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Forecasting U.S. Investment

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Abstract

The driving force of U.S. economic growth is expected to rotate from the fiscal stimulus and inventory rebuilding in 2009 to private demand in 2010, with consumption and particularly investment expected to be important contributors to growth. The strength of U.S. investment will hence be a crucial issue for the U.S. and global recovery. On the basis of several traditional models of investment, we forecast that the U.S. investment in equipment and software will grow by about 10 percent on average over the 2010–12 period. The contribution of investment to real GDP growth will be 0.8 percentage points on average over the same period.

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I. INTRODUCTION

This paper is part of a larger project that looks into main components of the U.S. private demand, which is a crucial element of the global economic recovery after the "Great Recession." In Lee et al. (2010) we analyzed U.S. household consumption, and concluded that the U.S. household consumption rate would remain lower than before the recession. Here, we develop a forecast of real investment in equipment and software, which is the primary component of non-residential business fixed investment.

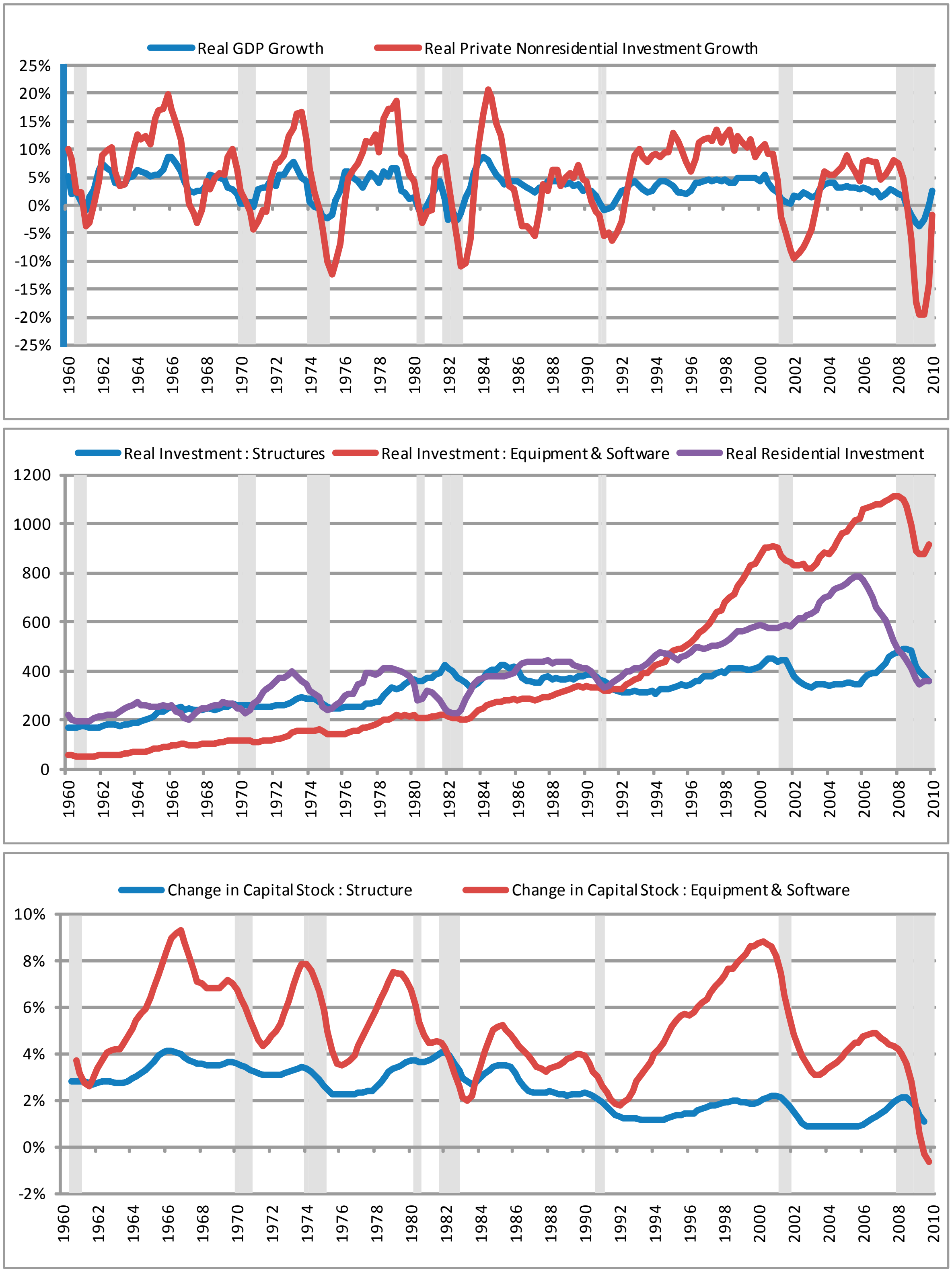
Non-residential business fixed investment is a highly volatile and procyclical series, and often declines sharply during recessions (Figure 1, top panel). In the ongoing Great Recession, the decline in investment has been particularly sharp—the year-on-year growth rate of investment fell to minus 20 percent in 2009, the largest decline in investment growth in all recessions since the 1960s. The question that we try to answer is: can we expect the investment rate to rebound similarly strongly?

In particular, we focus on investment in equipment and software (E&S hereafter), which has been the most important component of investment from a quantitative viewpoint since the mid-1990s (Figure 1, mid-panel)—its relative importance has far exceeded that of investment in non-residential structures or of residential investment. Moreover, the collapse of E&S investment during the Great Recession led the E&S capital stock to decline for the very first time since the 1950s, while the capital stock in non-residential structures kept growing, albeit at a slower rate than usual (Figure 1, bottom panel). Thus in quantitative terms, the movement in E&S investment will likely determine whether business fixed investment stages a strong rebound. Also from an econometric viewpoint, modeling E&S investment has enjoyed some success, whereas investment in non-residential structures does not necessarily respond to the business cycle and has been more difficult to model.

Our eventual forecast is an investment rebound of moderate strength, though subject to considerable uncertainty reflecting the well-known difficulty of modeling investment. On the basis of several traditional models of investment, we forecast that E&S investment will grow by about 10 percent on average over the 2010–12 period, before settling to the long-run average growth rate of about 4 percent thereafter. As a result, under most models that we consider, the contribution of investment to GDP growth is 0.8 percentage points on average over 2010–12, and the capital-to-output ratio will recover to the end-2008 level by the end of 2013.

The rest of this paper is organized as follows. Section II provides a verbal discussion of estimation results of various models of investment, Section III presents forecasts based on various models of investment, Section IV compares and summarizes forecast results, and Section V concludes.

Figure 1. Real GDP, Investment and Capital Stock



Source: Bureau of Economic Analysis and authors' calculations

II. Modeling Investment

The basis for our forecast is time series models of investment. We study the empirical performance of several traditional single-equation models (e.g. Oliner, Rudebusch, and Sichel, 1995 for a review). We present a verbal summary of the main results of these models in Table 1, while presenting the full regression results in the appendix.[2]

The first model is the accelerator model, which relates real investment to current and past changes in real output (Clark, 1917; and Jorgenson, 1971). The changes in output are viewed to be the primary determinant of the changes in the desired capital stock, which in turn determine the level of investment. The accelerator model has been a highly successful empirical relationship, though ignoring direct effects of price variables on investment. We find that up to 10 lags of changes in real GDP are statistically significant.

The second model is Tobin's Q model, which relates real investment-to-capital ratio to the ratio of firm value to the replacement cost of existing capital stock (namely average Q)—see Tobin (1969) and Hayashi (1982). Its conceptual genesis is often attributed to the idea of Keynes (1936) that an additional unit of capital (thus investment) is warranted, if the additional unit of capital would raise the value of the firm more than the cost of installing it. In our implementation, we use the average Q that is constructed as the ratio of the market value of equities and credit liabilities with respect to the value of tangible assets. We use data from the flow-of-funds for the non-financial corporate business sector.

We also considered a version of Tobin's Q adjusted for taxes, as in Summers (1981).[3] However, we find that the unadjusted Q performs better than the adjusted Q in terms of the explanatory power (R-squared). We also include the ratio of cash flow over nominal GDP and found it to improve the fit. The role of cash flows has been justified by the view that firms can use retained profits to finance new investment projects without having to borrow funds from credit markets. Despite ongoing debate on the economics of this correlation (e.g. Gomes 2001), we confirm empirically that a more plentiful cash position tends to be associated with stronger investment.

The third model is the neoclassical model, in which the user cost of capital plays an important role in determining the desired capital stock to output ratio, and thus investment (Jorgenson 1971). Considering that the relationship between the desired capital stock and the user cost is a

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[2] To take advantage of the longest possible time series in estimating the models, we start with the sample from 1955:Q1 through 2010:Q1. However, given the well-recognized possibility of a structural change in the United States around 1984 during the period known as the Great Moderation (Galí and Gambetti, 2009)[2], we test for parameter stability using a Chow test for structural break in 1984. When we find evidence of structural breaks, we use the post-break sample.

[3] In this latter case, we include tax adjustments based on the corporate tax rate, investment tax credits, and the present value of depreciation allowances. We are thankful to FRB staff, especially John Roberts, for providing us with the relevant series to construct the tax-adjusted Tobin's Q.

long-run relation, we estimate the relationship by cointegration methods, following the approach in Caballero (1994). In this case, we find a significant long-run relationship between the two variables, which improve when we include tax adjustments. When we estimate the model using a Vector Error Correction Model (VECM) with the user cost of capital and the E&S capital-output ratio, we find that the elasticity is one, consistent with theory. Although a structural break is found in 1984, we cannot reject unit elasticity either for the full sample or for the shorter post-1984 sample.

We have also looked into several auxiliary variables and relationships based on recent papers that focus on bond market variables, and comment on the results in the row labeled “Bond market”. We confirm the role of bond spreads, in particular in accounting for changes in investment, broadly consistent with several recent papers including Philippon (2009). We find that the uncertainty variable constructed by Nick Bloom has a negative correlation with investment. This is a comprehensive measure of aggregate uncertainty that combines information about the stock market, the labor market, and firm-level and industry-level returns, growth and sales dispersion rates.[4] A measure of leverage, constructed as the ratio of debt to equity for nonfinancial corporate businesses, is found to affect investment negatively.

