This study provides evidence that managerial incentives, shaped by compensation contracts, help to explain the empirical relationship between uncertainty and investment. We develop a model in which the manager, induced by an incentive contract, makes investment decisions for a firm that faces time-varying volatility. In the model, a manager's privately optimal investment response to a volatility shock depends on the compensation contract. We calibrate the model using compensation data and generate a panel of manager investment policies. The panel of manager incentives estimated in the model predicts firm investment responses to volatility shocks observed in the data.
1 Introduction

An empirical literature in macroeconomics and finance has found a strong connection between uncertainty shocks and capital investment policies.\textsuperscript{1} Theoretical explanations for the response of investment to changes in idiosyncratic volatility have traditionally focused on the real option feature of investment. With costly reversibility, an increase in volatility changes the optimal timing of investment.\textsuperscript{2} In addition, following the financial crisis of 2007–09, imperfections in financial markets have been explored as a potential mechanism that generates the observed link between uncertainty and investment.\textsuperscript{3}

In this paper we investigate the role of an agency conflict between a firm’s manager and shareholders in explaining the relationship between uncertainty and investment. Increasingly, compensation contracts for executives of US public firms consist largely of own company stock and options. These contracts expose a manager to firm-specific risk, which is not borne by diversified shareholders. This drives a wedge between the pricing kernels, and therefore optimal investment policies, of a firm’s manager and diversified shareholders. If shareholders are unable to perfectly monitor managers, firm investment policies observed in the data are likely to reflect the manager incentives induced by the compensation contract. Importantly, the manager’s optimal response to an uncertainty shock will depend on the structure of their incentive-based compensation contract.

We show that this agency conflict is important in understanding the response of investment to volatility shocks. To quantify the investment incentives of the manager, we develop a neoclassical model of firm investment that embeds an agency conflict between the manager and outside shareholders. Firms are operated by managers that are compensated with their own company’s stock and options, in addition to a fixed salary. Thus, the model explic-

\textsuperscript{1}See, for example, Leahy and Whited (1996), Guiso and Parigi (1999), Bloom, Bond, and Van Reenen (2007), Panousi and Papanikolaou (2012), Bachmann, Elstner, and Sims (2013), and Gilchrist, Sim, and Zakrajšek (2013).

\textsuperscript{2}See, for example, Brennan and Schwartz (1985), McDonald and Siegel (1986), and Dixit and Pindyck (1994).

\textsuperscript{3}Gilchrist, Sim, and Zakrajšek (2013) explore this effect in a model that also features capital irreversibility and investigate the quantitative impact of each mechanism.
itly links manager compensation contracts to optimal firm investment policies and provides predictions for the relationship between idiosyncratic volatility shocks, the compensation contract, and a manager’s optimal investment policy.

The model predicts conditional relationship between firm-specific uncertainty and investment that can vary across firms and over time. We show that an increase in firm-specific uncertainty can incentivize a manager to either increase or decrease firm investment, where the sign and magnitude of the response depend on the structure of the compensation contract.

We use firm-level data on production and compensation contracts for a sample of US public companies over the period 1956–2012, to calibrate the model to match firm-year-level variation. From the calibrated model, we compute the optimal investment response to a volatility shock for a manager with the observed compensation contract. We do this for each firm-year in our sample and compare this panel of estimated manager investment incentives to the investment policies that would be optimal for a diversified shareholder.

The panel of predicted manager investment responses to volatility shocks, which are estimated from the model, exhibit significant cross-sectional and time-series variation. Moreover, we show that the predicted manager responses, estimated from the model, have strong predictive power for firms’ observed investment responses to volatility shocks in the data. In particular, we find that the documented negative relationship between volatility and investment only is present for those firms which provide compensation contracts which predict this negative response. Taken together, our results suggest that understanding the structure of executive compensation contracts is important for understanding the link between uncertainty and investment observed in the data.

A significant strand of the investment literature has theoretically characterized the affect of uncertainty on optimal investment policies under different conditions for the firm’s production technology, capital adjustment costs, the market structure, and risk aversion. One set of results finds that greater uncertainty can generate an increase in firm investment. If a firm’s profits are convex in costs or demand, and the firm is able to easily scale up or down,
then greater uncertainty increases the marginal value of an additional unit of capital and, consequently, investment. A second set of results has predicted a negative relation between uncertainty and investment. These papers show that with costly reversibility of capital, an increase in uncertainty can increase the value of the option to delay investment and result in a drop in investment. This real options effect generally predicts investment responses should be dampened with an increase in uncertainty as a firm’s optimal inaction region expands. Thus, the response of investment to uncertainty predicted by economic theory can be ambiguous and depends critically on the assumptions of the model environment.

The empirical literature on the relationship between uncertainty and investment has, in most cases, found a negative relationship whereby an increase in uncertainty predicts a reduction in investment. Leahy and Whited (1996) study the empirical relationship between uncertainty, measured using the volatility of firm equity returns, and investment for a panel of US manufacturing firms. They find uncertainty has a strong negative impact on investment and that this is driven by uncertainty that is idiosyncratic to the firm, not a priced source of systematic risk. Bloom, Bond, and Van Reenen (2007) take a similar approach, using data for UK manufacturing firms for the period 1972–1991. They find evidence that the investment behavior of large manufacturing firms is consistent with a real options effect generated by costly reversibility.

Bachmann, Elstner, and Sims (2013) use business survey data for the US and Germany in a structural VAR framework and find innovations in this measure of uncertainty have a negative impact on economic activity. They find these effects to be prolonged, however, and argue that the observed responses are not consistent with the delay and fast rebound that would be predicted by a real options effect. Guiso and Parigi (1999) study a sample of Italian manufacturing firms and measure uncertainty using the subjective probability distribution of demand reported by the entrepreneurs in their sample. They find this measure of uncertainty

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4See Oi (1961), Hartman (1972), and Abel (1983)
5See, e.g., Bernanke (1983), Brennan and Schwartz (1985), McDonald and Siegel (1986), Pindyck (1988), and Dixit and Pindyck (1994).
displays a negative relation with the responsiveness of investment, consistent with a real options effect.

Panousi and Papanikolaou (2012) investigate the uncertainty-investment relationship by estimating panel regressions for US public firms, using idiosyncratic equity return volatility as their measure of uncertainty. They find a negative relationship between investment and uncertainty and show that the magnitude of this effect is increasing in the fraction of insider ownership. They attribute these results to the impact of undiversified idiosyncratic risk borne by managers that have incentive-based compensation packages.

An additional proposed explanation for the investment-uncertainty relationship comes from costly external financing. The basic intuition is that higher idiosyncratic volatility increases the probability of distress and consequently increases the cost of external financing. Gilchrist, Sim, and Zakrajšek (2013) investigate these two mechanisms in a general equilibrium model of firm investment and financing. They conclude that the costly external financing channel has a greater ability to explain the empirical patterns they find in the data.

Our focus in this paper, the role of executive compensation contracts, represents a third, complementary mechanism. While these proposed mechanisms need not be mutually exclusive, they each carry different implications and predictions for the relationship between uncertainty and investment. An important distinction of the agency conflict we study in this paper is that it predicts the relationship between investment and uncertainty will be conditional, varying both across firms and over time. In panel regressions of firm investment, we find support for this prediction.

This paper also relates to a growing literature that studies the quantitative impacts of agency conflicts on firm investment and financing policies. While the agency conflicts that arise between management and outside investors have long been studied, the literature that seeks to quantify these effects is more recent. Finally, previous work has considered the impact of undiversified, firm-specific risk on optimal firm policies in the setting of en-

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7See, for example, Nikolov and Schmid (2012), Morellec, Nikolov, and Schürhoff (2012), Nikolov and Whited (2013), Li and Whited (2013), and Glover and Levine (2014).
The remainder of the paper is organized as follows. Section 2 presents the model framework and introduces the measurement of the manager’s investment distortion. Section 3 discusses the data sources used in the model calibration. In Section 4 we present our calibration approach that gives us a panel of manager investment incentives. We also present model comparative statics and impulse responses to illustrate how features of the compensation contract shape a manager’s optimal investment policy and response to volatility shocks. In Section 5 we use firm-level investment data and panel of manager investment incentives computed from the model to test the model’s empirical predictions for the investment-uncertainty relationship. Section 6 concludes.

