and Mark Gertler. 1995. "Inside the Black Box: The Credit Channel of Monetary Policy Transmission." *Journal of Economic Perspectives*, *9* (4): 27–48.

Bloom, Nicholas. 2009. "The Impact of Uncertainty Shocks." *Econometrica*, *77(3)*, 623–685.

Caballero, Ricardo J. 1994. "Small Sample Bias and Adjustment Costs." *Review of Economics and Statistics*, *76* (1): 52–58.

Campbell, John Y., Martin Lettau, Burton G. Malkiel, and Yexiao Xu. 2001. "Have Individual Stocks Become More Volatile? an Empirical Exploration of Idiosyncratic Risk." *Journal of Finance*, *56* (1): 1–43.

Chirinko, Robert S. 1993. "Business Fixed Investment Spending: Modeling Strategies, Empirical Results, and Policy Implications." *Journal of Economic Literature*, *31* (4): 1875–1911.

Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans. 1999. "Monetary Policy Shocks: What Have We Learned and to What End?" in John B. Taylor and Michael Woodford, eds., *Handbook of Macroeconomics*, Vol. 1, Elsevier, pp. 65–148.

Cochrane, John H. 1991. "Production-Based Asset Pricing and the Link Between Stock Returns and Economic Fluctuations." *Journal of Finance*, *46* (1): 209–237.

Cochrane, John H. 1996. "A Cross-Sectional Test of an Investment-Based Asset Pricing Model." *Journal of Political Economy*, *104* (3): 572–621.

Cochrane, John H. 2011. "Discount Rates." *Journal of Finance*, *66(4)*, 1047–1108. AFA Presidential Address.

Eberly, Janice, Sergio Rebelo, and Nicolas Vincent. 2009. "Investment and Value: A Neoclassical Benchmark." *NBER Working Paper.*

Edge, Rochelle M. "The Effect of Monetary Policy on Residential and Structures Investment Under Differential Project Planning and Completion Times." Federal Reserve Board of Governors International Finance Discussion Papers No. 671 2000.

Fraumeni, Barbara. 1997. "The Measurement of Depreciation in the U.S. National Income and Product Accounts." *Survey of Current Business*, pp. 7–23.

Gilchrist, Simon and Egon Zakrajsek. 2007. "Investment and the Cost of Capital: New Evidence from the Corporate Bond Market." *Working Paper.*

Gomes, João F., Leonid Kogan, and Motohiro Yogo. 2009. "Durability of Output and Expected Stock Returns." *Journal of Political Economy*, *117(5)*, 941–986.

Graham, John R. and Campbell R. Harvey. 2002. "How do CFOs Make Capital Budgeting and Capital Structure Decisions?" *Journal of Applied Corporate Finance*, *15(1)*, 8–23.

Greenwood, Robin, Samuel Hanson, and Jeremy Stein. 2009. "A Gap-Filling Theory of Corporate Debt Maturity Choice." *Working Paper.*

Guedes, Jose and Tim Opler. 1996. "The Determinants of the Maturity of Corporate Debt Issues." *The Journal of Finance*, *51(5)*, 1809–1833.

Guiso, Luigi, Anil K. Kashyap, Fabio Panetta, and Daniele Terlizzese. 2002. "How Interest Sensitive is Investment? Very (when the data are well measured)." *Working Paper.*

Hansen, Lars P., John C. Heaton, and Nan Li. 2008. "Consumption Strikes Back? Measuring Long-Run Risk." *Journal of Political Economy*, *116(2)*, 260–302.

Hassett, Kevin A. and R. Glenn Hubbard. *Handbook of Public Economics*, Elsevier Science B.V.,

House, Christopher L. and Matthew D. Shapiro. 2008. "Temporary Investment Tax Incentives: Theory with Evidence from Bonus Depreciation." *American Economic Review*, *98* (3): 737–768.

Hulten, Charles R. and Frank C. Wykoff. 1981. "The Measurement of Economic Depreciation." in Charles R. Hulten, ed., *Depreciation, Inflation, and the Taxation of Income from Capital,*, Washington, D.C.: The Urban Institute Press, pp. 81–125.

Jermann, Urban J. 1998. "Asset Pricing in Production Economies." *Journal of Monetary Economics*, *41* (2): 257–275.

Kashyap, Anil K. and Jeremy C. Stein. 2000. "What Do a Million Observations on Banks Say About the Transmission of Monetary Policy?" *American Economic Review*, *90(3)*, 407–428.

Lettau, Martin and Jessica A. Wachter. 2007. "Why Is Long-Horizon Equity Less Risky? A Duration-Based Explanation of the Value Premium." *Journal of Finance*, *62* (1): 55–92.

Lettau, Martin and Sydney Ludvigson. 2001. "Consumption, Aggregate Wealth, and Expected Stock Returns." *Journal of Finance*, *56* (3): 815–849.

Litterman, Robert and Jose Scheinkman. 1991. "Common Factors Affecting Bond Returns." *Journal of Fixed Income*, *1*, 54–61.

Longstaff, Francis A. and Eduardo S. Schwartz. 1992. "Interest Rate Volatility and the Term Structure: A Two-Factor General Equilbrium Model." *Journal of Finance*, *47(4)*, 1259–1282.

Lown, Cara S. and Donald P. Morgan. 2006. "The Credit Cycle and the Business Cycle: New Findings Using the Loan Officer Opinion Survey." *Journal of Money, Credit, and Banking*, *38(6)*, 1575–1597.

Oliner, Stephen D., Glenn D. Rudebusch, and Daniel Sichel. 1995. "New and Old Models of Business Investment: A Comparison of Forecasting Performance." *Journal of Money, Credit, and Banking*, *27* (3): 806–826.

Oliner, Stephen D., Glenn D. Rudebusch, and Daniel Sichel. 1996. "The Lucas Critique Revisited: Assessing the Stability of Empirical Euler Equations for Investment." *Journal of Econometrics*, *70(1)*, 291–316.