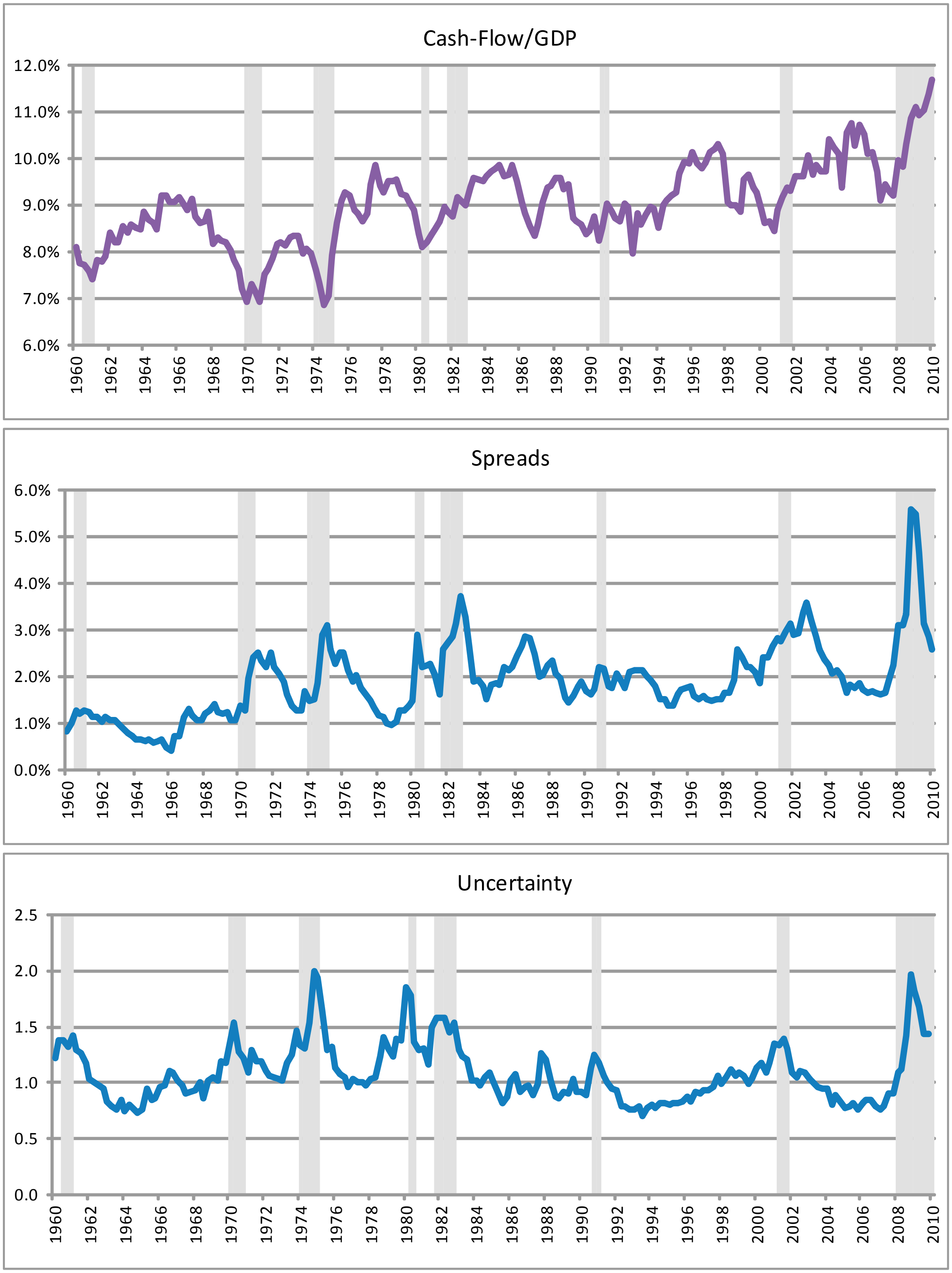
Based on the results of this section, we incorporate the effects of the following variables in our forecasting exercise: Tobin’s Q, the uncertainty index, the ratio of cash flow over nominal GDP, the spread between Baa Corporate bonds and the 10-year Treasury bill, and leverage ratio (debt/equity ratio). We plot these variables in Figures 2 and 3 to show how they behave during the cycle. We observe in the Great Recession that the qualitative behavior of all these variables has been same as in usual recessions, but that the size of change has been much larger this time around. The ratio of cash-flow over GDP increased during the last four recessions, but the increase was particularly striking during the Great Recession. The spread between the Baa corporate bonds and the 10-year bill also increased during recessions, and this increase was particularly important during the Great Recession, exceeding 500 basis points. The same pattern is observed for Nick Bloom’s uncertainty measure, which spikes during recessions and declines during expansions. It is worth noting that Tobin’s Q dips at the onset of recessions but increases in the mid-recessions. As the end of the recession nears, stock markets recover and with them, Tobin’s Q recovers too. Finally, it is more difficult to find a clear pattern in the behavior of the debt/equity ratio (leverage). During recessions, this ratio first increases and then drops, but this behavior seems to be driven by the collapse and subsequent recovery of asset prices. In different recessions this ratio has behaved differently, having been much higher in the 1980s, declined through the 1990s, and then increased again during the 2000s.

[4] See Bloom (2009) and Bloom, Floetotto and Jaimovich (2009).

Table 1. Models of Investment

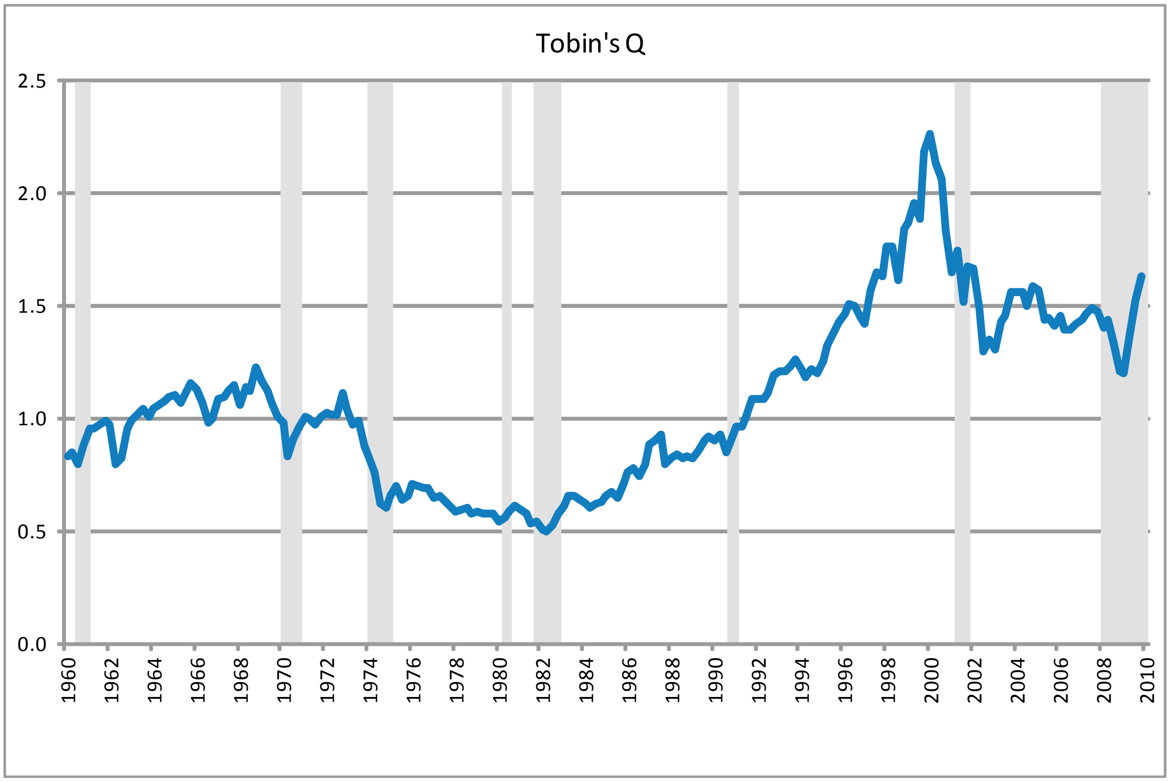
Name	Dependent Variable	Independent Variables	Comments	Sample period
Accelerator	Real E&S investment	One period lagged capital stock, Lagged changes in Real GDP	All variables (up to 10 lags of Real GDP changes) significant	1984:Q1-2010:Q1
Tobin's Q	Real E&S investment to capital stock ratio	Ratio of firm value to the replacement cost of existing capital stock, and ratio of cash flow over GDP	All variables significant. Q measure adjusted for taxes delivers lower R-squared	1984:Q1-2010:Q1
User cost of capital	Real E&S capital to output ratio	User cost of capital	Elasticity of 1 estimated within a VECM model. Tax-adjusted measures perform better.	1984:Q1-2010:Q1
Bond market	Real E&S investment to capital stock ratio	Spread between Baa corporate bonds and 10 year Treasuries, measures of uncertainty, cash flow over GDP, leverage ratio.	All variables except spreads significant and with the right sign. Spreads become significant when regression is performed in y-o-y differences	1960:Q1-2010:Q1