2 Model

We employ a neoclassical model of investment that embeds an agency friction to study the impact of incentive-based executive compensation contracts on firm investment behavior. To study how uncertainty interacts with compensation-induced investment incentives, we extend Glover and Levine (2014) to allow for stochastic volatility of the firm’s productivity process.

2.1 Firm production, volatility and financing

Firm \( i \) at time \( t \) generates profits according to

\[
\pi_{i,t} = e^{z_{i,t}} k_{i,t}^{\alpha} - f_i
\]

where \( z_{it} \) is firm-specific productivity, \( k_{it} \) is the stock of capital, and \( f_i \) are fixed costs of production. We assume that the log of a firm’s idiosyncratic productivity evolves according to

\[
z_{i,t+1} = \rho z_{i,t} - \frac{\sigma_t^2}{2} + \sigma_t \epsilon_{i,t+1}
\]

See, for example, Bitler, Moskowitz, and Vissing-Jørgensen (2005) and Chen, Miao, and Wang (2010).

See Gourio and Michaux (2013) and Gilchrist, Sim, and Zakrajšek (2013) for examples of models with time-varying volatility of the productivity process.
where $\epsilon_{i,t+1} \sim \mathcal{N}(0, 1)$. The volatility of innovations to log productivity, $\sigma_t$, is stochastic and follows a two-state Markov chain with transition matrix parameterized by $p_{LL}$ and $p_{HH}$:

$$P_{\sigma} = \begin{bmatrix} p_{LL} & 1 - p_{LL} \\ 1 - p_{HH} & p_{HH} \end{bmatrix}. \quad (3)$$

Volatility $\sigma_t$ is common across firms and represents the average level of idiosyncratic volatility in the economy. Note that the process for log productivity, $z_{i,t}$, is constructed such that the conditional mean of productivity, $\mathbb{E}[e^{z_{i,t+1}} | z_{i,t}, \sigma_t]$, does not depend on $\sigma_t$. This is convenient in that shocks to idiosyncratic volatility do not represent shocks to expected aggregate productivity even though they are common across firms.

Henceforth, firm and time subscripts are suppressed, and we adopt recursive notation throughout where the $'$ superscripts denote next period values.

Each period the firm makes an investment decision $i$ and capital accumulates according to

$$k' = (1 - \delta)k + i \quad (4)$$

where $\delta \in (0, 1)$ represents the depreciation rate of capital. Investment is subject to convex adjustment costs given by

$$\Phi(i, k) = b \left( \frac{i}{k} - \delta \right)^2 k. \quad (5)$$

If internal cash flows are insufficient to pay for current-period investment, the firm may finance investment externally. External financing entails a proportional cost on the size of the issuance $e$:

$$\Lambda(e) = \lambda e \quad (6)$$

where $\lambda \geq 0$.

The firm pays corporate income tax on earnings, after deducting depreciation, at a rate $\tau_c$ and equity payouts are taxed at a personal rate of $\tau_d$. The firm’s net cash flows are

$$D(i, k, z) = (1 - \tau_c)\pi(k, z) + \tau_c \delta k - i - \Phi(i, k) \quad (7)$$

which correspond to external financing when $D$ is negative. Finally, after accounting for any equity issuance costs, the after-tax value of the dividend is

$$d(i, k, z) = (1 + \mathbb{1}_{[D<0]} \lambda - \mathbb{1}_{[D>0]} \tau_d)D(i, k, z), \quad (8)$$
where negative \( d(i, k, z) \) represents external financing.

### 2.2 Benchmark Value of the Firm

In the frictionless benchmark case, investment is chosen to maximize the expected present value of future cash flows, \( V^*(k, z, \sigma) \). In this case the value of the firm satisfies the following Bellman equation:

\[
V^*(k, z, \sigma) = \max \left\{ 0, \max_i \left[ d(i, k, z) + \beta \mathbb{E}[V^*(k', z', \sigma') | z, \sigma] \right] \right\},
\]

where \( k' = (1 - \delta)k + i \). Denote as \( i^*(k, z, \sigma) \) the investment policy function that satisfies this maximization. The outer max represents the shareholders’ limited liability protection. This specification will serve as the frictionless benchmark to understand how incentive-based compensation contracts impact a manager’s optimal investment policy.

### 2.3 The Manager

The manager derives value from the firm distinct from the shareholder. Specifically, the manager derives utility from the compensation she is awarded. We define the compensation contract by \( \Theta \equiv \{\theta_s, \theta_o, F\} \), where \( \theta_s \) is stock compensation, \( \theta_o \) is option compensation, and \( F \) is fixed salary, as these three terms comprise the vast majority of compensation for executives in practice. Furthermore, we assume the manager has constant relative risk aversion (CRRA) preferences:

\[
U(c) = \frac{c^{1-\gamma}}{1-\gamma}.
\]

The manager lives for one period, making a single investment decision before retiring and receiving payment from the fixed and incentive-based compensation contract. Therefore, the manager chooses investment to maximize her expected utility over next-period compensation:

\[
\max_{k'} \mathbb{E}\left[ U(C(k', z', \sigma', k, z, \sigma)) \right | z, \sigma]
\]
where tomorrow’s value of compensation is

\[
C(k', z', \sigma', k, z, \sigma) = (1 + r_f)\theta_s d(i, k, z) + F + \theta_s V(k', z', \sigma' | \Theta) + \theta_o \max(V(k', z', \sigma' | \Theta) - S(i, k, z, \sigma), 0),
\]

\[i = k' - (1 - \delta)k,\]

\[V(k, z, \sigma | \Theta) \text{ is the market value of the manager-run firm, and } S(i, k, z, \sigma) \text{ is the strike price on the manager’s option compensation. In practice, most options are issued at a strike price equal to the current market price (at the money), and we therefore make the assumption that the strike price is the ex-dividend equity value:}

\[
S(i, k, z, \sigma) = V(k, z, \sigma | \Theta) - d(i, k, z).
\]

The first term in the manager’s compensation, \((1 + r_f)\theta_s d(i, k, z)\), is the dividend payment she receives in the current period that will depend on the manager’s investment decision. This dividend, which may be negative in the case of equity issuance, is held in a risk-free account until the next period. Given the utility maximization problem in (11), we define \(i(k, z, \sigma | \Theta)\) as the manager’s investment policy which maximizes her utility.

The market value of the manager-run firm, \(V(k, z, \sigma | \Theta)\), which is the expected present value of all future cash flows paid by the firm when management controls investment decisions, is defined as

\[
V(k, z, \sigma | \Theta) = \max \{0, d(i(k, z, \sigma | \Theta), k, z) + \beta \mathbb{E}[V(k', z', \sigma' | \Theta) | z, \sigma] \},
\]

where

\[k' = (1 - \delta)k + i(k, z, \sigma | \Theta).\]

Note that even though the manager chooses investment and financing policies for the firm, the shareholders maintain their limited liability protection.

\[\text{This might appear to induce myopia on the part of the manager given that the entire payoff is received by the manager only one year hence. However, this is not the case: the manager’s payoff is a function of the market value of the firm, which incorporates her investment decision, as well as all future investment decisions of future managers, all of whom have identical incentives. Thus, a one-period manager problem maintain parsimony by eliminating modeling a full consumption-savings problem without inducing managerial myopia.}\]
2.4 Investment Friction

We have now defined the frictionless benchmark investment rate, \( i^*(k,z,\sigma)/k \), and the investment rate chosen by the manager, \( i(k,z,\sigma|\Theta)/k \). We now define the state-dependent over-investment incentive of the manager as the difference in these investment rates:

\[
\omega_0(k,z,\sigma|\Theta) = \frac{i(k,z,\sigma|\Theta) - i^*(k,z,\sigma)}{k}.
\]

(15)

For the current state \((k,z,\sigma)\), positive values for \(\omega_0\) indicate that the manager has an incentive to invest more, and take on more risk, than is first-best optimal. Negative values indicate a manager which prefers to invest less, and take on less risk, than shareholders.