Schaller, Huntley. 2006. "Estimating the Long-Run User Cost Elasticity." *Journal of Monetary Economics*, *53* (4): 725–736.

Stohs, Mark Hoven and David C. Mauer. 1996. "The Determinants of Corporate Debt Maturity Structure." *The Journal of Business*, *69(3)*, 279–312.

Summers, Lawrence H. 1981. "Taxation and Corporate Investment: A q-Theory Approach." *Brookings Papers on Economic Activity*, *1981(1)*, 67–140.

Tevlin, Stacey and Karl Whelan. 2003. "Explaining the Investment Boom of the 1990s." *Journal of Money, Credit, and Banking*, *35* (1): 1–22.

Titman, Sheridan and Roberto Wessels. 1988. "The Determinants of Capital Structure Choice." *Journal of Finance*, *43* (1): 1–19.

van Ark, Bart and Robert Inklaar. "Catching up or getting stuck? Europe's troubles to exploit ICT's productivity potential." 2006. GGDC Research Memorandum GD-79.

A Further robustness tests

This section describes table 1A, which has extra robustness tests for the regressions of $\bar{D}$ on the term spread and other controls. Column 1 includes up to three lags of the term spread. The second lag enters significantly, and with a coefficient slightly larger than the first lag. This sort of lagged response to price changes is commonly found in the literature. It is generally interpreted as being due to planning and delivery lags. The second column includes every one of the other controls simultaneously, instead of individually as in tables 2 and 3. The result is that the coefficients on the various other controls all become marginally significant at best, while the term spread is still highly significant. There is thus something different about the term spread from all of the other business cycle, volatility, and investment controls. Column 3 is identical to column 2 except it only uses one lag of the term spread, and the coefficient is still significant at the one percent level.

Finally, column 4 includes the current and lagged values of volatility instead of just the leading value. The leading value has a negative sign, indicating that high future volatility lowers duration today (consistent with a model of irreversible investment). The current value has a positive sign. One way to reconcile this is if the volatility variable should actually enter as a first difference: an *increase* in volatility lowers average duration, instead of a high value by itself. The lagged level of volatility is uncorrelated with $\bar{D}_t$.

B Model

From the text, we can write Tobin's Q for asset i as

$$
\begin{aligned}
Q_t &= (r+\delta)\int_{k=0}^{\infty}\exp(-k\delta)\exp\left(\int_{j=0}^{k}\begin{array}{c}-\bar{r}-z_t^r-\exp(-\phi_r j)\,x_t^r+\frac{\bar{\delta}+\bar{r}}{(\phi_r+\bar{\delta}+\bar{r})}x_t^r \\ +z_t^b+\exp(-\phi_b j)\,x_t^b-\frac{\bar{\delta}+\bar{r}}{(\phi_r+\bar{\delta}+\bar{r})}x_t^b\end{array} dj\right)dk \\
&= (r+\delta)\int_{k=0}^{\infty}\exp(-k\delta)\exp\left(\begin{array}{c}-k\bar{r}-kz_t^r+\phi_r^{-1}(\exp(-\phi_r k)-1)\,x_t^r+\frac{\bar{\delta}+\bar{r}}{(\phi_r+\bar{\delta}+\bar{r})}kx_t^r \\ +kz_t^b-\phi_b^{-1}(\exp(-\phi_b k)-1)\,x_t^b-\frac{\bar{\delta}+\bar{r}}{(\phi_r+\bar{\delta}+\bar{r})}kx_t^b\end{array}\right)dk
\end{aligned}
$$

Noting that

$$I_{i,t} = \eta_1 Q_t^\gamma$$

we have

$$\frac{\sum_i D_i I_i}{\sum_i I_i} = \frac{\sum_i D_i \eta_1 \left((\bar{r}+\delta_i) \int_{k=0}^{\infty} \exp\left(-k\left(\delta_i+\bar{r}\right)\right) \exp\left(\begin{array}{c} b_{it} - kz_t^r + \phi_r^{-1}\left(\exp\left(-\phi_r k\right)-1\right) x_t^r + \frac{\bar{\delta}+\bar{r}}{\left(\phi_r+\bar{\delta}+\bar{r}\right)} k x_t^r \\ +kz_t^b - \phi_b^{-1}\left(\exp\left(-\phi_b k\right)-1\right) x_t^b - \frac{\bar{\delta}+\bar{r}}{\left(\phi_r+\bar{\delta}+\bar{r}\right)} k x_t^b \end{array} \right) \right)}{\sum_i \eta_1 \left((\bar{r}+\delta_i) \int_{k=0}^{\infty} \exp\left(-k\left(\delta_i+\bar{r}\right)\right) \exp\left(\begin{array}{c} b_{it} - kz_t^r + \phi_r^{-1}\left(\exp\left(-\phi_r k\right)-1\right) x_t^r + \frac{\bar{\delta}+\bar{r}}{\left(\phi_r+\bar{\delta}+\bar{r}\right)} k x_t^r \\ +kz_t^b - \phi_b^{-1}\left(\exp\left(-\phi_b k\right)-1\right) x_t^b - \frac{\bar{\delta}+\bar{r}}{\left(\phi_r+\bar{\delta}+\bar{r}\right)} k x_t^b \end{array} \right) \right)}$$