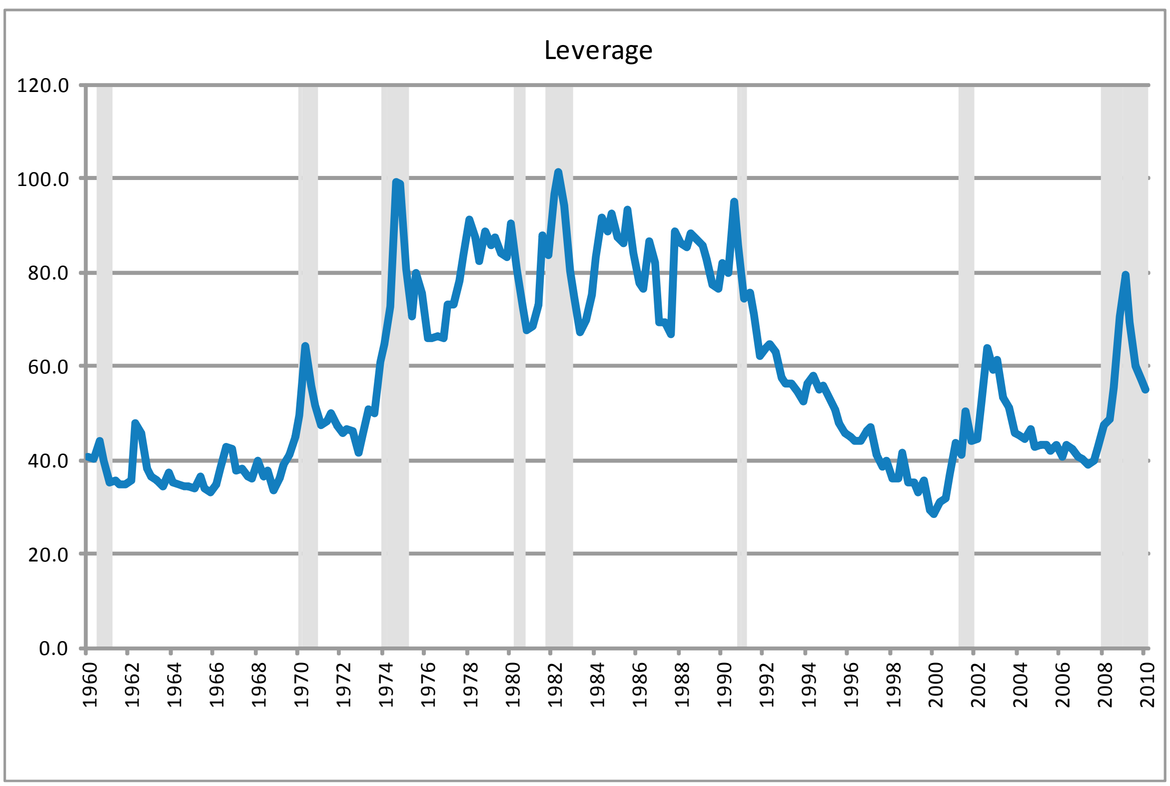
Figure 2. Evolution of Determinants of Investment



Source: Haver Analytics, BEA, Flow of Funds and Bloom (2009).

Figure 3. Evolution of Determinants of Investment





Source: Haver Analytics, BEA, Flow of Funds and Bloom (2009)

III. FORECASTS

In the first subsection, we present the forecasts associated with the single-equation accelerator and Tobin's Q models, and VECM model based on the user cost of capital.[5] These models require forecasts of the explanatory variables, and we run two separate VARs to generate them.

- In the first VAR, we include the investment-output ratio and real GDP growth. We obtain a forecast for real GDP growth which we feed into the accelerator model, and also a forecast for real E&S investment which we later compare with other forecasts. We call this bivariate VAR the "small VAR."
- In the second VAR, we expand the small VAR with Tobin's Q, the ratio of cash flow over GDP, Nick Bloom's uncertainty measure, the spread between Baa bonds and 10-year treasuries, and the leverage ratio (ratio of debt/equity). We call this second VAR "the large VAR."

While we discuss the VAR results and investment forecasts in Section III.B., here in Table 2 we show the implied annual forecasts for real GDP growth from VAR models and WEO (World Economic Outlook October 2010) for background information.

Table 2. Annual GDP Growth
(in percent)

	WEO	VAR	
		Small	Large
2010	2.6	3.6	4.5
2011	2.3	2.8	4.8
2012	3.0	2.4	2.3
2013	2.9	2.2	1.6
2014	2.8	2.2	2.0
2015	2.6	2.2	2.3

We discuss the forecasts for the next several years, for all models forecast that the growth rate of investment return to their long-run values. Although the long-run growth rates differ somewhat with specifics of econometric models, they are usually in the range of 4–5 percent per year.

[5] We do not present the forecasts coming from the bond market model as they were very similar to the ones coming from Tobin's Q.

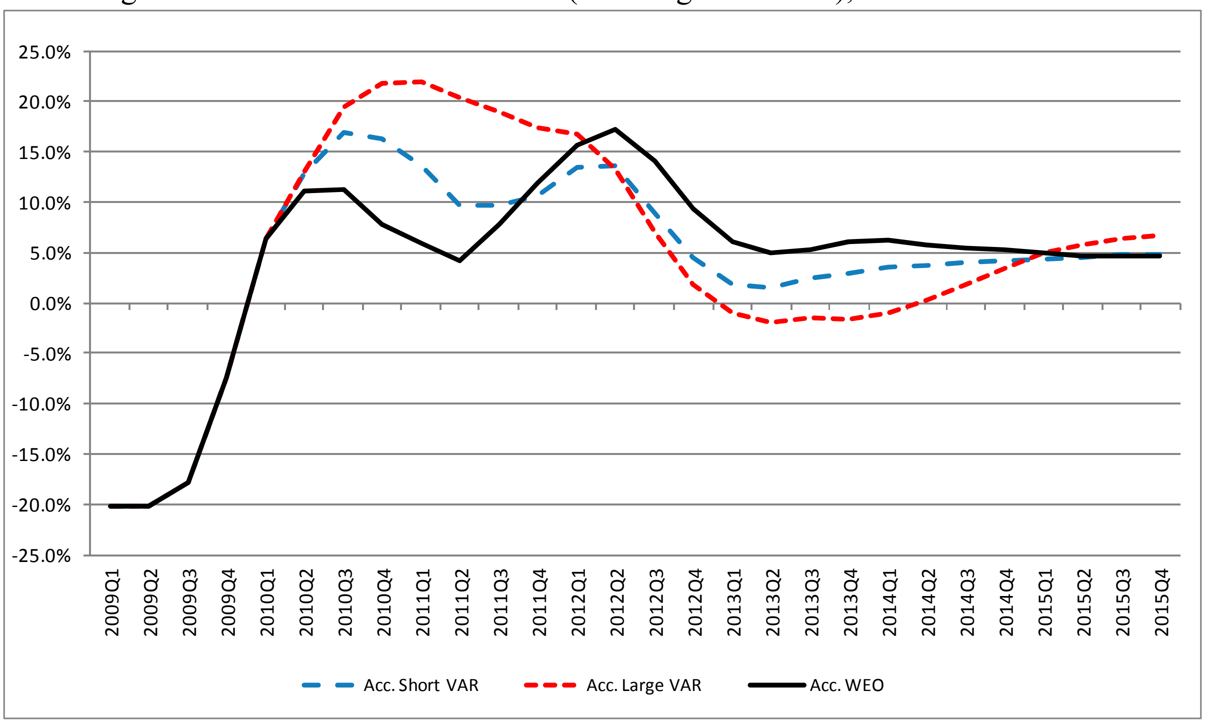
A. From Traditional Investment Models

Accelerator Model

The accelerator model requires forecasts for the level of real GDP, and we feed the model with three different real GDP forecasts: two quarterly VAR forecasts from the large and small VARs, and the quarterly WEO forecast. Figure 4 displays the three resulting forecasts for E&S investment.

Since the large VAR forecasts the highest real GDP growth, the investment rate implied by the accelerator model using these forecasts is highest, and turns negative for some quarters in 2013 before returning to a long-run growth rate (Figure 4). The accelerator-model forecasts based on the small VAR projections come next, and still imply double-digit growth rates of investment through mid-2012. The projections based on the WEO for real GDP are somewhat less optimistic for 2010 and 2011, which reflects lower real GDP growth projections. Due to the long lags embedded in the accelerator model, investment reaches double-digit growth rates in 2010 and again in 2012.

Figure 4. E&S Investment Forecasts (Y-O-Y growth rates), Accelerator Model

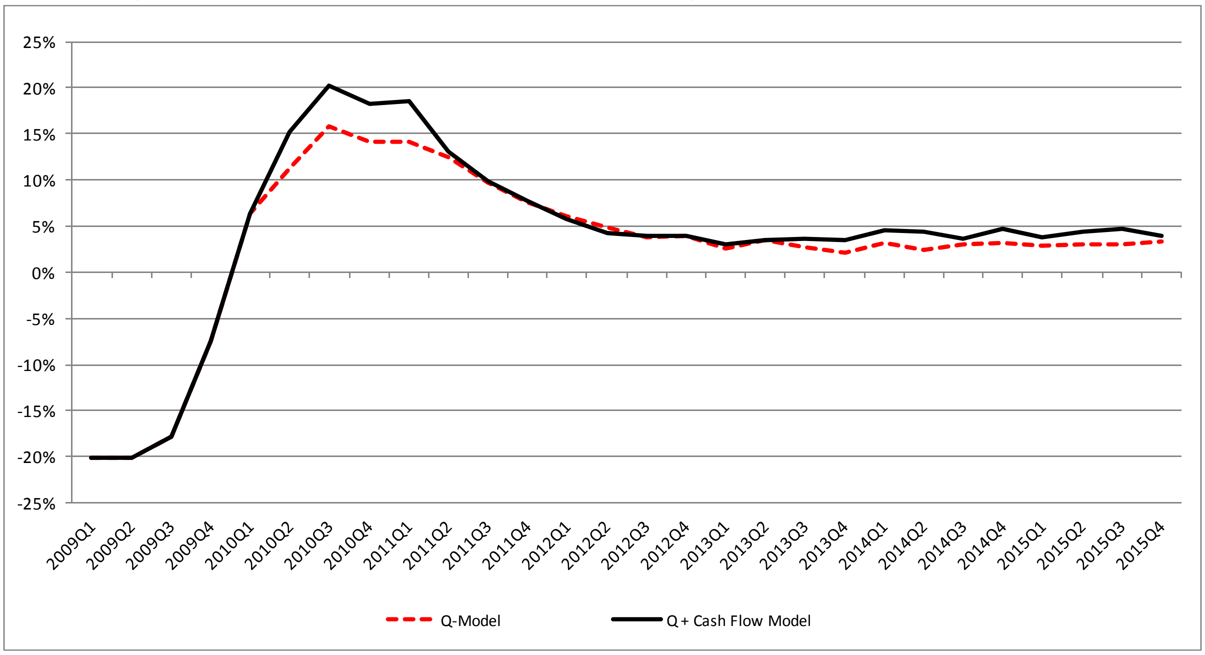


Tobin's Q Model

Having tried several versions of models based on Tobin's Q, we discuss representative forecasts based on two of them. (Similar results are obtained from other forecasts.) The first forecast is based on the model with the average Q as the only explanatory variable, where we feed forecasts coming from the large VAR. The second forecast is based on a model that includes a measure of cash flow as another explanatory variable, again using the large VAR forecasts.[6] The resulting forecasts are presented in Figure 5. Since these models predict the investment-capital ratio in E&S, we make use of a standard capital accumulation equation with a depreciation rate of 18 percent to back out the implied levels of capital stock and investment.[7]