We are interested in the manager’s investment response to volatility shocks. To this end, we construct the difference between the manager’s investment incentive in the high and low states as a measure of the investment-volatility sensitivity. The construction of this variable, denoted \(\omega^{HML}\), is discussed in Section 4.3.

3 Data

3.1 Data Description

We collect data on executive compensation, firm financial statements, and equity returns for a sample of US public companies for the period 1956-2012. Firms’ accounting data is taken from the Compustat annual database and equity returns and values come from CRSP. We gather data on salary and equity and option ownership stakes for firm CEO’s from two data sources. The first is the Execucomp database, which lists compensation information for top officers of companies included in the S&P 1500 index. This database provides compensation data for a subset of executives of US public companies at an annual frequency for the period 1992-2012. We supplement the Execucomp data with the hand-collected database constructed in Frydman and Saks (2010).\(^{11}\)

\(^{11}\)We thank Carola Frydman for making these data available on her website.
for top officers from 10-K and proxy statements for the period of 1936-1991. Their sample consists of all companies that were among the 50 largest companies in the US in the year 1940, 1960, or 1990. We use the compensation data they report for the company CEO and merge this with accounting data from Compustat and equity return data from CRSP. Requiring non-missing data from all three sources, we have an unbalanced panel of 85 unique firms for the period 1956-1991. We extend the sample for these firms using ExecuComp data for the period 1992-2012. This unbalanced panel of 85 unique firms spanning the period 1956-2012 we refer to as the “Frydman-Saks” sample.

Additionally, we construct what we refer to as the “Execucomp Sample,” which consists of all firms in the Execucomp database in the period 1992-2012. We merge these data for CEO compensation from ExecuComp with firm accounting and return data as before and arrive at a sample of 24,624 firm-year observations, consisting of 2,435 unique firms over the period 1992-2012. In all cases, we apply a standard set of filters used in the empirical finance literature.\(^\text{12}\)

We define investment to be capital expenditures divided by the lagged replacement value of capital. The replacement value of capital is calculated using the approach of ?. Our results are qualitatively similar if investment is defined as capital expenditures divided by lagged net property, plant, and equipment.

### 3.2 Compensation contracts

Before estimating the investment incentives derived from the model, we first explore the time variation in the mean and median compensation contract over our two samples. Figure 1 plots the mean and median equity and option compensation for the Frydman-Saks sample in Panel A and for the ExecuComp sample in Panel B. Equity compensation is indicated with a solid line on the left axis, and option pay is indicated with a dashed line on the right axis.

For the Frydman-Saks sample, there is significant time variation in both the mean and

\(^\text{12}\)For example we remove firms with negative book assets, negative sales, negative gross property, plant, and equipment.
median, with a significant and temporary rise in equity pay in the late eighties. The median level of incentive pay, both for stock and option, rises dramatically throughout the nineties, and then falls somewhat in the last seven years of the sample.

For the ExecuComp sample, which includes a much broader cross section of firms, we see a dramatic rise and fall of option compensation between 1993 and 2012, starting at a mean of 0.5%, more than doubling to 1.1% in 2004, and then falling again to 0.6% in 2012. During the same period, we see a dramatic fall in equity compensation, from a mean of over 3.1% in 1993 to 1.7% in 2012. Medians follow similar patterns. These patterns suggests that the convexity of the manager’s compensation increased significantly in the 1993–2004 period, as compensation shifted away from equity and toward option pay, before falling again after 2005. This dramatic decline in option compensation, coupled with a decline in stock pay, suggests that the manager’s incentives to invest in risky capital may have declined during this period, something we will explore quantitatively in the model.

4 Calibration and Model Evaluation

In this section, we first discuss the choice and construction of parameter values used to calibrate the model and describe the numerical evaluation of the model. Next, we gain intuition for the investment incentive estimates that come out of the model and their relationship to volatility shocks by exploring comparative statics in the compensation contracts and impulse responses to volatility shocks.

4.1 Parameter choice

Calibrating the model involves selecting parameter values which are either common across all firms, specific to a firm across all years, or specific to a firm for a given year. Common parameters include the production parameters, returns to scale $\alpha$, depreciation rate $\delta$, persistence in productivity $\rho$, and capital adjustment costs $b$. The discount rate $\beta$, external financing costs $\lambda$, and corporate income and dividend tax rates $\tau_c$ and $\tau_d$ are also common across firms. We use these parameter values from Glover and Levine (2014), who directly
estimate the production parameters using data on earnings, labor, and capital. The external financing cost parameter $\lambda$ is taken from Gomes (2001) and set to 0.02. The manager’s risk aversion $\gamma$ is also common across firms, and is set to 3 in the calibration. Alternative parameter choices for risk aversion change the distribution of estimated $\omega_{it}$, however the rank ordering of these estimates across firm-year observations remain similar. The complete set of parameter values which are common across all firms are given in Panel A of Table I.

We use the model to estimate the manager’s investment incentive $\omega_{it}$ for each firm at each year. To do this, we need firm-year data on the terms of the compensation contract. The distributional properties of the panel of equity compensation $\theta_s$, option compensation $\theta_o$, and fixed salary as a fraction of capital $F/k$ are shown for the ExecuComp and Frydman-Saks samples. Equity and option compensation is reported in percent of total shares outstanding.

The final two rows report the distribution of the firm-specific parameters for idiosyncratic volatility in the high and low volatility states, $\sigma^L_i$ and $\sigma^H_i$. This parameter represents the firm-specific volatility parameter, $\beta_i$, multiplied by the common component of idiosyncratic volatility, $\sigma_t$, to give the firm’s volatility. The firm-specific component is fixed over time, and time variation in firm-level volatility is driven by changes in $\sigma_t$. See the Section 4.2 for details on it’s construction.

The fixed costs of production $f$ is chosen at the firm-year level and set equal to the 10th percentile of profits in a simulation in which fixed costs have been set to zero. This heuristic, used in Glover and Levine (2014), in combination with the external financing cost given by Gomes (2001), generates an average equity issuance frequency of about 4%.

4.2 Constructing the volatility parameters

We calibrate the Markov chain for idiosyncratic firm volatility as follows. For each firm in our sample and each year, we regress the firm’s daily equity returns on the three factors of Fama and French (1992). Define the volatility of the residuals from this regression of daily returns for firm $i$ in year $t$ as $\sigma^E_{it}$. Given a nonzero amount of debt, this corresponds to idiosyncratic, levered equity volatility. To construct an unlevered measure of firm $i$’s idiosyncratic volatility
for year \( t \), defined \( \sigma^A_{it} \), we divide this measure by a firm’s quasi-market leverage ratio, defined as book debt divided by the sum of book debt and market equity:

\[
\sigma^A_{it} = \frac{E}{D + E} \sigma^E_{it}
\]  

(16)

We compute the mean idiosyncratic, unlevered volatility for year \( t \), \( \bar{\sigma}^A_t \), as the cross-sectional average of the \( \sigma^A_{it} \) measures. We fit a two-state Markov chain to this average idiosyncratic volatility series such that \( \bar{\sigma}^A_t \in \{ \bar{\sigma}^{A,L}, \bar{\sigma}^{A,H} \} \). We identify the high volatility state \( (\sigma^{A,H}) \) as years in which the process is above the 90th percentile of its unconditional distribution in our estimated sample. We set \( \sigma^{A,L} \) and \( \sigma^{A,H} \), the mean idiosyncratic volatility in the low and high states, to their conditional means in the sample. We then calibrate the transition probabilities, \( p_{LL} \) and \( p_{HH} \) for the constructed Markov chain to match the observed frequencies in our sample. Finally, we allow each firm’s idiosyncratic volatility to load differentially on the Markov chain of average idiosyncratic volatilities. We restrict this loading to be common across states, so we have the relation:

\[
\sigma^{A,S}_{i} = \beta_i \sigma^{A,S} \quad S \in \{ L, H \}
\]

(17)

Given the parameters of the Markov chain for average idiosyncratic volatility, we compute the \( \beta_i \) for each firm by matching the unconditional unlevered volatility of its residual equity return. This gives a firm-specific estimate for the idiosyncratic component of a firm’s unlevered equity volatility.