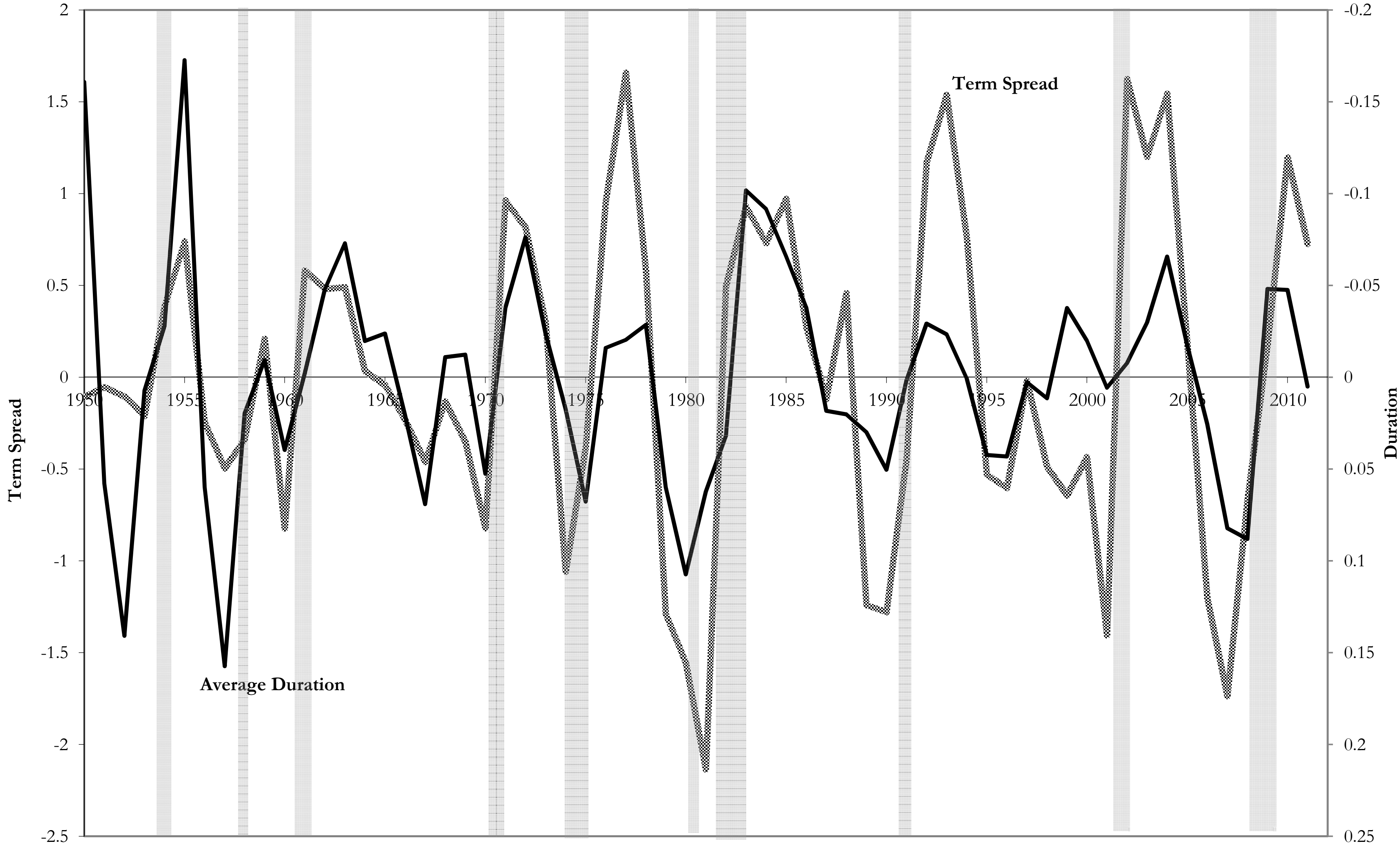
Taking a first-order approximation with respect to $\left\{z_t^r, x_t^r, z_t^b, x_t^b\right\}$ around the point $\{0,0,0,0\}$, yields

$$\frac{\sum_i D_i I_i}{\sum_i I_i} \approx \sum_i D_i \gamma \left\{ \begin{array}{c} \left[\phi_r^{-1}\left(\delta_i+\bar{r}+\phi_r\right)^{-1} D_i^{-1} - \phi_r^{-1} + \frac{\bar{\delta}+\bar{r}}{\left(\phi_r+\bar{\delta}+\bar{r}\right)} D_i\right] x_t^r \\ -\left[\phi_b^{-1}\left(\delta_i+\bar{r}+\phi_b\right)^{-1}\left(r+\delta\right) - \phi_b^{-1} + \frac{\bar{\delta}+\bar{r}}{\left(\phi_b+\bar{\delta}+\bar{r}\right)} \frac{1}{\left(\delta+\bar{r}\right)}\right] x_t^b \\ -D_i z_t^r + D_i z_t^b + b_i \end{array} \right\}$$

to make this more easily interpretable, I take a linear approximation to the term in brackets around the point $D_i = \bar{D}$, where $\bar{D} = \left(\bar{\delta}+\bar{r}\right)^{-1}$, yielding