The model with Tobin's Q as the only explanatory variable, when combined with the VAR forecast of Q, forecasts a more robust rebound in investment, of about 12 percent in 2010 and 11 percent in 2011, followed by a long-run growth rate almost 4 percent. Adding measures of cash flow generates a forecast of an even stronger rebound in investment—an annual growth rate of investment of 15 percent in 2010 and 12 percent in 2011—since for 2010 the ratio of cash flow to GDP is still projected to be above its historical average. As both measures return to their historical averages, the growth rates of investment decline.

Figure 5. E&S Investment Forecasts (Y-O-Y growth rates), Tobin's Q Model



[6] We also performed forecasts of Tobin's Q model using forecasts for Q and the cash flow/GDP that came from univariate ARIMA models. In this case, the implied investment growth rates were a bit lower than what we show in Figure 5, because the univariate forecasts are lower than the ones coming from the large VAR. The shape of the forecasts was quite similar.

[7] These models imply negative residuals for the investment equations in 2009:Q4. When we perform the forecasts we take into account the future behavior of these residuals, given that they are highly autocorrelated. If we assume that the residuals are zero, we would get too strong a rebound of investment in 2010, and a crash in 2011.

Cost of Capital Model

We follow a few steps to generate forecasts. First, we estimate a Vector Error Correction Model (VECM) with the E&S capital-output ratio and the cost of capital, imposing a unitary long-run elasticity between the two variables as suggested by the theory (Caballero, 1994).[8] Next, we obtain unconditional forecasts of the E&S capital-output ratio based on the estimated VECM. Then finally, we use the real GDP forecast from the "small VAR" model (VECM1 model in Figure 6) and from the "large VAR" model (VECM2), to back out the path of the real capital stock from the capital-output forecasts. We use a standard capital accumulation equation with an annual depreciation rate of 18 percent to back out the implied real E&S investment series.

The forecasts based on the VECM1 imply a large, double-digit rebound in investment during 2010–11, and a gradual return to a long-run investment growth rate (of 4.5 percent). Using the real GDP growth forecasts for the WEO produces a somewhat lower growth rate for investment in 2010 and a double-digit growth rate in 2011, similar to the pattern shown in Figure 4, and thus is not presented here. In VECM2 (using the large VAR), the recovery in real investment is very strong in 2010, averaging 23.5 percent in that year. This recovery is so strong as to be followed by several quarters of negative growth in investment in 2011–13, while the growth rate in investment eventually returns to a long-run rate (of 4.5 percent).

In both cases (the VECM model gives us the same capital-output ratio forecasts), the forecast implies that the capital-output ratio returns by the end of 2014 to the same value (41.9 percent) as in the middle of 2009:Q2 (Figure 7). This forecast for the E&S capital-output ratio is stronger than those implied by many other investment forecasts, as will be discussed in the concluding section. We also experimented with a single-equation approach under several assumptions for the behavior of the user cost of capital. Given parameter estimates, we obtained unrealistically negative growth rates of investment, and abandoned this approach.

[8] Actually, we conduct a formal likelihood ratio test and found that the assumption of unit elasticity could not be rejected, both for the 1963:Q1–2010:Q1 and the 1984:Q1–2010:1 sample.

Figure 6. Investment Forecasts (Y-O-Y growth rates), User Cost of Capital Model

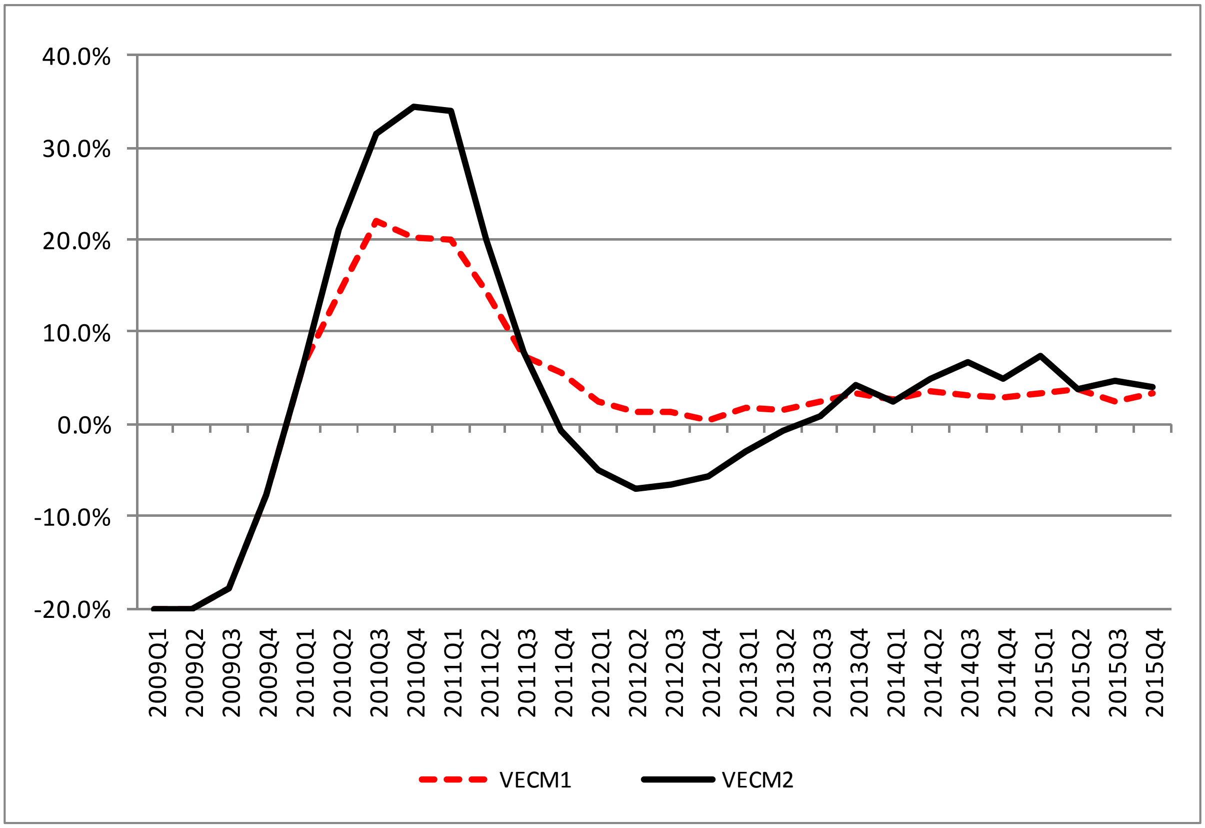
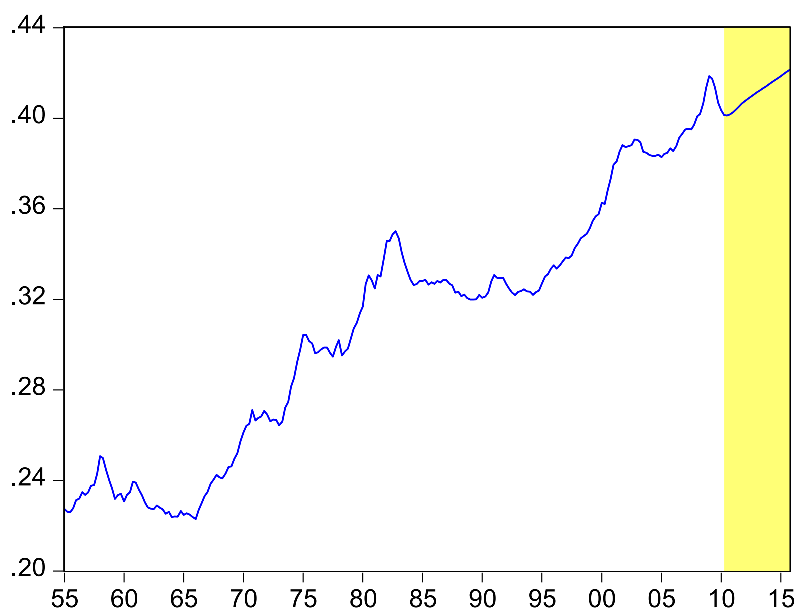