For each firm we now have estimates of the firm’s unlevered equity volatility, i.e. asset volatility, in the high and low volatility states: \( \beta_i \sigma^{A,H} \) and \( \beta_i \sigma^{A,L} \). However, in the model the parameter of interest is the volatility of shocks to the log productivity process \( z_{it} \). Therefore, we must map the estimates of asset volatility to \( \sigma_{it} \), the volatility of innovations to the log productivity process. We take this approach because estimating the volatility of productivity at the firm level requires many years of data, as accounting data is at a low frequency. This indirect approach allows us to exploit high frequency equity data to construct asset volatility which is then mapped to \( \sigma_i \).
We estimate the relationship between asset volatility $\sigma_i^A$ and volatility of productivity shocks $\sigma_i^{TFP}$ by estimating the following cross-sectional regression:

$$
\sigma_i^{TFP} = \alpha + \lambda \bar{\sigma}^A + \gamma_j + \epsilon_i
$$

where $\gamma_j$ are industry fixed effects, and $\bar{\sigma}^A$ is the unconditional expected asset volatility given by

$$
\bar{\sigma}^A = \left[ \mathbb{P}(k = L)\sigma_{A,L} + \mathbb{P}(k = H)\sigma_{A,H} \right].
$$

The dependent variable, $\sigma_i^{TFP}$, is estimated as the standard deviation of the firm’s TFP residual using the approach of Olley and Pakes (1996). We require at least 5 observations of the TFP residual to be included in the sample.

Using the coefficient estimates, ($\hat{\alpha}$, $\hat{\lambda}$, and $\hat{\gamma}_j$), we construct predicted values for the firm’s volatility of productivity in the high and low volatility states:

$$
\sigma_i^{H} = \hat{\alpha} + \hat{\lambda}\beta_i + \hat{\gamma}_j
$$

$$
\sigma_i^{L} = \hat{\alpha} + \hat{\lambda}\beta_i + \hat{\gamma}_j.
$$

These predicted values, $\sigma_i^{H}$ and $\sigma_i^{L}$, are used as the firms’ parameters for high and low volatility in the model.\(^{13}\)

### 4.3 Evaluating the model and constructing incentive estimates

For each firm-year set of parameters, the model is evaluated numerically. Given the optimal investment policy for the manager, $i(k, z, \sigma | \Theta)$, and for the frictionless benchmark, $i^{*}(k, z, \sigma)$, we construct a very long simulation of the firm. At each simulation period, we construct the state-dependent investment incentive $\omega_0(k, z, \sigma | \Theta)$ given in (15). We construct our estimates of the manager’s overinvestment incentives $\omega^H_i$ and $\omega^L_i$ for that given firm-year set of parameters by taking the expectation for $\omega_0$ conditional on being in the high or low

\(^{13}\)Note that we construct these values for all firms in the sample, not just those that meet the data requirements to be included in the cross-sectional regression in (18).
volatility states:

\[
\omega^H_{it} \equiv \omega^H(\Theta) = E \left[ \omega_0(k, z, \sigma | \Theta) \mid \Theta, \sigma = \sigma^H \right] \\
\omega^L_{it} \equiv \omega^L(\Theta) = E \left[ \omega_0(k, z, \sigma | \Theta) \mid \Theta, \sigma = \sigma^L \right].
\]

(21)

This gives the investment incentive for firm \(i\) in year \(t\) conditional on the volatility state in year \(t\) is high or low but integrating the state dependence on \(k\) and \(z\).\(^{14}\) We then construct our data-conditional estimate of investment incentives \(\omega_{it}\) by selecting \(\omega^H_{it}\) if the volatility state in the data is high at year \(t\), and by selecting \(\omega^L_{it}\) if the volatility state in the data is low at year \(t\):

\[
\omega_{it} = \omega^H_{it}, \quad \text{if} \quad \sigma_t = \sigma^H \\
\omega_{it} = \omega^L_{it}, \quad \text{if} \quad \sigma_t = \sigma^L.
\]

(22)

The difference between these investment incentive, \(\omega_{it}^{HML} \equiv \omega^H_{it} - \omega^L_{it}\), gives the spread between the manager’s investment incentive were year \(t\) volatility realized to be in high state versus the low state. We will use \(\omega_{it}^{HML}\) as a measure of the anticipated response in investment to changes in volatility driven by a change in the manager’s incentives. We will explore if this measure predicts the relationship between uncertainty and investment seen in the data.

Before exploring the panel of investment incentive estimates, we look at how the individual components of compensation impact investment incentives and the investment response to volatility changes by looking at comparative statics and impulse responses within the model.

4.4 Comparative statics

In this section we explore comparative statics with respect to the terms of the compensation contracts to gain insight into how these variables affect the investment incentives of the manager, and how these incentives interact with time-varying volatility.

\(^{14}\)Note that the year \(t\) refers to the year \(t\) of data used to parameterize the model, not the year within the simulation.
The comparative statics with respect to fixed, equity, and option compensation are shown in Figures 2, 3, and 4, respectively. Each of the three figures follows a common structure. The top row shows the investment incentive from the model for a range of values for the compensation parameter of interest, while the other two compensation parameters are held constant. Columns A and B show these results for different choices of one of the compensation parameters which is held constant. Given that the investment incentive is a function of the current volatility state, we show $\omega^H$ and $\omega^L$ as the investment incentive conditional on being in the high and low volatility state, defined in (21). The top rows of plots show $\omega^H$ as a solid line, and $\omega^L$ as a dashed line. The bottom row of plots shows the difference between these high- and low-volatility conditional investment incentives, $\omega^{HML}$.

4.4.1 Fixed compensation

Figure 2 plots investment incentives for a range of values for fixed salary compensation, in the absence of option pay ($\theta_o = 0.0\%$), shown in Column A, and with a median-firm level of option compensation ($\theta_o = 0.47\%$), shown in Column B. For all plots, stock compensation is fixed at the median-firm level ($\theta_s = 0.37\%$). The manager is risk averse to the firm’s equity value, as it composes a non-trivial portion of total compensation. When fixed pay is very low, and there is not option compensation, most of the manager’s utility comes from her risky stock holdings, causing the manager to invest less in risky capital. As fixed pay increases, the fraction of the manager’s wealth tied to risky investment declines, and the manager is willing to take on more risk and under-invest less, hence the increasing lines in the top plot of Column A. Because the manager’s under-investment is driven by her desire to avoid risk, the manager is willing to invest at a higher level when volatility is low (dashed line) than when volatility is high (solid line). The magnitude of this difference is declining in magnitude with the amount of safe fixed pay, shown in the bottom plot of Column A.

Column B of Figure 2 repeats the exercise in the presence of option pay. With option pay, the payoff to the manager is more convex than to the shareholder, making risky projects more desirable to the manager. This tradeoff, between the risk aversion of the manager
over the risky capital investment and the convexity of payoff from option compensation, can make the investment incentive positive in the presence of option compensation, as it is for the parameter values in Column B. In the top row of Column B, both $\omega^H$ (solid) and $\omega^L$ (dashed) are increasing in fixed pay, just as before. However, the high convexity of the manager’s payoff has made the investment incentives positive. In addition, as the level of fixed pay increases, the fraction of total pay that is risky declines, making the manager less risk avoidant. For fixed pay high enough, this drives $\omega^H$ to exceed $\omega^L$, meaning that the manager actually prefers to increase investment when volatility increases. The bottom plot in Column B shows this sign change of $\omega^{HML}$ as fixed pay increases.

### 4.4.2 Equity compensation

Figure 3 performs a similar exercise, but this time equity compensation, rather than fixed pay, is varied. Just as before, Columns A and B show the comparative statics with no option pay and with a median-firm level of option pay. The parameter for fixed pay is invariant at the median-firm level ($F/k = 0.20\%$). Without option pay, the fraction of the manager’s pay that is tied to risky capital increases in the manager’s equity holding, causing a monotonic decline in the manager’s incentive to invest. Also, as the equity holdings increase, the manager becomes relatively more risk avoidant when volatility is high (solid line) than when volatility is low (dashed line). This difference is shown in the bottom plot of Column A.