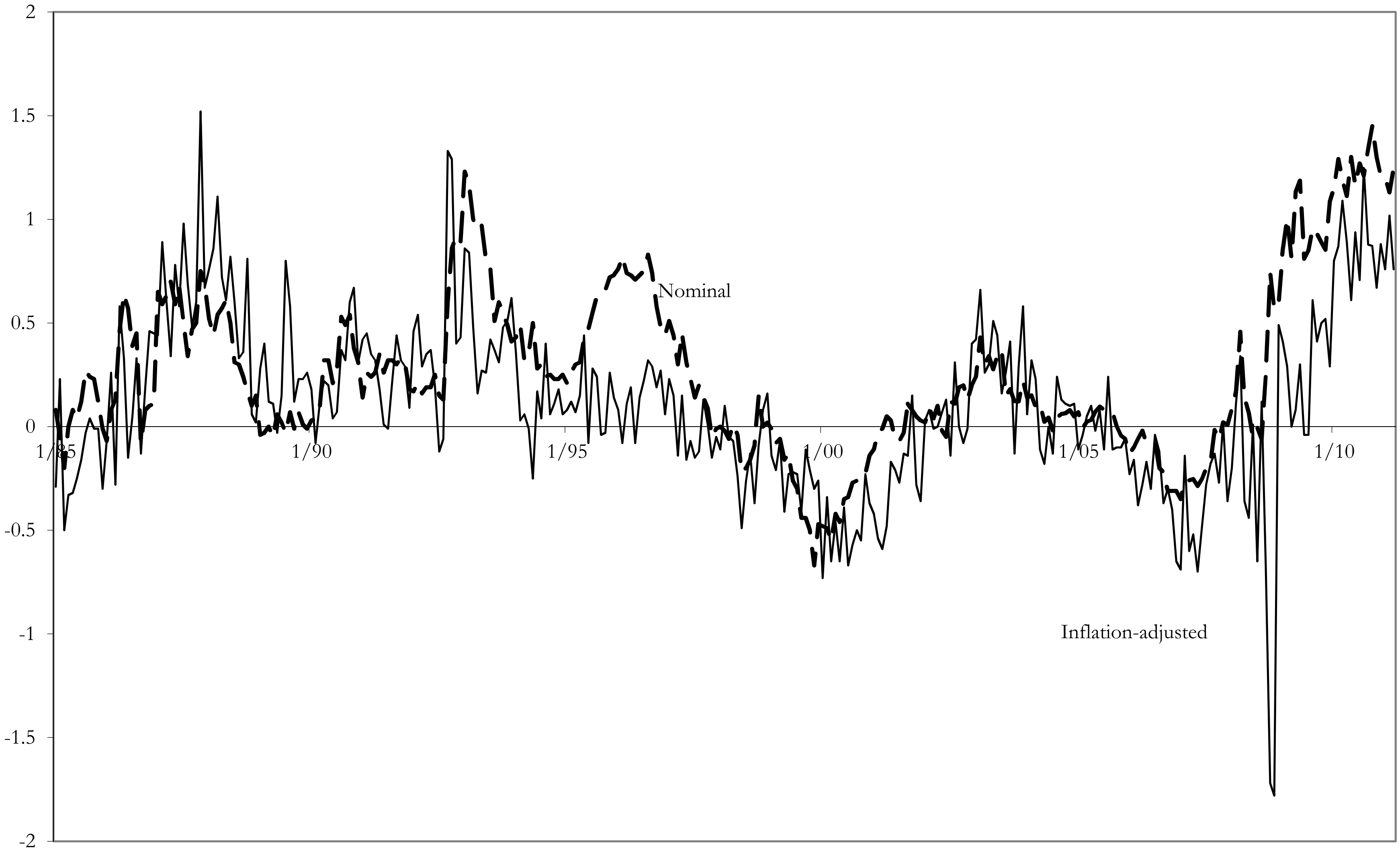
$$\begin{aligned} \frac{\sum_i D_i I_i}{\sum_i I_i} &\approx \sum_i D_i \gamma \left\{ \begin{array}{c} \frac{\phi_r \bar{D}}{\left(\phi_r \bar{D}+1\right)^2}\left(D_i - \bar{D}\right) x_t^r - \frac{\phi_b \bar{D}}{\left(\phi_b \bar{D}+1\right)^2} x_t^b \\ -D_i z_t^r + D_i z_t^b + b_{it} \end{array} \right\} \\ &= \gamma \left[\begin{array}{c} \frac{\phi_r \bar{D}}{\left(\phi_r \bar{D}+1\right)^2} var\left(D_i\right) x_t^r - \frac{\phi_b \bar{D}}{\left(\phi_b \bar{D}+1\right)^2} var\left(D_i\right) x_t^b \\ -\sum_i D_i^2\left(z_t^r - z_t^b\right) + \sum_i D_i b_{it} \end{array} \right] \end{aligned}$$

Figure 1. The average duration of investment versus the term spread



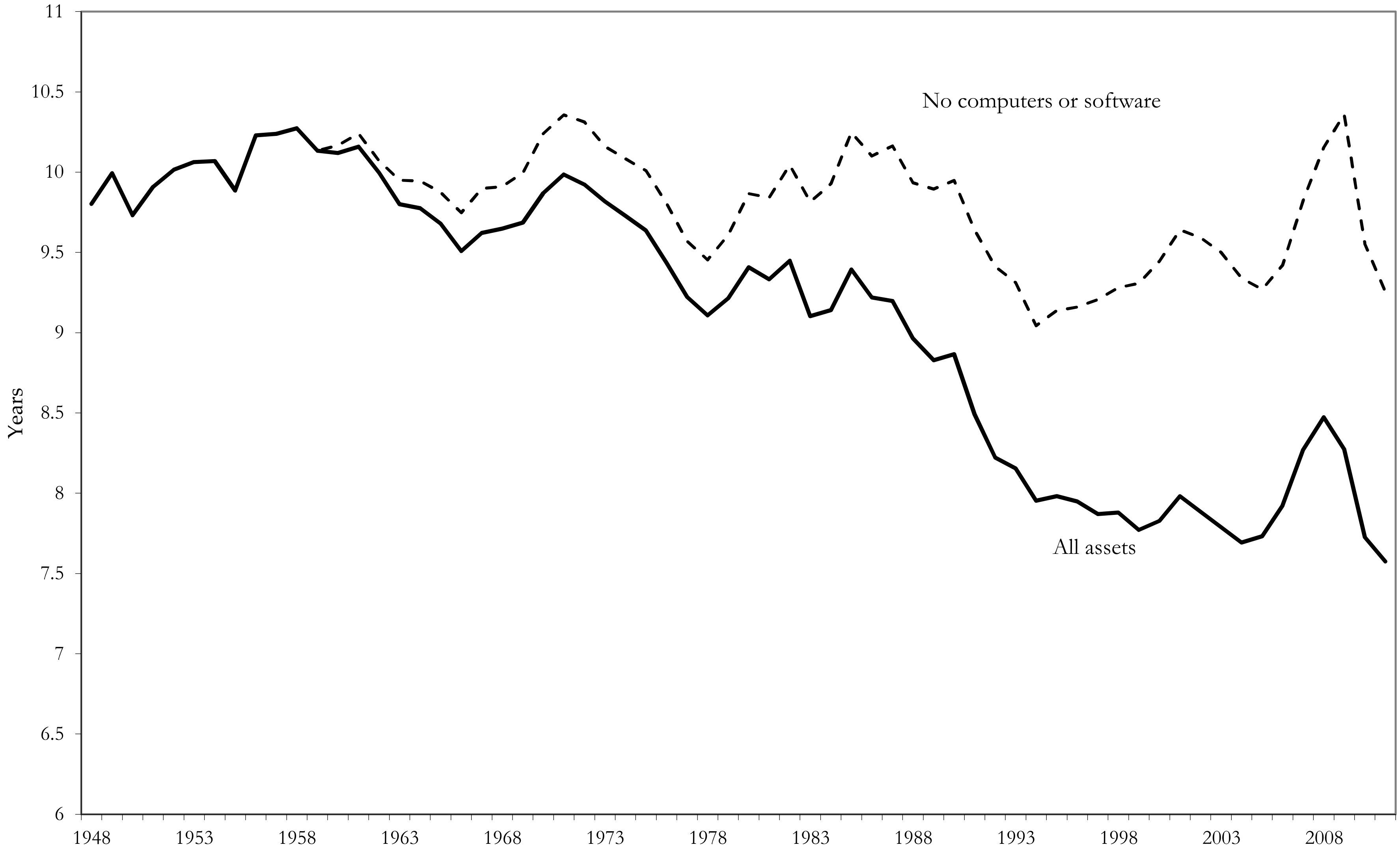
Note: The term spread is the gap between the 10 and 1-year treasury yields at the beginning of the year. Both variables are HP-detrended. The axis for average duration is reversed. Grey bars indicate NBER-dated recessions.