Figure 7. E&S Capital-Output Ratio, Cost of Capital Model



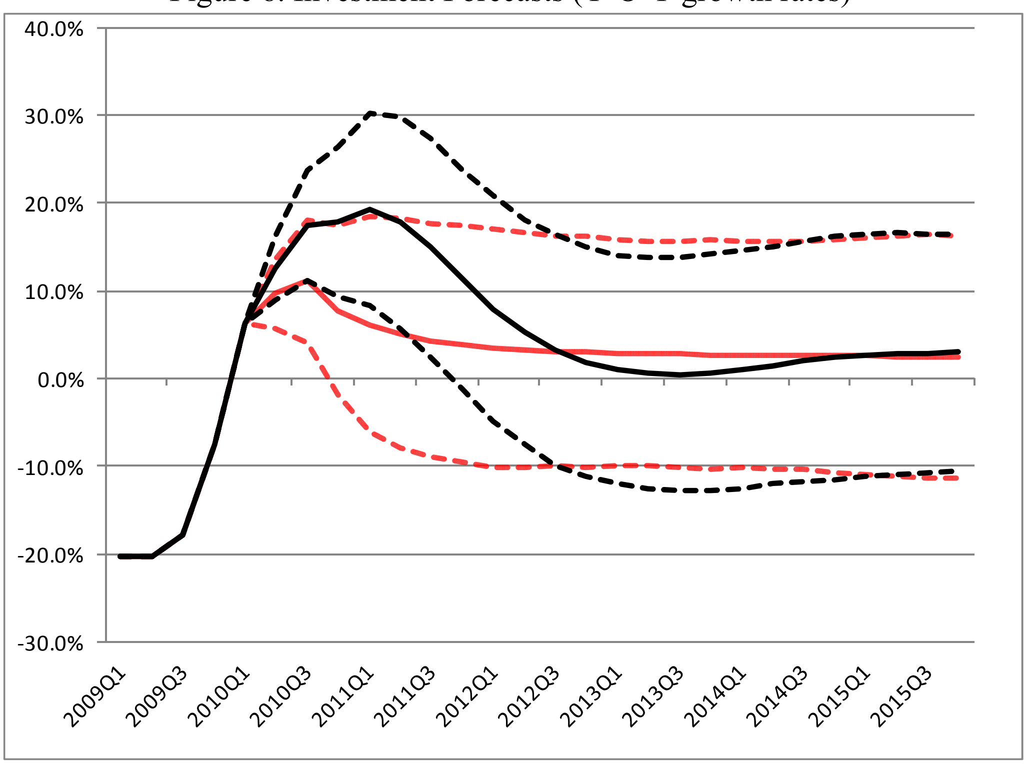
Note: White area denotes historical data; shaded area denotes forecast.

B. From VARs

In this section, we present the forecast based on the VAR models which were used as inputs in the previous subsection. As we have mentioned before, we have estimated two VARs: "small VAR" using the ratio of the real investment over real GDP ratio, and the growth rate of real GDP, in the spirit of the accelerator model; and the "large VAR" that include variables shown to explain investment behavior in other models (Table 1), namely Tobin's Q, the uncertainty index, the ratio of cash flow over nominal GDP, and the spread between Baa corporate bonds and the 10-year Treasury bills. We do not find evidence of a structural break either in the small or in the large VAR, and thus use the largest possible sample.

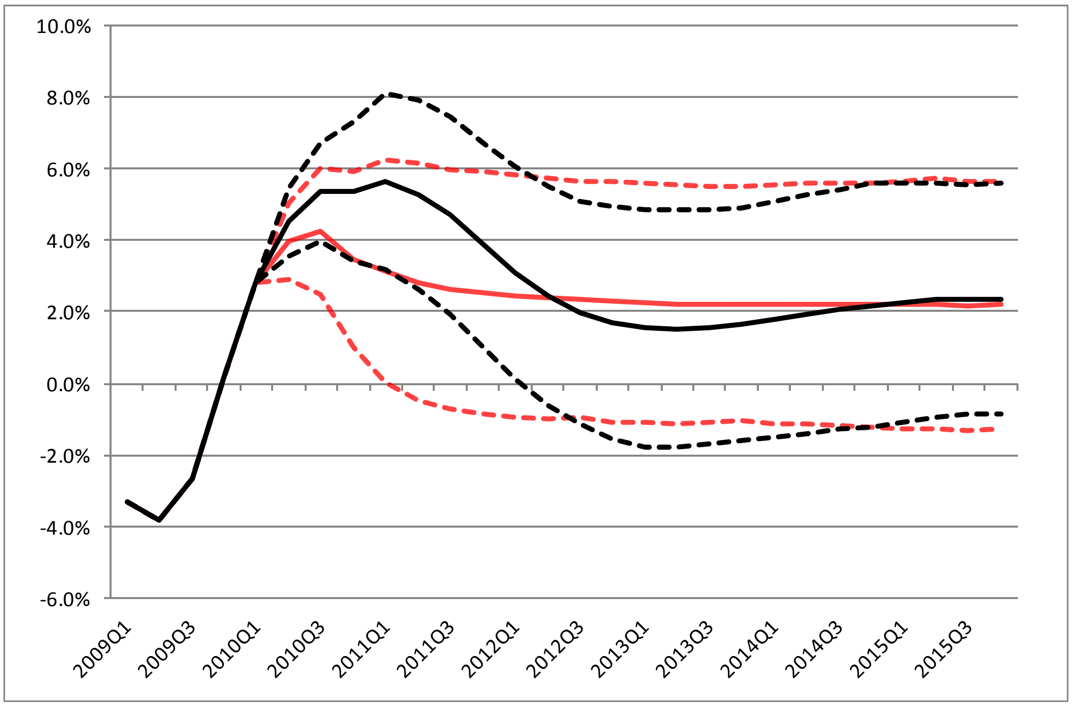
The small VAR suggests only a modest rebound of investment, which will reach a year-on-year investment growth rate of 11.5 percent in 2010:Q3, thereafter declining to around 3 percent year-on-year growth rate (Figure 8). On the other hand, the large VAR (black line) forecasts a higher growth rate (close to 20 percent in 2010:Q4), because the model also forecasts that: (i) Tobin's Q will increase from a relatively low level, and (ii) uncertainty and spreads will decline to their historical means from high values during the crisis. These offset a sizable decline in the ratio of cash flows to nominal GDP, from the current high values back to its historical mean.

Figure 8. Investment Forecasts (Y-O-Y growth rates)



A similar pattern arises for the growth rate of real GDP. (In the opening of Section III, we commented on the annual growth rate.) The small VAR forecasts a small rebound of real GDP in 2010-2011 with growth of 3.6 percent in 2010 and 2.8 percent in 2011, similar to the WEO. In subsequent years, growth rate is forecast to go back to its 2.2 percent long-run average. On the other hand, the large VAR forecasts a strong rebound and growth rates much higher than the WEO—4.5 percent for 2010 and 4.8 for 2011—because financial conditions and uncertainty improve from the Great Recession and go back to more favorable historical averages. This analysis is unconditional, and these numbers would be much smaller, if credit spreads and uncertainty were to remain at high levels, and if asset prices and Tobin's Q would not recover.

Figure 9. Real GDP Forecasts (Y-O-Y growth rates)



Notes: Black line = large VAR; red line = small VAR. Dashed lines represent two standard deviation bands

IV. Comparing Forecast and Caveats

In Table 3 we present a summary of the forecasts for E&S investment, in terms of growth rates, contribution to GDP growth and the E&S capital-output ratio. The large VAR, the VECM1 model, the accelerator model and Tobins' Q imply sustained double-digit growth rates during 2010–11, and a smooth decline towards a long-run growth rate of 4–5 percent. The small VAR model forecasts single-digit growth rates for both 2010 and 2011. In this instance, the parsimonious specification appears to limit the amplification mechanism too tightly, for the accelerator model forecasts nearly twice as strong investment growth as the small VAR model under the same forecast for GDP growth rates.

The VECM2 model (a forecast based on "the cost of capital" model) suggests a strong rebound in 2010, followed by a decline in 2012. This pattern looks quite volatile but is comparable to the behavior of investment after the 1982 recession: after rebounding to more than 20 percent (y-o-y) growth by the end of 1984, real investment averaged to a negative growth rate during 1986–87 (while the economy kept on expanding). However, we discount this forecast in our final assessment, because it combines the capital-output ratio from a very parsimonious VAR with the more optimistic growth projections coming from the large VAR, thereby implying a quantitatively important deviation from a balanced growth path for the U.S. economy.

Table 3. Summary E&S Investment

Annual Investment Growth
(in percent)

	VAR		Accelerator		Tobin's Q		User Cost of Capital	
	Small	Large	Small	Large	Baseline	With CF	VECM1	VECM2
2010	8.8	13.6	13.1	15.2	11.9	15.0	13.9	23.5
2011	4.9	15.7	10.9	19.6	10.9	12.1	12.5	14.0
2012	3.2	4.6	10.0	9.4	4.6	4.4	2.3	-6.1
Average	*5.6*	*11.3*	*11.3*	*14.7*	*9.1*	*10.5*	*9.5*	*10.4*

E&S Contribution to GDP Growth
(in percentage points)

	VAR		Accelerator		Tobin's Q		User Cost of Capital	
	Small	Large	Small	Large	Baseline	With CF	VECM1	VECM2
2010	0.6	0.9	0.9	1.0	0.8	1.0	1.1	1.6
2011	0.4	1.2	0.8	1.5	0.8	0.9	0.9	1.1
2012	0.2	0.4	0.8	0.8	0.4	0.4	0.2	-0.5
Average	*0.4*	*0.8*	*0.8*	*1.1*	*0.7*	*0.8*	*0.7*	*0.7*

E&S Capital-Output Ratio in the Forecast

	VAR		Accelerator		Tobin's Q		User Cost of Capital	
	Small	Large	Small	Large	Baseline	With CF	VECM1	VECM2
2010	0.398	0.398	0.401	0.399	0.402	0.404	0.402	0.402
2011	0.391	0.393	0.400	0.397	0.400	0.404	0.405	0.405
2012	0.387	0.398	0.406	0.409	0.400	0.406	0.409	0.409

Models also differ somewhat in their forecasts of the contribution to real GDP growth, and of the E&S capital-output ratio. The contribution of E&S investment to growth during the 2010–12 period ranges from 0.4 to 1.1 percent. The cost-of-capital and accelerator models predict that the E&S capital-output ratio will keep growing, resuming its trend over the last 40 years. However, the VARs predict that this ratio will remain stable or even decline in the next three years.

Forecasts from various models are associated with considerable statistical uncertainty. Table 4 reports the 95 percent confidence interval for forecasts of investment growth rates over 2009-2012. The confidence band is particularly large for forecasts obtained from Tobin's Q and VECM1 models, reflecting both the parameter uncertainty and the uncertainty associated with forecasts of regressors that are in turn used as inputs for investment forecasts. The extent of uncertainty is a reminder of the limitation that confronts an effort to forecast investment, which may be particularly large in the recovery from this recession.