In the presence of option pay, shown in Column B, as equity pay approaches zero the manager’s only wealth tied to the firm is in the form of option compensation. This means that the manager has a highly convex payoff, causing the manager’s expected payoff to be increasing in volatility. The manager balances this desire for taking additional risk against the value loss resulting from inefficiently high investment. When equity holdings are low enough, the manager chooses to invest more when volatility is high than when volatility is low. This is reflected in the difference between $\omega^H$ and $\omega^L$ shown in the bottom plot of Column A. As equity holdings become large enough, the value loss resulting from inefficiently high investment becomes more costly to the manager, and the incentive to overinvest declines.
For equity holdings high enough, the manager is more willing to invest when volatility is low, which is reflected in negative value of $\omega^H - \omega^L$.

### 4.4.3 Option compensation

Finally, Figure 4 repeats the comparative statics by varying option compensation. In this figure, Column A sets equity pay to a very low level ($\theta_s = 0.01\%$), and Column B sets equity pay to the median-firm level ($\theta_s = 0.37\%$). The parameter for fixed pay is invariant at the median-firm level ($F/k = 0.20\%$). When equity pay is very low, all the risk exposure of the manager to the firm comes from option compensation. As the level of option compensation increases, the manager’s incentive to take on risk increases, as shown by the sharp rise in $\omega^H$ (solid) and $\omega^L$ (dashed) in the top plot of Column A. Because the manager is trading off a desire to increase volatility resulting from her convex payoff and the value loss generated by inefficient investment, when equity holdings are low the manager overinvests more when volatility is high. This positive $\omega^{HML}$ is shown in the bottom plot of Column A. Interestingly, this pattern is not monotonic. As option pay becomes large enough, the manager’s fraction of total wealth that is tied to the firm increases, making her more cautious toward risk. As option pay increases, this risk aversion eventually dominates and the investment incentive declines. Accordingly, this also reduces the spread between $\omega^H$ and $\omega^L$. If fixed pay were increasing one-for-one with option pay, we would not observe this hump shape in the investment incentives.

In the presence equity compensation, shown in Column B of 4, the spread between the investment incentives in the high- and low- volatility states reverse. This results from the manager internalizing more of the value loss generated by inefficient overinvestment, as well as less of an incentive to take on increased risk. Without option pay, the manager has incentive to underinvest at a much higher rate when volatility is high than when volatility is low. As option pay increases, the manager’s willingness to take on risk increases and this spread declines.

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15We do not set equity pay exactly to zero because when the manager can issue equity without bearing any cost, the equilibrium investment decisions are not well-defined.
4.5 Response to volatility shocks

The comparative statics showed that the manager’s investment incentives depend on current volatility. To understand how volatility interacts with compensation contracts in driving investment decisions, in this section we explore the manager’s investment responds to shocks in volatility. We construct impulse responses to volatility shocks in the following way. For a given compensation contract, we run a simulation by allowing the firm to evolve naturally for many periods. Then, at event year 0, the firm is given a high shock to volatility such that $\sigma_{t=0} = \sigma^H$, after which the firm is allowed to evolve naturally. This exercise is repeated for 500,000 firms, and the mean investment rates at each event year are plotted in Figure 5. The dashed lines indicate the mean investment response for the firm simulated under the frictionless benchmark, while the solid lines are for the manager-run firm. The benchmark and manager-run firm receive the same sequences of shocks to $z$ and $\sigma$, but their capital stocks $k$ evolve independently.

Panel A shows the response to a high volatility shock at year 0 for a firm with median-firm parameter values ($\theta_s = 0.37\%$, $\theta_o = 0.47\%$, and $F/k = 0.20\%$). We see that investment rates drop in both the benchmark and manager-run case, however, the manager reduces investment to a larger degree, and investment rates remain lower for several years following the shock. This is a result of the manager being risk averse over the idiosyncratic volatility.

In Panel B we change the compensation contract to include a high degree of stock and no option pay ($\theta_s = 1.0\%$, $\theta_o = 0.0\%$). With no convexity in the payoff, and a high fraction of the manager’s payoff tied to equity, the manager’s over-reaction to the volatility shock is exacerbated, and investment rates are significantly lower than under the frictionless benchmark. However, given this initial over-reaction, manager’s begin to increase investment rates rapidly, and by year 4 investment rates exceed the benchmark, although the capital stock remains lower.

Finally, Panel C shows the impulse response when option compensation is high and equity pay is low ($\theta_s = 0.01\%$, $\theta_o = 2.0\%$). Under this contract, the manager’s payoff is highly convex, making an increase in volatility valuable. In this setting, the manager not
only invests more relative to the benchmark, but invests at a level higher than prior to the high volatility shock. The convexity of the option compensation makes investment in risky capital more attractive when idiosyncratic volatility is higher.

The investment response of the manager to changes in volatility is a function of the manager’s compensation contract. For example, a more convex payoff for the manager causes higher investment in response to high volatility shocks, and high equity exposure generates stronger underinvestment. The model allows us to measure the degree and direction of the manager’s response to volatility shocks. We test this empirical prediction of the model in the following section.

4.6 Estimates of the investment incentive

After solving the model over the full sample of firms, we summarize the manager’s investment incentives in Table II, separately for the ExecuComp and Frydman-Saks samples. The first row shows the mean, standard deviation, and percentiles for $\omega_{it}$, the overinvestment incentive for the manager of firm $i$ at date $t$ conditional on the actual volatility state at date $t$. The second and third rows show these summary statistics for the estimated investment incentive were the firm in the high volatility state, $\omega^H_{it}$, and the low volatility state, $\omega^L_{it}$. Distributional information about the difference in these estimates, $\omega^H_{it} - \omega^L_{it}$, is given in the fourth row. This difference represents the change in the manager’s investment incentives that would occur if the current volatility state switched from low to high. In words, for the ExecuComp sample, were the current volatility state switched from low to high, on average a manager would have the incentive to overinvest 0.31 percentage points less.

We see that the conditional investment incentive, $\omega_{it}$, is on average positive, at 0.83 percentage points. This means that on average the manager would like to invest at a rate 83 basis points higher than the investment rate that maximizes the present value of future cashflows given by the frictionless benchmark. In addition, 63% of the ExecuComp, and 86% of Frydman-Saks, sample have an incentive to overinvest relative to the benchmark.

In Figure 6 we explore the time series dynamics of the mean overinvestment incentives for
the Frydman-Saks sample in Panel A and for the ExecuComp sample in Panel B. The top row plots the time series of cross-section means of $\omega^H_{it}$ (dotted line), $\omega^L_{it}$ (dash-dotted line), and $\omega_{it}$ (solid line). For most of the Frydman-Saks sample, volatility is in the low state, and thus $\omega_{it} = \omega^L_{it}$. For the latter part of the sample, there are two high-volatility periods: 1998–2002, and 2008–2009. We see in the figure that the investment incentive dropped during those periods due to the increase in volatility. We see this more closely in the top plot in Panel B, and the significant drop in investment incentives during these high-volatility periods.

The bottom row plots the mean difference between the manager’s investment incentive between the high and low volatility states: $\omega^H_{it} - \omega^L_{it}$. This shows there is significant time variation in the degree to which the manager’s incentives respond to changes in volatility. We see for the ExecuComp sample that the response of a shift from low to high volatility went from less $-0.4\%$ in 1993, rose to as high as $-0.1\%$ at its peak in 2004, and then fell to $-0.5\%$ in 2012. We will test this prediction of time variation, as well as cross-sectional variation, in investment responses to volatility shocks later in paper.

Glover and Levine (2014) show that the manager’s investment incentives induced by their compensation contracts has strong predictive power for $Q$, changes in investment rates, and acquisition activity. In contrast, in this paper we are interested in the investment response to changes in volatility and we therefore focus our empirical tests on that relationship.

5 Changes in volatility: empirical predictions

The model has direct predictions for the interaction between changes in volatility and the investment incentives of the manager. The comparative statics of the model, shown in Figures 2, 3, and 4, show a non-trivial relationship between the components of compensation and investment as a function of the current level of idiosyncratic volatility. In this section we investigate this empirical prediction of the model.

Specifically, for a given compensation contract, we use the model to estimate the investment incentive of the manager if volatility is high, $\omega^H$, and if the volatility is low, $\omega^L$. The difference in these investment incentives, $\omega^{HML} = \omega^H - \omega^L$, gives a prediction of the change
in the investment rate that would result from switching from the low volatility state to the high volatility state. Our model predicts that the sensitivity of changes in investment rates to volatility changes should correlate with $\omega^{HML}$.