Figure 2. United Kingdom 10/5 year term spreads, 1985–2011



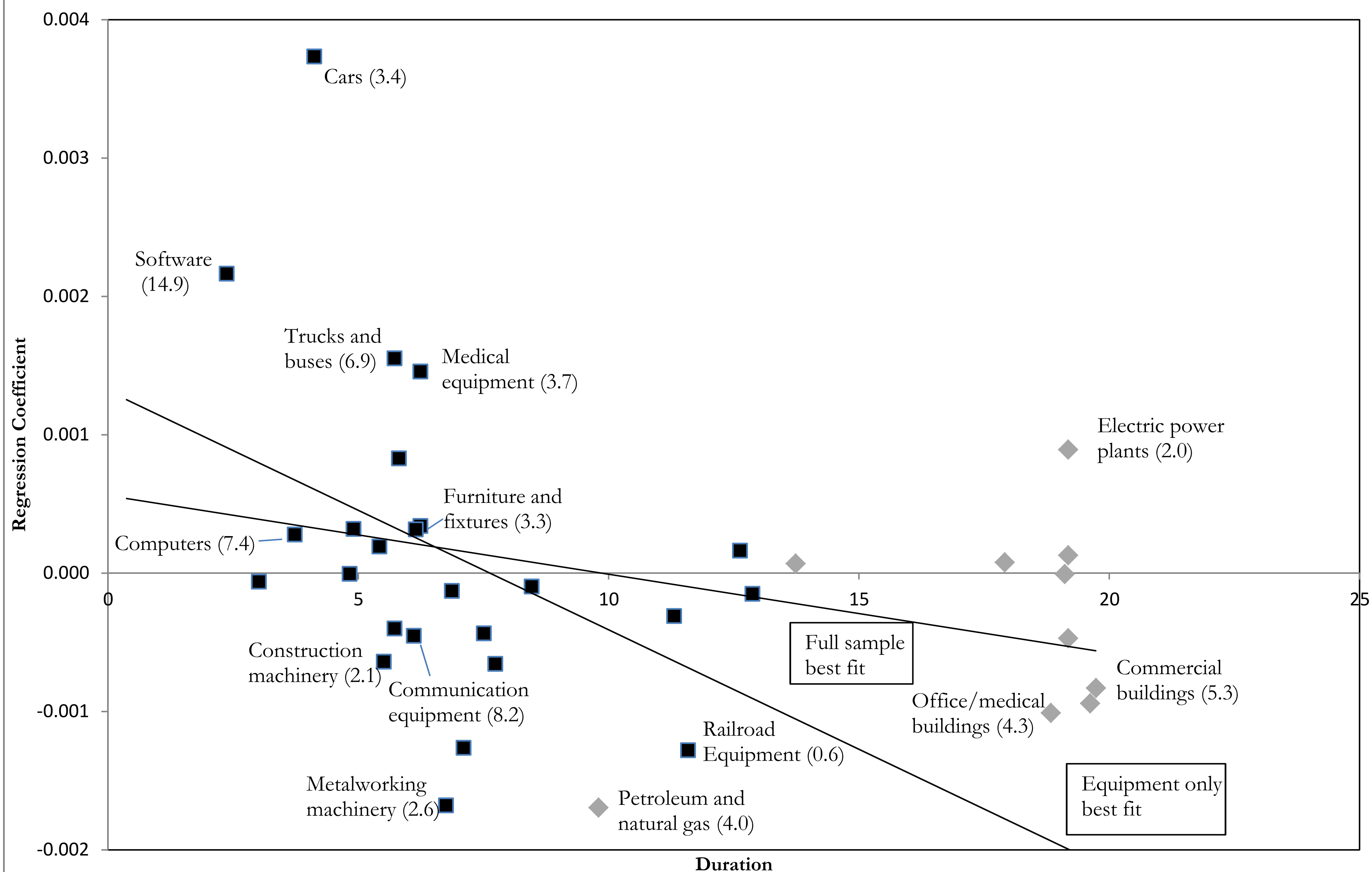
Note: gap between yields on 10 and 5-year nominal and inflation-protected bonds