Table 4. 95 Percent Confidence Interval for Annual E&S Investment Growth
(In percent)

	VAR-Small		VAR-Large		Accelerator-Small		Accelerator-Large	
	Low	High	Low	High	Low	High	Low	High
2010	3.9	13.7	9.9	17.7	8.4	17.3	10.7	20.9
2011	-5.1	15.7	5.7	26.2	-1.8	22.7	5.0	33.1
2012	-10.2	14.4	-6.1	14.5	-2.2	21.8	-4.5	25.2
	Tobin's Q		Tobin's Q with CF		User Cost of Capital - VECM1		User Cost of Capital - VECM2	
	Low	High	Low	High	Low	High	Low	High
2010	0.1	23.2	4.7	24.1	-13.8	47.2	-0.5	49.5
2011	-5.1	28.7	-5.8	30.3	-17.7	44.6	-11.4	46.0
2012	-11.4	21.1	-11.3	19.4	-22.3	31.2	-28.1	19.8

Table 5 compares our forecasts with the Consensus Forecasts and the April 2010 WEO forecast. Consensus Forecasts only provide figures for aggregate business investment, and we need to forecast nonresidential structures for comparison. Since most models have a very poor fit in explaining this particular component of investment, we borrow the WEO's forecast for nonresidential structures, and then use that forecast to construct forecasts for aggregate business investment. The WEO forecast implies that structures investment declines at a rate of 13.9 percent in 2010 and 2.4 percent in 2011. As a result, total business investment rates are lower than E&S investment rates. Consensus Forecasts show an accelerating rate of investment, from 2.5 percent in 2010 to 7.4 percent in 2011. This pattern is replicated by our econometric models other than VECM2 (which we discount).

Forecasts from our econometric models do not point to exact common numbers for the growth rates in E&S equipment in coming years. As can be seen in Tables 3 and 4, significant uncertainty arises among different models and statistically within each model. Similar differences are also observed relative to other forecasts (Table 5). Moreover, if the Great Recession were to mark a structural break from the historical relationship, econometric forecasts would fail to capture the new post-break relationship. Acknowledging these limitations, we summarize our econometric forecasts of Table 3 as indicating double-digit growth rates in E&S investment for the next two years before returning to long-run average growth rates. To take the averages over the three-year interval (2010–12, Table 3), econometric models forecast E&S investment growth of about 10 percent per year.

Table 5. Annual Business Investment Growth
(in percent)

	WEO	Consensus			VAR	
		Average	High	Low	Small	Large
2010	5.0	2.5	4.0	0.0	-0.3	3.0
2011	8.9	7.4	11.4	2.7	3.1	11.4

	Accelerator		Tobin's Q		User Cost of Capital	
	Small	Large	Baseline	With CF	VECM1	VECM2
2010	2.7	4.2	1.8	4.0	4.4	9.8
2011	7.7	14.4	7.7	8.7	8.2	10.3

V. Conclusion

Though subject to considerable uncertainty, several representative econometric models forecast that E&S investment will rebound with moderate strength in the next two years, reaching double-digit growth rates in 2010 and 2011. Thereafter, we expect that growth rates will stay in the single-digit range and gradually reach the long-run average of 4–5 percent. As a result, the contribution of investment to GDP growth is 0.8 percentage point on average over 2010–12.

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Appendix. Models of Investment

In this appendix we discuss four different single-equation approaches to model the behavior of investment, and then discuss our preferred specification for each approach. The four approaches are as follows: (i) accelerator model, (ii) models based on Tobin's Q, (iii) models based on the user cost of capital, and finally (iv) models based on alternative measures of Tobin's Q using bond market data, based on a recent paper by Philippon (2008). We also discuss the outcome of Chow tests for structural breaks in the "Great Moderation" (post - 1984) period.

Accelerator Model

The accelerator model relates the current investment rate to lagged changes in the level of real GDP. The idea is that changes in GDP proxy for the change in the desired capital stock, and adjustment costs lead to partial adjustment every period. The basic equation in this model is given by

$$I_t = \alpha + \sum_{i=0}^{N} \beta_i \Delta Y_{t-i} + \delta K_{t-1} + u_t \ , \tag{1}$$

where *I* is real business investment, K is the capital stock, Y is real GDP, and Δ is the first difference operator. A common approach is to run these regressions on the investment/capital stock ratio by dividing the variables in the previous equation by the lagged capital stock. Also, this transformation allows comparability with Tobin's Q model

$$\frac{I_t}{K_{t-1}} = \frac{\alpha}{K_{t-1}} + \sum_{i=0}^{N} \beta_i \frac{\Delta Y_{t-i}}{K_{t-1}} + \delta + e_t. \tag{2}$$

We have run regressions based on equations (1) and (2) using both aggregate private nonresidential business investment and its equipment and software (E&S) component. The other main component of business investment (nonresidential structures) is more difficult to model, because it includes items such as public utilities, schools, hospitals and the like that do not necessarily respond to business cycle fluctuations. In all cases we use quarterly data from 1984:01 to 2009:04, since we find that a Chow test does reject the null hypothesis of no structural change around that date. In general, we find that the post-1984 estimates imply that more lags are significant, and that the estimated coefficients are larger in the second subsample. In the following tables we present the regression results from using aggregate private nonresidential business investment. The estimates for equation (1) are as follows:

Table A.1a. Accelerator Model, Aggregate Business Investment

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	-949.373	59.651	-15.915	0.000
β_1	0.268	0.067	3.953	0.000
β_2	0.383	0.059	6.398	0.000
β_3	0.286	0.092	3.092	0.002
β_4	0.394	0.077	5.116	0.000
β_5	0.416	0.087	4.781	0.000
β_6	0.269	0.098	2.753	0.007
β_7	0.284	0.084	3.385	0.001
β_8	0.171	0.084	2.029	0.045
β_9	0.176	0.120	1.463	0.146
β_{10}	0.280	0.112	2.479	0.015
δ	0.150	0.005	29.479	0.000
R-squared	0.982	S.E. of regression		49.186
Adjusted R-squared	0.980	Durbin-Watson stat		0.246

As can be seen from Table A.1a, up to 10 lags are significant in the regressions. On the other hand the contemporaneous change of real GDP was not significant and excluded. Estimates using equation (2) are very similar, as we can see from Table A.1b.

Table A.1b. Accelerator Model, Aggregate Business Investment/Capital Ratio

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	-927.798	52.373	-17.715	0.000
β_1	0.299	0.071	4.215	0.000
β_2	0.391	0.066	5.930	0.000
β_3	0.321	0.094	3.385	0.001
β_4	0.441	0.078	5.631	0.000
β_5	0.400	0.077	5.141	0.000
β_6	0.227	0.098	2.305	0.023
β_7	0.306	0.076	4.009	0.000
β_8	0.140	0.091	1.533	0.128
β_9	0.086	0.130	0.659	0.511
β_{10}	0.224	0.111	2.009	0.047
δ	0.149	0.004	32.764	0.000
R-squared	0.934	S.E. of regression		0.004
Adjusted R-squared	0.926	Durbin-Watson stat		0.230

Next, in Tables A.1c–A.1d we show the same results using the level of E&S investment, and the E&S investment capital ratio.

Table A.1c. Accelerator Model, E&S Investment

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	-446.084	21.274	-20.967	0.000
β_1	0.356	0.066	5.336	0.000
β_2	0.336	0.045	7.357	0.000
β_3	0.199	0.054	3.688	0.000
β_4	0.267	0.044	5.999	0.000
β_5	0.237	0.045	5.280	0.000
β_6	0.158	0.059	2.638	0.009
β_7	0.132	0.042	3.116	0.002
β_8	0.114	0.043	2.612	0.010
β_9	0.186	0.052	3.546	0.000
β_{10}	0.169	0.055	3.049	0.003
δ	0.261	0.005	48.187	0.000
R-squared	0.992	S.E. of regression		27.602
Adjusted R-squared	0.991	Durbin-Watson stat		0.525

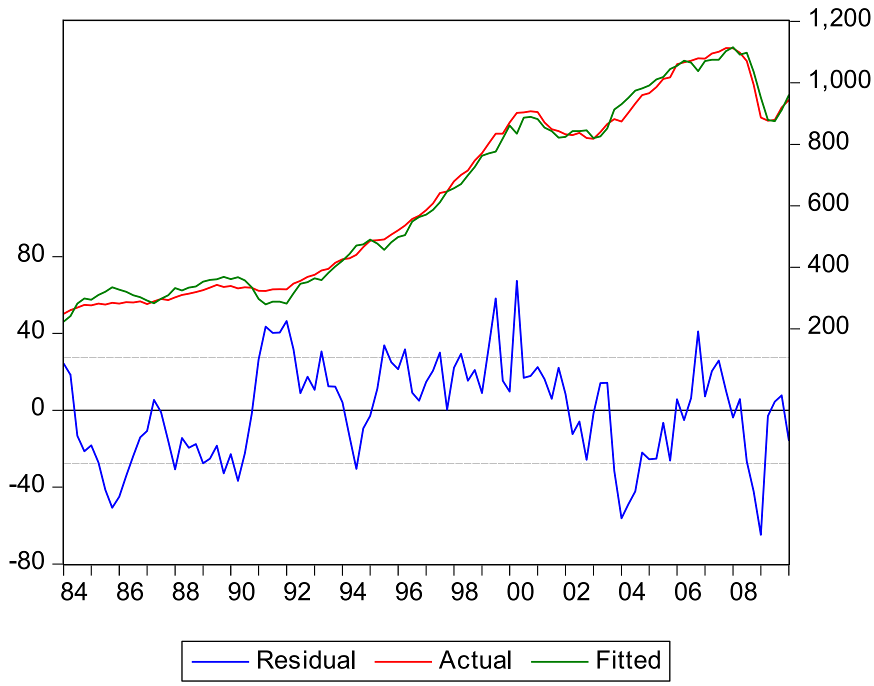
In this case, also up to ten lags are significant, and the R-squared of the regression is higher. Using E&S investment on equation (2) delivers very similar parameter estimates as we can see in Table A.1d.