In what follows we test this empirical prediction using a panel regression approach, followed by an event study.

### 5.1 Panel regression: investment-volatility sensitivity

To test the predicted relationship between investment-volatility sensitivity and manager’s investment incentives we estimate a panel regression of changes in investment rates on changes in firm-specific volatility and various controls. Our prediction is that the coefficient on changes in volatility should be monotonically increasing in the model-estimated $\omega^{HML}$. The dependent variable in all regressions is constructed as the one-year change in a firm’s investment rate, $I_{it}^{K}$. As discussed before, the model has predictions about changes in investment rates on changes in volatility, which is the direct empirical test we perform. An advantage to this empirical approach is that differencing removes unobservable firm heterogeneity, mitigating the concern that the results are driven by correlation between our measure and an unrelated, but unobserved, firm characteristic.

A firm’s idiosyncratic volatility, $(\sigma_{i,t-1})$ is constructed as the standard deviation of the residual in a regression of the firm’s daily equity returns on the Fama-French 3 factor portfolios. To test the model predictions, we compute innovations in firm idiosyncratic volatility as follows. We define $\eta_{i,t}$ as the innovation in firm $i$’s log idiosyncratic volatility at date $t$.

This innovation is estimated for the panel of firms in our sample via the regression:

$$\log(\sigma_{i,t}) = \mu_i + \xi \log(\sigma_{i,t-1}) + \eta_{i,t}$$

(23)

where $\mu_i$ represents a firm-specific intercept. Therefore, our innovations are computed as the fitted residuals, $\eta_{it}$.

\footnote{For the results that follow, we have also implemented alternative specifications that use the difference in log idiosyncratic volatility, $\log(\sigma_{i,t}) - \log(\sigma_{i,t-1})$, in place of $\eta_{it}$. In all cases, the results are very similar. Alternative specifications for the regression (23) using additional lags of $\log(\sigma_{i,t})$ also produce very similar results. Additional lags included in (23) were generally statistically insignificant.}
The regression is specified as follows:

$$\Delta \left( \frac{I_{i,t}}{K_{i,t-1}} \right) = \beta_0 + \beta_1 \eta_{i,t-1} + \beta_2 \Delta \log(Q_{i,t-1}) + \beta_3 \Delta \left( \frac{CF_{i,t-1}}{K_{i,t-2}} \right) + \beta_4 \Delta \log(K_{i,t-1}) + \beta_5 \Delta \log \left( \frac{E_{i,t-1}}{A_{i,t-1}} \right) + \nu_i + \gamma_t + \epsilon_{i,t}$$  \hspace{1cm} (24)

The independent variables, somewhat standard in investment regressions, are defined as follows. The innovation in a firm’s idiosyncratic volatility, $\eta_{it}$, is constructed as described above. Controls include Tobin’s $q$ ($Q_{i,t-1}$), defined as the sum of a firm’s market equity and book debt normalized by net PP&E; cash flow ($CF_{i,t-1} / K_{i,t-2}$), defined as operating income before depreciation normalized by lagged net PP&E; capital stock $K_{i,t-1}$, defined as a firm’s net PP&E normalized by the average PP&E for all other firms in the sample in that year; and the leverage ratio, $E_{i,t} / A_{i,t}$, defined as the ratio of the firm’s book equity to book assets. All independent variables are in one-year changes, denoted by the operator $\Delta$, and all regressions include firm ($\nu_i$) and year ($\gamma_t$) fixed-effects.\(^{17}\) Standard errors are clustered at the firm-level.

Before exploring the relationship between the coefficient on volatility innovations and the investment incentive, Table III shows the unconditional results for this panel regression for the full ExecuComp sample. Column (1), which shows the univariate regressions, shows a strong negative relationship between changes in investment and lagged innovations in volatility, $\eta_{i,t-1}$. This coefficient becomes insignificant in Columns (2) and (3) with the inclusion of changes in Tobin’s $q$ and change in cash flow. In the full specification in Column (4), the coefficient on volatility innovations is again significantly negative at the one-percent level.

We test whether the coefficient on changes in volatility corresponds to the model-estimated $\omega_{HML}$ in Table IV by running the full specification of the panel regression conditioning on various levels of $\omega_{HML}$. The model predicts that lower values of $\omega_{HML}$ predicts lower values for the coefficient on volatility changes. We divide the sample into four groups using different subsamples on $\omega_{HML}$: very negative ($\omega_{i,t-1}^{HML} < -1\%$), slightly negative ($\omega_{i,t-1}^{HML} < -0.5\%$), slightly positive ($\omega_{i,t-1}^{HML} > 0.5\%$), and very positive ($\omega_{i,t-1}^{HML} > 1\%$). We find strong sup-

\(^{17}\)The results without firm fixed effects are similar.
port for the predictions of the model: the coefficient estimates increase monotonically and significantly as $\omega^{HML}$ increases. In addition, the coefficient is significantly negative for the negative $\omega^{HML}$ bins and the coefficient is positive, although not significant, for the very positive $\omega^{HML}$ bin. These results provide evidence that the relationship between volatility and investment is driven at least in part by the manager’s investment incentives induced by her compensation contract.\(^{18}\)

To provide some context for the magnitude of these estimates, consider the effect of a change in $\eta_{i,t-1}$ for a firm in the lowest group ($\omega^{HML}_{i,t-1} < -1\%$). For a firm of this group, a one standard deviation change to $\eta_{i,t-1}$ corresponds to a predicted reduction in the investment rate of 1.9 percentage points. That magnitude of change is equal to 14\% of the cross-sectional standard deviation in the 2012 change in investment rates for firms in our sample. Thus, these effects seem to be economically significant in their ability to explain cross-sectional variation in the changes in investment rates, even after using a number of controls and fixed effects in the regression.

5.2 Volatility shocks of 1998 and 2008

The previous sections show that the model-implied manager investment incentive, specifically $\omega^{HML}_{it} \equiv \omega^H_{it} - \omega^L_{it}$, predicts the response in investment to changes in volatility seen in the data. In this section, we explore the investment response of firms to two large volatility increases seen in the data: 1998 and 2008. In constructing the two-state markov process for volatility, detailed in Section 4.2, these two years are unique in that they represent an upward shock to volatility. Specifically, volatility is in the low state in both 1997 and 2007, followed by the high state in 1998 and 2008. The upward volatility shocks in those years are a natural opportunity to explore the investment response for firms which differ in their manager’s investment-volatility sensitivity, $\omega^{HML}_{it}$.

Figure 7 shows the investment patterns following these volatility shocks. In the year prior

\(^{18}\)These results are robust to various regression specifications. In particular, the results are similar to a specification including lagged changes in investment rates as an independent variable, using the two-step GMM estimation proposed by Arellano and Bond (1991) to address the bias generated under OLS when the lagged dependent variable is included as a regressor.
to the volatility increase, 1997 and 2007, firms are sorted in three bins based on their model-estimated $\omega_{it}^{HML}$ for those years. The bin cutoffs are at the 20th and 80th percentiles for those years, representing low, medium, and high $\omega_{it}^{HML}$, and the assignments are maintained through the entire period shown. For each year shown, each firm’s investment rate is scaled by its own initial investment rate in year 1997 or 2007, and the mean and median of these scaled investment rates are shown in Panel A and B. The solid line represents the firms in the low-$\omega_{it}^{HML}$ bin, dashed for the middle bin, and dotted for the high bin. The investment rates are scaled by the initial pre-shock investment rates to control to heterogeneity in the investment rate levels across the different subsets. Thus, the mean and median rates shown represent percent changes in investment rates and do not reflect the levels. The sample of scaled investment rates is trimmed at the 2.5 and 97.5 percent levels to eliminate the effect of outliers. Firms are required to have data for all years shown to be included in the sample.