Figure 3. Average Duration of Investment, 1948–2011



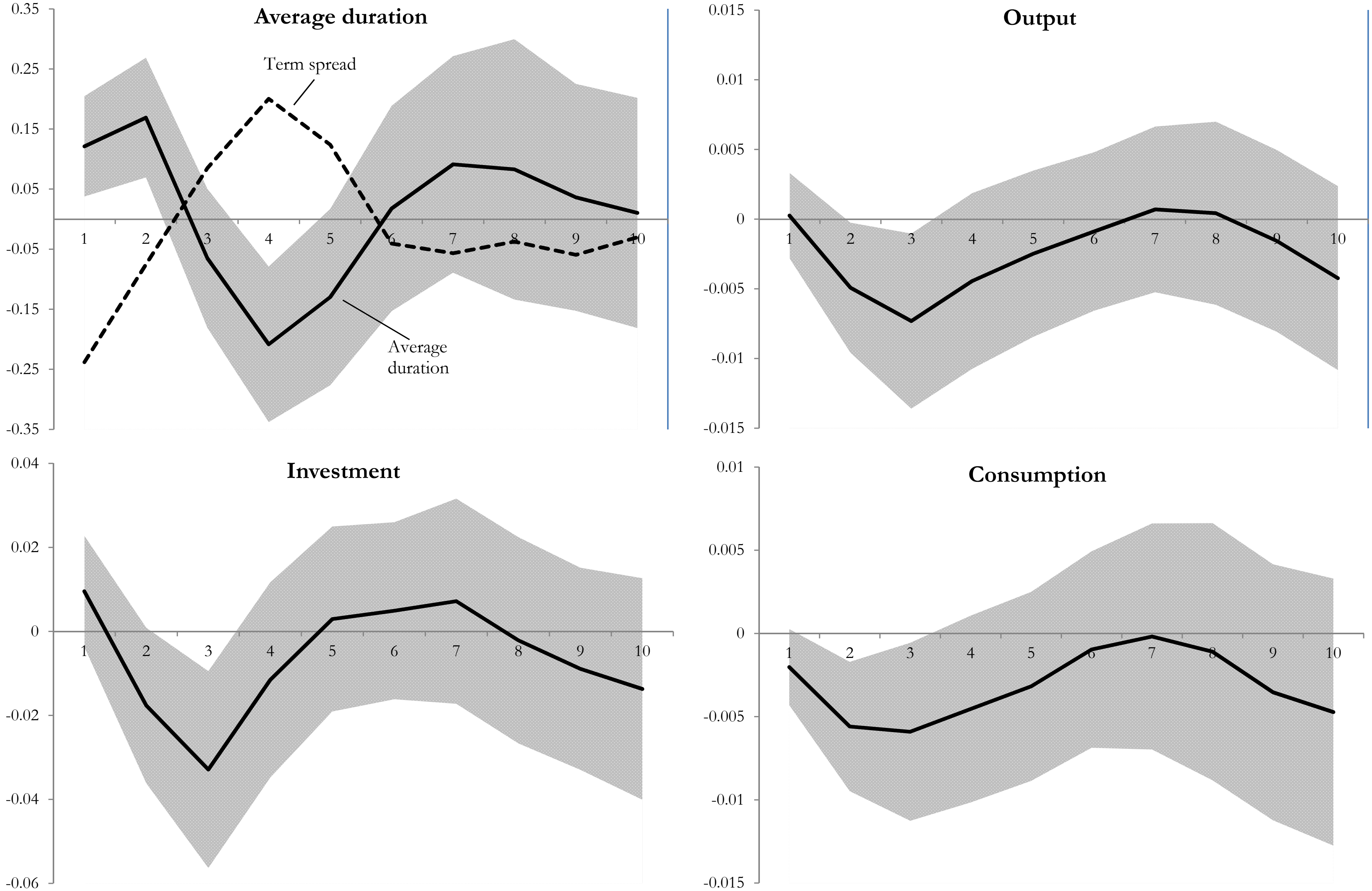
Note: average duration is duration summed across all assets, weighted by nominal investment shares. Investment is obtained from the BEA fixed asset tables.