Table A.1d. Accelerator Model, E&S Investment/Capital Ratio

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	-449.402	22.644	-19.845	0.000
β_1	0.315	0.066	4.742	0.000
β_2	0.309	0.062	4.962	0.000
β_3	0.203	0.059	3.434	0.000
β_4	0.258	0.050	5.139	0.000
β_5	0.201	0.051	3.948	0.000
β_6	0.100	0.055	1.819	0.072
β_7	0.119	0.043	2.757	0.007
β_8	0.082	0.040	2.051	0.043
β_9	0.107	0.045	2.342	0.021
β_{10}	0.125	0.049	2.563	0.012
δ	0.268	0.005	45.899	0.000
R-squared	0.951	S.E. of regression		0.008
Adjusted R-squared	0.945	Durbin-Watson stat		0.370

In both cases the Durbin-Watson statistic is much smaller than 2, suggesting highly correlated residuals. The regression results of Table A.1b are similar to what has been obtained in the previous empirical literature (for instance, Oliner, Rudebusch, and Sichel, 1995). Finally, we should also mention that we tried to estimate the accelerator model with non-residential investment structures, but it was difficult to get meaningful coefficients (most of the specifications they were not significant, and in some of them they were significant but of the wrong sign). Next we proceed to examine the residuals for the regression of Table A.1b. The model needs a series of negative residuals in 2008:Q3–2009:Q1 to explain the "Great Recession" data.

Figure A.1. Residuals from preferred accelerator model (1c)



Tobin's Q model

The next models that we examine are those related to Tobin's Q. The baseline regression is given by:

$$\frac{I_t}{K_{t-1}} = \alpha + \beta Q_t + \delta CF_{t-1} + e_t. \tag{3}$$

We consider four cases initially. As left-hand side variables, we use the investment/capital ratio for nonresidential business investment, and for E&S. As right-hand side variables, we consider two versions of Tobin's Q, unadjusted for taxes, and adjusted for taxes. Our definitions for the two types of Q are the ones in Summers (1981) and Bernanke et al. (1988). See also Oliner, Rudebusch, and Sichel (1995). Basically we take as average Q the ratio of a firm's market value (equities and credit market debt) with respect to its replacement cost (value of tangible assets). Then, we include tax adjustments based on the corporate tax rate, investment tax credits, and the present value of depreciation allowances.[9] Finally, we also

[9] We are thankful to FRB staff for providing us with the relevant series to construct the tax-adjusted Tobin's Q.

augment the Tobin's Q regression with measures of cash-flow of firms. Such measure is typically a good indicator for investment activities of firms that face financing constraints and hence need to rely on self-financing. We use the cash-flow/nominal GDP series.
In the following tables we present the regressions we have mentioned. In all cases, we found evidence of a structural break in 1984, confirming that this relationship has changed during the Great Moderation. In the earlier subsample, we find that the coefficient on Tobin's Q in the pre-1984 period is not significant, and sometimes it is negative and significant. On the other hand, in the post-1984 period, the coefficient is indeed significant and of the right sign.

Table A.2a. Tobin's Q Model with E&S Investment/ Capital Ratio

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	0.062	0.007	8.110	0.000
β	0.082	0.005	13.728	0.000
R-squared	0.794	S.E. of regression		0.016
Adjusted R-squared	0.792	Durbin-Watson stat		0.205

Table A.2b. Tobin's Q Model with Aggregate Investment/ Capital Ratio

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	0.039	0.004	8.673	0.000
β	0.033	0.003	10.425	0.000
R-squared	0.647	S.E. of regression		0.009
Adjusted R-squared	0.644	Durbin-Watson stat		0.118

Both measures of investment are affected by Tobin's Q, but the elasticity is larger for E&S than aggregate investment. Also, using E&S investment delivers a higher R-squared than using total business investment. Next, we repeat the same regressions using the tax-adjusted Tobin's Q measure

Table A.2c. Tobin's Q Model with E&S Investment/ Capital Ratio, Tax-Adjusted Q

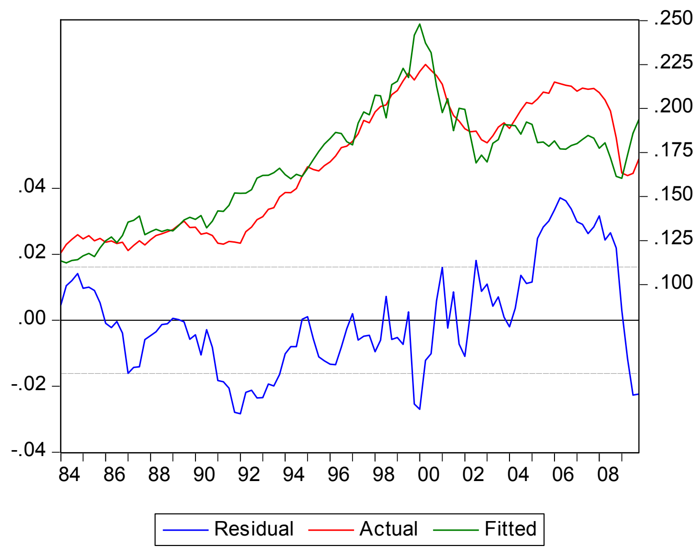
Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	0.045	0.007	5.641	0.000
β	0.054	0.003	14.271	0.000
R-squared	0.807	S.E. of regression		0.015
Adjusted R-squared	0.805	Durbin-Watson stat		0.249

Table A.2d. Tobin's Q Model with Aggregate Investment/ Capital Ratio, Tax-Adjusted Q

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	0.030	0.004	7.613	0.000
β	0.022	0.001	12.413	0.000
R-squared	0.682	S.E. of regression		0.009
Adjusted R-squared	0.679	Durbin-Watson stat		0.147

For the post-1984 period, models using the tax-adjusted Q perform just slightly better than the models without tax-adjustments. We should note that for the aggregate sample, models without tax adjustments perform just a bit better. Given that both Q measures deliver very similar results, we decided to use the unadjusted measure in the VAR.

Figure A.2. Residuals from preferred Tobin's Q model (2a)

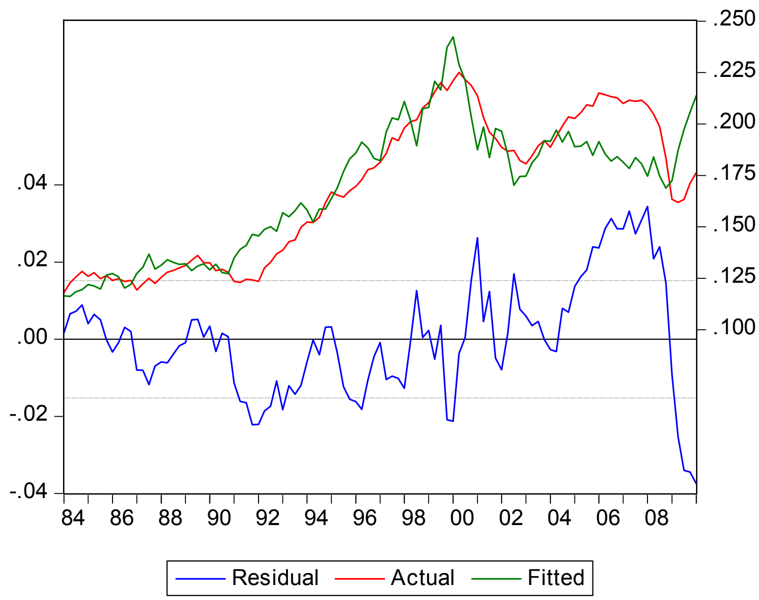


Next, we extend the previous regressions with the ratio of cash flow/nominal GDP. We present the regressions and results for the case of E&S investment, and unadjusted Tobin's Q. The results for the other specifications are qualitatively similar (i.e. higher R-squared with E&S investment and very similar results between adjusted and unadjusted Q measure).

Table A.3a. Tobin's Q Model with E&S Investment, Cash Flow

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	-0.012	0.046	-0.281	0.778
β	0.077	0.004	19.100	0.000
δ	0.852	0.492	1.731	0.086
R-squared	0.817	S.E. of regression		0.015
Adjusted R-squared	0.814	Durbin-Watson stat		0.251

Figure A.3. Residuals from Tobin's Q Model, with E&S Investment and Cash Flow



Introducing cash flows is significant but it makes it more difficult for the model to explain the drop in investment. Cash flows for firms have been healthy and at historical highs, so once we include them the model predicts stronger investment than it actually was observed. So the negative shock is even bigger than before.

Also, it is important to notice that estimates of equation (2) (Tables A.1b and A.1d) always imply higher R-squares and lower standard errors of the regression than those based on the Tobin's Q model of equation (3). Hence, Tobin's Q model is worse than the accelerator model when it comes to explain the I/K ratio in E&S.

Cost of capital models

In this section we study two models. One is based on the neoclassical model by Jorgenson. Then second one is based on the cointegrating relationship estimated by Caballero (REStat, 1994).

Neoclassical model

The basic equation in this model is similar to the accelerator model:

$$I_t = \alpha + \sum_{i=0}^{N} \beta_i \Delta\left(\frac{Y_{t-i}}{R_{t-i}}\right) + \delta K_{t-1} + u_t, \tag{4}$$

where R is the real user cost of capital, following the definition in Caballero (1994): it equals the real rate of interest (3-month T-bill rate minus the change in the investment deflator) plus depreciation, and expressed in GDP deflator units. We constructed a second measure that includes tax adjustments. In all cases we found that there is a break in the regressions in 1984, so we report the post-1984 estimates. As with other models, the pre-1984 estimates imply that less parameters are significant.
As was the case with the accelerator model, we also run regressions of the following kind:

$$\frac{I_t}{K_{t-1}} = \frac{\alpha}{K_{t-1}} + \sum_{i=0}^{N} \beta_i \frac{\Delta\left(\frac{Y_{t-i}}{R_{t-i}}\right)}{K_{t-1}} + \delta + e_t\,. \tag{5}$$

The best results are obtained when modeling E&S investment and using the unadjusted user cost of capital measure. Using the unadjusted cost-of-capital measure on aggregate private investment implies that none of the β coefficients is significant. Using the tax-adjusted measure also implies that none of the β coefficients is significant, with either aggregate investment or E&S investment.