Panel A of Figure 7 reveals investment response predicted by the model. For both the 1998 and 2008 shocks, firms with managers who have the highest $\omega_{it}^{HML}$ (dotted line) invest at a rate higher than those with the lowest $\omega_{it}^{HML}$ (solid line) in the years following the volatility increase. Furthermore, the investment response across the three subgroups is monotonic in $\omega_{it}^{HML}$. The economic magnitude of the differences is also significant. During the expansion in 1998, the highest group had investment rates which increases 11% while the lowest group’s rates increased by only 2%, a gap which increased the following year. During the financial crisis, investment rates across the board declined significantly in 2009; however, the lowest-$\omega_{it}^{HML}$ group’s investment rates decreased on average by 33% from their 2007 levels, while the highest-$\omega_{it}^{HML}$ group’s investment rates decreased by only 20%. The results using median values is shown in Panel B. The results are qualitatively similar, confirming the results are not due to outliers or strong skewness in the distribution of investment rates.

The two periods, 1998 and 2008, represent very different periods in terms of aggregate conditions, the prior occurring during an expansion and the latter being driven by the financial crisis. An potential explanation for the pattern observed in Figure 7 is that the model-constructed variable $\omega_{it}^{HML}$ is correlated with the firm’s optimal investment response to an
aggregate productivity or demand shock. Then the response to the 2008 shock is not driven by a differential response to volatility, but by heterogeneity of the firms’ loadings on the aggregate productivity or demand shock. However, if this were the case we would expect that following the 1998 shock, which corresponded to a positive aggregate productivity or demand shock, that the lowest $\omega^{HML}_i$ firms would have the strongest positive response to the shock. That the ordering of the investment responses across $\omega^{HML}$ subgroups is preserved in both the expansion and contraction suggests that the model-estimated $\omega^{HML}$, and thus managers’ incentives, play a role in the investment response to volatility shocks.

6 Conclusion

We find evidence that manager incentives are important for understanding firm’s investment response to changes in volatility. The previous literature has focused primarily on financial frictions and the “wait-and-see” real option effect in understanding the impact of uncertainty on investment. Using a large panel of model-predicted incentives of the manager’s response to volatility shocks, we find that our measure predicts investment responses in both the cross section and time series. Further, we show that accounting for manager incentives helps to explain why some firms’ investment rates declined so significantly. This suggests that future research should consider the impact of delegated control and agency conflicts when studying the relationship between uncertainty and investment.
References


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Li, Shaojin, and Toni M Whited, 2013, Collateral, taxes, and leverage, *Available at SSRN 2360391*.


Table I: Model Parameters

This table presents the calibrated and estimated parameters of the model. Where applicable, the parameter refers to an annual frequency. Panel A reports the production and financing parameters that are set to be common to all firms. Panel B displays statistics for the distribution of the contract parameters and firm specific volatility, where $\theta_S$ and $\theta_O$ refer to the manager’s shares in stock or options, respectively, as a fraction of the total shares outstanding. The manager’s fixed pay normalized by capital is denoted $F/k$. A firm’s idiosyncratic volatility in the low and high state are denoted by $\sigma_L^i$ and $\sigma_H^i$. All compensation contract moments are displayed as percentages.

Panel A: Production parameters

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<td>Productivity shock persistence</td>
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<td>Discount factor</td>
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Panel B: Statistics for the Distribution of Compensation Parameters

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<th>p25</th>
<th>p50</th>
<th>p75</th>
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</table>
Table II: Distribution of Model Computed Conditional Overinvestment Incentives

This table presents statistics for the distributions of conditional manager overinvestment incentives, \( \omega \), computed in the calibrated model. The overinvestment incentive for the manager of firm \( i \) at date \( t \), conditional on the volatility state at date \( t \), is denoted \( \omega_{it} \). The value \( \omega_{it}^H \) denotes the overinvestment incentive for the manager of firm \( i \) at date \( t \) if the economy were in a high volatility state. The analog for a low volatility state is given by \( \omega_{it}^L \). All values are reported in percentage points at an annual frequency.

<table>
<thead>
<tr>
<th>Execucomp Firms</th>
<th>mean</th>
<th>sd</th>
<th>p5</th>
<th>p10</th>
<th>p25</th>
<th>p50</th>
<th>p75</th>
<th>p90</th>
<th>p95</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \omega_{it} )</td>
<td>0.83</td>
<td>1.80</td>
<td>-2.13</td>
<td>-1.48</td>
<td>-0.41</td>
<td>0.84</td>
<td>2.30</td>
<td>2.98</td>
<td>3.38</td>
</tr>
<tr>
<td>( \omega_{it}^H )</td>
<td>0.64</td>
<td>2.17</td>
<td>-3.01</td>
<td>-2.14</td>
<td>-0.89</td>
<td>0.49</td>
<td>2.29</td>
<td>3.41</td>
<td>4.15</td>
</tr>
<tr>
<td>( \omega_{it}^L )</td>
<td>0.95</td>
<td>1.52</td>
<td>-1.59</td>
<td>-1.04</td>
<td>-0.23</td>
<td>1.01</td>
<td>2.30</td>
<td>2.86</td>
<td>3.10</td>
</tr>
<tr>
<td>( \omega_{it}^H - \omega_{it}^L )</td>
<td>-0.31</td>
<td>0.80</td>
<td>-1.48</td>
<td>-1.21</td>
<td>-0.82</td>
<td>-0.39</td>
<td>0.00</td>
<td>0.68</td>
<td>1.26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FS Firms</th>
<th>mean</th>
<th>sd</th>
<th>p5</th>
<th>p10</th>
<th>p25</th>
<th>p50</th>
<th>p75</th>
<th>p90</th>
<th>p95</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \omega_{it} )</td>
<td>1.62</td>
<td>1.25</td>
<td>-0.74</td>
<td>-0.26</td>
<td>0.81</td>
<td>1.92</td>
<td>2.61</td>
<td>2.97</td>
<td>3.15</td>
</tr>
<tr>
<td>( \omega_{it}^H )</td>
<td>1.40</td>
<td>1.51</td>
<td>-1.35</td>
<td>-0.74</td>
<td>0.43</td>
<td>1.70</td>
<td>2.57</td>
<td>3.13</td>
<td>3.43</td>
</tr>
<tr>
<td>( \omega_{it}^L )</td>
<td>1.64</td>
<td>1.23</td>
<td>-0.65</td>
<td>-0.24</td>
<td>0.90</td>
<td>1.94</td>
<td>2.62</td>
<td>2.96</td>
<td>3.14</td>
</tr>
<tr>
<td>( \omega_{it}^H - \omega_{it}^L )</td>
<td>-0.24</td>
<td>0.35</td>
<td>-0.76</td>
<td>-0.63</td>
<td>-0.47</td>
<td>-0.26</td>
<td>-0.04</td>
<td>0.22</td>
<td>0.42</td>
</tr>
</tbody>
</table>
Table III: Change in Investment Regressions: ExecuComp Sample

We perform panel regressions of the change in a firm’s investment rate on lagged changes in the firm’s log idiosyncratic volatility and changes in control variables. The dependent variable in all regressions is constructed as the one year change in a firm’s investment rate, \( \frac{I_{i,t} - I_{i,t-1}}{K_{i,t-1}} \). A firm’s idiosyncratic volatility, \( \sigma_{i,t-1} \), is constructed as the standard deviation of the residual in a regression of the firm’s daily equity returns on the Fama-French 3 factor portfolios. Tobin’s q \( (Q_{i,t-1} - 1) \) is the sum of a firm’s market equity and book debt normalized by net PPE. We construct cash flow \( \left( \frac{CF_{i,t-1}}{K_{i,t-2}} \right) \) as operating income before depreciation normalized by lagged net PPE. \( K_{i,t-1} \) is a firm’s net PPE normalized by the average PPE for all other firms in the sample in that year. A firm’s leverage ratio, \( \frac{E_{i,t}}{A_{i,t}} \), is measured as the ratio of the firm’s book equity to book assets. The sample consists of the unbalanced panel of Execucomp firms for the period 1992-2012 at an annual frequency. All regressions include firm and year fixed-effects. Standard errors are clustered at the firm-level and the reported \( R^2 \) measures the within-firm variation.