Figure 4. Coefficients from regressions of investment shares on the term spread



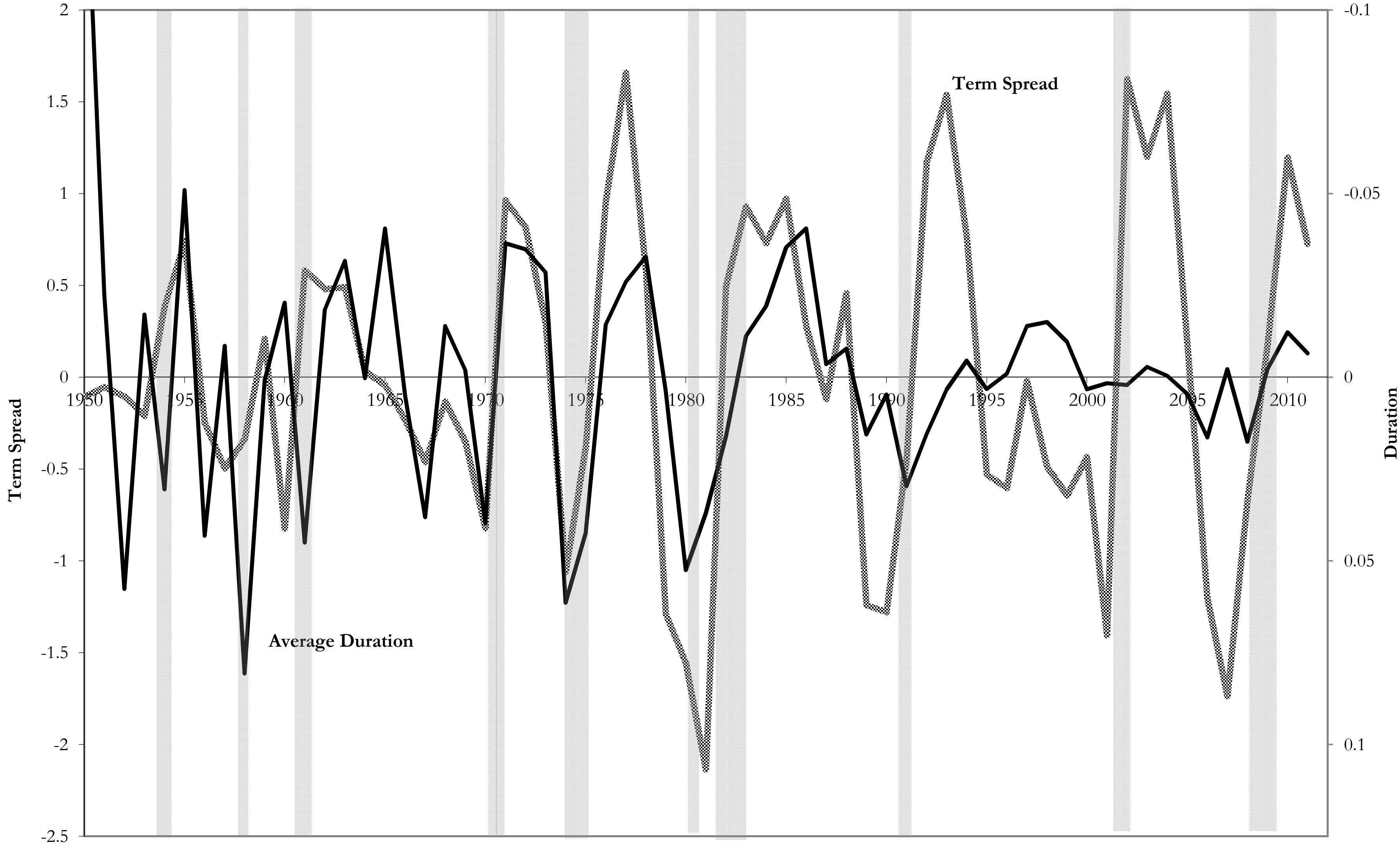
Note: Coefficients from regressions of each asset's share of aggregate investment on the term spread. Both variables are detrended with the HP filter with a smoothing parameter of 25. Numbers in parentheses are investment shares over 1993–2011

Figure 5. Responses to an orthogonalized Fed Funds rate shock



Notes: Reponses to a unit-standard-deviation innovation to the Fed Funds rate. Average duration is detrended and normalized to have unit standard deviation. Output, consumption, and investment are reported in logs. Gray regions indicate 9-percent confidence regions.

Figure 6. Average duration of consumer durable purchases versus the lagged term spread



Note: Average duration of consumer durables is defined analogously to that for durable equipment. Both variables are HP-detrended. The axis for average duration is reversed. Grey bars indicate NBER-dated recessions.

Table 1. Assets, depreciation rates, and durations

Depreciation rate (percent)	Duration (years)	Asset
		Information processing equipment and software
0.25	3.73	Computers and peripheral equipment
0.40	2.37	Software
0.14	6.11	Communication equipment
0.14	6.24	Medical equipment and instruments
0.14	6.24	Nonmedical instruments
0.18	4.90	Photocopy and related equipment
0.31	3.01	Office and accounting equipment
		Industrial equipment
0.09	8.46	Fabricated metal products
0.05	12.62	Engines and turbines
0.12	6.75	Metalworking machinery
0.10	7.74	Special industry machinery, n.e.c.
0.11	7.51	General industrial, including materials handling, equipment
0.05	12.88	Electrical transmission, distribution, and industrial apparatus
		Transportation equipment
0.15	5.72	Trucks, buses, and truck trailers
0.22	4.12	Autos
0.12	7.10	Aircraft
0.06	11.31	Ships and boats
0.06	11.59	Railroad equipment
		Other equipment
0.14	6.15	Furniture and fixtures
0.12	6.87	Agricultural machinery
0.16	5.51	Construction machinery
0.15	5.72	Mining and oilfield machinery
0.16	5.42	Service industry machinery
0.18	4.83	Electrical equipment, n.e.c.
0.15	5.81	Other nonresidential equipment
		Structures
0.02	18.83	Office, including medical buildings
0.02	19.73	Commercial
0.03	16.89	Manufacturing
0.02	19.18	Electric
0.02	19.18	Other power
0.02	19.18	Communication
0.08	9.80	Petroleum and natural gas
0.05	13.73	Mining
0.02	19.62	Other buildings
0.03	17.91	Railroads
0.02	19.11	Farm

Note: Depreciation rates are otained from the BEA. Duration is measured as $1.03/(0.03+\delta)$.

Table 2. Regressions of the average duration of investment

						First differences		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Assets:	Equip.	Equip.	Equip.	Equip.	All	Equip.	Within	Between
Term spread(t-1)	-0.58 ***		-0.53 ***	-0.56 ***	-0.37 ***	-0.39 ***	-0.22 ***	-0.17 ***
	[0.10]		[0.10]	[0.11]	[0.12]	[0.11]	[0.08]	[0.06]
Corporate TS(t-1)		-0.55 ***						
		[0.08]						
Duration(t-1)			0.19 **					
			[0.08]					
Term spread (t)				-0.04				
				[0.08]				
Term Spread(t+1)				0.08				
				[0.08]				
N	62	62	62	61	62	62	62	62
R2	0.33	0.31	0.37	0.34	0.13	0.21	0.17	0.19

Note: * indicates significance at the 10 percent level, ** 5 percent level, *** 1 percent level. Annual data, 1950–2008, where available. The dependent variable is the average duration of investment. Investment and depreciation rates are obtained from BEA. The term spread is the 10-year minus the 1-year treasury yield at the end of the calendar year. The corporate term spread is the spread between the Moody's AAA corporate 30 year index and the St. Louis Fed's 3 month commercial paper yield. Columns 7 through 9 give results from first differenced regressions. Column 8 uses the effect of within-industry reallocation on average duration as the dependent variable. Column 9 is defined analogously using cross-industry reallocation. All variables are detrended with the HP filter with a smoothing parameter of 25 and standardized to have unit variance. Newey-West standard errors with a 3-year window are reported in brackets.