In our preferred specification, the results are as follows:

Table A.4a. Neoclassical Model, E&S Investment

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	-298.095	34.180	-8.721	0.0000
β_0	0.037	0.015	2.421	0.017
β_1	0.027	0.012	2.155	0.033
β_2	0.030	0.015	1.965	0.052
β_3	0.025	0.015	1.618	0.108
δ	0.241	0.016	14.901	0.000
R-squared	0.957	S.E. of regression		61.891
Adjusted R-squared	0.955	Durbin-Watson stat		0.119

Table A.4b. Neoclassical Model, E&S Investment/Capital Ratio

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	-335.163	17.039	-19.669	0.000
β_0	0.028	0.011	2.413	0.017
β_1	0.018	0.011	1.528	0.129
β_2	0.020	0.011	1.742	0.084
β_3	0.019	0.011	1.614	0.109
δ	0.258	0.006	39.296	0.000
R-squared	0.809	S.E. of regression		0.015
Adjusted R-squared	0.800	Durbin-Watson stat		0.108

The R-squared are much smaller than the accelerator model, and the standard deviation of the error is larger, suggesting worse performance. These models still imply negative shocks to investment, similar to the accelerator model (we do not repeat the same figure, to save space.

Cointegration Analysis and the Neoclassical Mmodel

Caballero (1994) has estimated a cointegrating relationship between the capital-output ratio and the cost of capital. The regression is as follows:

$$log\left(\frac{K_t}{Y_t}\right) = \alpha + \beta log(R_t) + e_t, \tag{6}$$

where K/Y is the capital-output ratio and R is the user cost of capital, and *log* is the natural logarithm. We try several specifications, with tax adjusted and unadjusted measures of the user cost of capital. In order to consistently estimate the cointegration relationship, we estimate the previous long-run relationship using Dynamic OLS (Stock and Watson, Econometrica, 1993). Unlike Caballero (1994), we were not able to get an estimate for beta close to one.

The best results were achieved by using E&S investment, and the tax-adjusted cost of capital. In all other cases the parameter estimates were not significant, or of the wrong sign. We use two leads and lags of first-differenced real cost of capital in the Dynamic OLS regressions.

Table A.5a.Cointegration Model, DOLS Estimates, 1963–2009 Sample

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	-1.849	0.068	-26.99	0.000
β	-0.295	0.028	-10.217	0.000
R-squared	0.368	S.E. of regression		0.133
Adjusted R-squared	0.350	Durbin-Watson stat		0.054

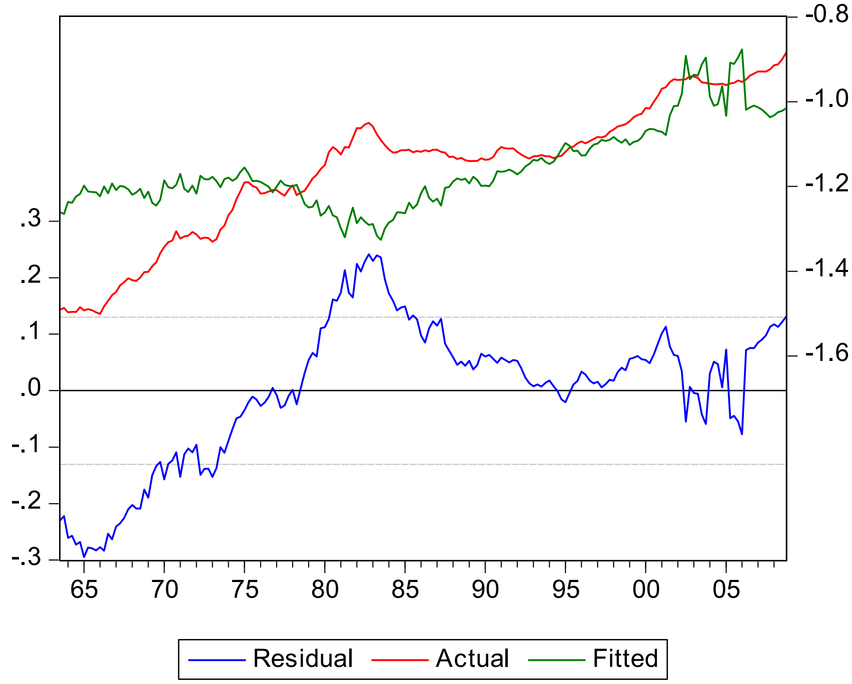
Note that the residuals are still highly autocorrelated, so it is difficult to tell if the variables are cointegrated or not. When we use the shorter sample, we find that the elasticity actually declined over time, and a Chow-test suggests that there has been a structural break in the coefficients.

Table A.5b. Cointegration Model, DOLS Estimates, 1984–2009 Sample

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	-1.561	0.036	-42.319	0.000
β	-0.202	0.014	-14.065	0.000
R-squared	0.674	S.E. of regression		0.049
Adjusted R-squared	0.657	Durbin-Watson stat		0.222

And the residuals of this regression suggest that in fact the capital-output ratio has been higher than predicted by the model, hence capital should still fall by more. This is despite the fact that the cost of capital has been low in this recession due to low interest rates.

Figure A.4. Residuals from Cointegration Model, 1965–2009 Sample



A second approach we thus take is to estimate a Vector Error Correction model between the two variables. Using the whole sample, we estimate a VECM with two lags and find, through a likelihood ratio test, that we cannot reject that the cointegrating vector is (1,1). In this case, the p-value of the test is 0.283 so we can't reject the null hypothesis. Next, we run a likelihood ratio test with a structural break in 1984 and find that we cannot reject that there is a break in that date. Finally, we reestimate the VECM with three lags and again can't reject the null hypothesis that the cointegrating vector is (1,1) at the 10 percent level, although we would reject it at the 5 percent confidence level. We use this last VECM in the paper to forecast the K/Y ratio.

Models Based on Bond Market Data

In a recent paper, Philippon (2008) has suggested that using bond prices instead of equity prices to estimate the value of Tobin's Q is a promising avenue. In particular, Phillipon constructs his measure (that he calls "Bond Q") as a function of the real risk free rate, the spread between bond yields and treasuries, leverage, and uncertainty. In this section we reproduce Philippon (2008) results, but instead of constructing his "Q" measure we run unrestricted regressions using his same ingredients, and also include the cash flow/GDP measure.

We estimate the following equation:

$$\frac{I_t}{K_{t-1}} = \alpha + \beta_o SPREAD_{t-1} + \beta_1 RR_{t-1} + \beta_2 UNC_{t-1} + \beta_3 LEV_{t-1} + \beta_4 CF_{t-1} + e_t, \quad (7)$$

where SPREAD denotes the spread of 10-Year Baa corporate bonds over Treasuries, RR is the real rate defined as the Federal Funds rate minus expected inflation, UNC is the uncertainty measure constructed by Bloom (2009), LEV is the leverage ratio defines as value of debt/equity, and CF is the ratio of cash flow divided by nominal GDP. The results are presented in the following regression:

Table A.6a. Bond Market Model with E&S Investment/ Capital Ratio

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	-0.034	0.047	-0.723	0.470
β_0	0.019	0.005	3.545	0.000
β_1	-0.000	0.001	-0.881	0.378
β_2	-0.028	0.015	-1.885	0.060
β_3	-0.000	0.000	-3.138	0.002
β_4	2.379	0.444	5.353	0.000
R-squared	0.578	S.E. of regression		0.027
Adjusted R-squared	0.567	Durbin-Watson stat		0.194

As we can see, when running the regression on the level of I/K for E&S, the spread measure comes with the wrong sign, while the real interest rate is insignificant. On the other hand, the measure of aggregate uncertainty (taken from Nick Bloom), leverage and cash flow are significant and with the correct sign. We estimated this equation using the whole sample 1960–2009. A Chow test confirms that there is a break in 1984. However, when we estimated the same equation using post-1984 data, we found that only leverage and cash flow/GDP measures become significant.

We also run the same regression using year-on-year changes of all variables. That is, we apply the year-on-year difference operator to all variables of equation (7). In this case, the change in the spread comes with the right sign, and is significant. The change in leverage is significant, but all other variables become non-significant.

Table A.6b. Bond Market Model with E&S Investment/ Capital Ratio, Year-on-Year Regression

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	0.002	0.000	3.021	0.002
β_0	-0.011	0.001	-9.171	0.000
β_1	-0.000	0.000	-0.030	0.975
β_2	-0.001	0.003	-0.348	0.728
β_3	-0.000	0.000	-2.321	0.021
β_4	-0.130	0.139	-0.936	0.350

R-squared	0.572	S.E. of regression	0.007
Adjusted R-squared	0.560	Durbin-Watson stat	0.443

In this case, no evidence of structural break was found.

A simpler regression can be given by:

$$\left(\frac{I_t}{K_{t-1}} - \frac{I_{t-4}}{K_{t-5}}\right) = \alpha + \beta_o(SPREAD_{t-1} - SPREAD_{t-5}) + \beta_1(Q_{t-1} - Q_{t-5}) + e_t, \qquad (8)$$

where we use the 4-quarter difference operator and include Tobin's Q. Only the change in the real interest rate and Tobin's Q are significant, so we report those results in the following Table.

Table A.6c. Bond Market Model with Spreads and Tobin's Q, E&S Investment/ Capital Ratio, Year-on-Year regression

Parameter	Coefficient	Std. Error	t-Statistic	Prob.
α	0.001	0.000	2.469	0.014
β_0	-0.011	0.001	-9.229	0.000
β_1	0.022	0.005	4.192	0.000

R-squared	0.613	S.E. of regression	0.006
Adjusted R-squared	0.609	Durbin-Watson stat	0.543

In this case, also no evidence of structural break was found.