Table 3. Robustness tests

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Term Spread(t-1)	-0.29 **	-0.35 ***	-0.64 ***	-0.44 ***	-0.39 ***	-0.50 ***	-0.61 ***
	[0.12]	[0.10]	[0.10]	[0.10]	[0.08]	[0.08]	[0.09]
Unemployment(t-1)	-0.43 ***			0.07			
	[0.14]			[0.21]			
GDP(t-1)		0.37 ***		0.44 **	0.39 ***		
		[0.09]		[0.18]	[0.11]		
Investment(t)			-0.14 **	-0.20 *			
			[0.11]	[0.12]			
SD_profits(t+1)					-0.01		
					[0.09]		
SD_returns(t+1)					-0.29 ***		
					[0.07]		
Bank tightness(t)						-0.05	
						[0.10]	
Value spread(t)							-0.21 ***
							[0.09]
N	62	62	62	62	44	39	62
R2	0.44	0.47	0.35	0.50	0.65	0.52	0.37

Note: See table 2. The dependent variable is the detrended average duration of equipment investment. The value spread is the gap between log book/market (B/M) for the top and bottom 30 percent of firms ranked by B/M, among the smaller 50 percent of firms, measured at the beginning of the year. SD_profits and SD_returns are the cross-sectional standard deviations of quarterly firm profit growth and stock returns, controlling for a time trend and 3-digit industry dummies. The unemployment rate is the national rate obtained from the BLS. GDP is real GDP from the BEA. Bank tighness is the Fed's Survey of Senior Loan Officers index (from Morgan and Lown, 2006). Investment is aggregate real nonresidential equipment investment. All variables are detrended with the HP filter with a smoothing parameter of 25 (except for the value spread, for which it is 100), and standardized to have unit variance.

Table 4. Consumer durables, depreciation rates, and durations

Depreciation rate (percent)	Duration (years)	Asset
		Motor vehicles and parts
0.28	3.27	Autos
0.25	3.70	Light trucks
0.90	1.11	Motor vechicle parts & accessories
		Furnishings and household equipment
0.13	6.63	Furniture
0.18	4.90	Clocks, lamps, lighting fix & other
0.18	4.91	Carpets and other floor coverings
0.18	4.89	Window coverings
0.16	5.37	Household appliances
0.18	4.90	Glassware, tableware, & household uten
0.18	4.90	Tools & equipment for house & garden
		Recreational goods and Vehicles
0.20	4.45	Video & audio equipment
0.18	4.92	Photographic equipment
0.44	2.21	Personal computers and peripheral equip
0.76	1.31	Computer software & accessories
0.18	4.91	Calcs, typewrtrs, & oth info proc equip
0.18	4.91	Sporting equip, supplies, guns, & ammo
0.18	4.91	Motorcycles
0.18	4.92	Bicycles & accessories
0.18	4.90	Pleasure boats
0.18	4.91	Pleasure aircraft
0.26	3.52	Other recreational vehicles
0.18	4.91	Recreational books
0.20	4.46	Musical instruments
		Other durable goods
0.16	5.36	Jewelry & watches
0.32	2.95	Therapeutic appliances & equip
0.18	4.91	Educational books
0.13	6.63	Luggage & similar personal items
0.18	4.88	Telephone & facsimile equipment

Note: Depreciation rates are otained from the BEA. Duration is measured as $1.03/(0.03+\delta)$.

Table 5. Regressions of the long-term corporate level and issues shares

	(1)		(2)	(3)		(4)
	Levels		Levels	Issues		Issues
Duration	0.013	***	-0.008	0.021	**	-0.008
	[0.005]		[0.006]	[0.11]		[0.012]
Fixed Effects?	No		Yes	No		Yes
N	1,040		1,040	1,023		1,023

Note: The long term level share is the share of total corporate debt accounted for by long term (>1 year maturity) debt. The issues share is the share of issues accounted for by long term debt. Duration is the average duration rate of the industry's capital stock. All regressions include year dummies. Standard errors reported in brackets are corrected for clustering within industries. Annual data for 22 industries, 1950–2008.

Table 1A. Further robustness tests

	(1)		(2)		(3)		(4)	
Term Spread(t-1)	-0.24	**	-0.38	***	-0.41	***	-0.55	***
	[0.09]		[0.07]		[0.09]		[0.07]	
Term Spread(t-2)	-0.24	***	-0.28	***				
	[0.08]		[0.07]					
Term Spread(t-3)	0.12		0.13	*				
	[0.09]		[0.08]					
Unemployment(t-1)			0.21		-0.06			
			[0.29]		[0.28]			
GDP(t)			-0.05		0.01			
			[0.12]		[0.14]			
GDP(t-1)	0.35	***	0.55	**	0.32			
	[0.10]		[0.25]		[0.24]			
Investment(t)			-0.07		-0.20			
			[0.18]		[0.17]			
Investment(t-1)			-0.10		0.04			
			[0.22]		[0.24]			
SD_returns(t+1)			-0.23	**	-0.19	**	-0.25	***
			[0.10]		[0.09]		[0.08]	
SD_returns(t)							0.16	**
							[0.07]	
SD_returns(t-1)							-0.10	*
							[0.05]	
N	62		47		47		45	
R2	0.50		0.73		0.68		0.55	

Note: See tables 2 and 3.