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta_{i,t-1} )</td>
<td>-0.0707**</td>
<td>-0.00646</td>
<td>-0.0185*</td>
<td>-0.0258**</td>
</tr>
<tr>
<td></td>
<td>(-7.00)</td>
<td>(-0.66)</td>
<td>(-2.00)</td>
<td>(-3.24)</td>
</tr>
<tr>
<td>( \Delta \log(Q_{i,t-1}) )</td>
<td>0.247**</td>
<td>0.218**</td>
<td>0.0988**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(22.89)</td>
<td>(20.18)</td>
<td>(12.83)</td>
<td></td>
</tr>
<tr>
<td>( \Delta \left( \frac{CF_{i,t-1}}{K_{i,t-2}} \right) )</td>
<td>0.000797</td>
<td>0.00614*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.18)</td>
<td>(2.03)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Delta \log(K_{i,t-1}) )</td>
<td>-0.980**</td>
<td></td>
<td>(-24.25)</td>
<td></td>
</tr>
<tr>
<td>( \Delta \log \left( \frac{E_{i,t-1}}{A_{i,t-1}} \right) )</td>
<td>0.0271</td>
<td></td>
<td>(1.29)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>18055</td>
<td>17937</td>
<td>15702</td>
<td>15625</td>
</tr>
<tr>
<td>Adjusted ( R^2 )</td>
<td>0.031</td>
<td>0.157</td>
<td>0.147</td>
<td>0.418</td>
</tr>
</tbody>
</table>

\( t \) statistics in parentheses
* \( p < 0.05 \), ** \( p < 0.01 \)
Table IV: *Change in Investment Regressions by $\omega^{HML}$: ExecuComp Sample*

The table reports regressions of changes in investment rates for four subsamples of firms. We perform regression specification (4) of Table III for subsamples of firm-year observations sorted according to the measure $\omega_{i,t-1}^{HML} = \omega_{i,t-1}^H - \omega_{i,t-1}^L$ computed in the model. The controls are the same as described in Table III. The sample consists of the unbalanced panel of Execucomp firms for the period 1992-2012 at an annual frequency. All regressions include firm and year fixed-effects. Standard errors are clustered at the firm-level and the reported $R^2$ measures the within-firm variation.

<table>
<thead>
<tr>
<th></th>
<th>(1) $\omega_{i,t-1}^{HML} &lt; -1%$</th>
<th>(2) $\omega_{i,t-1}^{HML} &lt; -0.5%$</th>
<th>(3) $\omega_{i,t-1}^{HML} &gt; 0.5%$</th>
<th>(4) $\omega_{i,t-1}^{HML} &gt; 1%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_{i,t-1}$</td>
<td>-0.0701***</td>
<td>-0.0413**</td>
<td>-0.000890</td>
<td>0.00360</td>
</tr>
<tr>
<td></td>
<td>(-2.87)</td>
<td>(-3.73)</td>
<td>(-0.04)</td>
<td>(0.11)</td>
</tr>
<tr>
<td>$\Delta \log(Q_{i,t-1})$</td>
<td>0.0936**</td>
<td>0.0958**</td>
<td>0.0948**</td>
<td>0.100**</td>
</tr>
<tr>
<td></td>
<td>(4.73)</td>
<td>(8.46)</td>
<td>(4.40)</td>
<td>(4.43)</td>
</tr>
<tr>
<td>$\Delta \left(\frac{CF_{i,t-1}}{K_{i,t-2}}\right)$</td>
<td>0.00899</td>
<td>0.00815</td>
<td>0.00305</td>
<td>0.00790</td>
</tr>
<tr>
<td></td>
<td>(0.94)</td>
<td>(1.33)</td>
<td>(0.42)</td>
<td>(0.74)</td>
</tr>
<tr>
<td>$\Delta \log(K_{i,t-1})$</td>
<td>-1.221**</td>
<td>-1.067**</td>
<td>-1.118**</td>
<td>-0.999**</td>
</tr>
<tr>
<td></td>
<td>(-16.27)</td>
<td>(-22.38)</td>
<td>(-8.65)</td>
<td>(-9.88)</td>
</tr>
<tr>
<td>$\Delta \log\left(\frac{E_{i,t-1}}{A_{i,t-1}}\right)$</td>
<td>0.0218</td>
<td>0.0237</td>
<td>0.0413</td>
<td>0.163*</td>
</tr>
<tr>
<td></td>
<td>(0.39)</td>
<td>(0.93)</td>
<td>(0.49)</td>
<td>(2.31)</td>
</tr>
<tr>
<td>Observations</td>
<td>2340</td>
<td>6547</td>
<td>2375</td>
<td>1499</td>
</tr>
<tr>
<td>Adjusted $R^2$</td>
<td>0.522</td>
<td>0.470</td>
<td>0.412</td>
<td>0.379</td>
</tr>
</tbody>
</table>

$t$ statistics in parentheses

* $p < 0.05$, ** $p < 0.01$
Figure 1: Equity and option compensation. Shows the cross-sectional mean (top row) and median (bottom row) equity (dashed line) and option (solid line) compensation. Equity and option compensation are expressed as a fraction of total shares outstanding. Panel A shows the Frydman-Saks sample spanning 1956–2012, and Panel B shows the ExecuComp sample spanning 1993–2012.
Figure 2: Comparative statics: fixed compensation. Shows comparative statics for the investment incentive $\omega_H$, $\omega_L$, and their difference, by varying fixed pay $F/k$. The parameter for stock compensation represents the median firm ($\theta_s = 0.37\%$). For Column A, option compensation has been set to zero ($\theta_o = 0\%$). For Column B, option compensation has been set to its median value ($\theta_o = 0.47\%$). The top row plots investment incentives conditional on volatility being high, $\omega_H$, (solid line) and conditional on volatility being low, $\omega_L$, (dashed line). The bottom row plots the difference in these values: $\omega_H - \omega_L$. 
Figure 3: **Comparative statics: equity compensation.** Shows comparative statics for the investment incentive $\omega_H$, $\omega_L$, and their difference, by varying equity compensation $\theta_s$. The parameter for fixed pay represents the median firm ($F/k = 0.20\%$). For Column A, option compensation has been set to zero ($\theta_o = 0\%$). For Column B, option compensation has been set to its median value ($\theta_o = 0.47\%$). The top row plots investment incentives conditional on volatility being high, $\omega_H$, (solid line) and conditional on volatility being low, $\omega_L$, (dashed line). The bottom row plots the difference in these values: $\omega_H - \omega_L$. 

36
A. Low equity pay ($\theta_s = 0.01\%$)  
B. Median equity pay ($\theta_s = 0.37\%$)

Figure 4: **Comparative statics: option compensation.** Shows comparative statics for the investment incentive $\omega_H, \omega_L$, and their difference, by varying option compensation $\theta_o$. The parameter for fixed pay represents the median firm ($F/k = 0.20\%$). For Column A, equity compensation has been set very low ($\theta_s = 0.01\%$). For Column B, equity compensation has been set to its median value ($\theta_s = 0.37\%$). The top row plots investment incentives conditional on volatility being high, $\omega_H$, (solid line) and conditional on volatility being low, $\omega_L$, (dashed line). The bottom row plots the difference in these values: $\omega_H - \omega_L$. 


Figure 5: **Impact of a volatility shock.** Shows the impulse response for a firm which receives a high volatility shock in year 0, and the volatility process is allowed to evolve naturally thereafter. The plots show average investment rate responses for the manager-run firm (solid line) and for the frictionless benchmark (dashed line). The results are shown for three different compensation contracts: Panel A shows the results for the median compensation contract in the Execucomp sample ($\theta_s = 0.37\%, \theta_o = 0.47\%, \text{ and } F/k = 0.20\%$); Panel B shows results for a high stock, no option contract ($\theta_s = 1.0\%, \theta_o = 0.0\%, \text{ and } F/k = 0.20\%$); and Panel C shows results for a low stock, high option contract ($\theta_s = 0.01\%, \theta_o = 2.0\%, \text{ and } F/k = 0.20\%$). Each plot is the average of 500,000 firm simulations where each firm has been allowed to evolve naturally over a long horizon prior to year 0.
Figure 6: **Investment incentives.** The top row shows the cross-sectional mean investment incentive conditional on being in the high volatility state, $\omega_H$ (dash-dotted line), in the low volatility state, $\omega_L$ (dotted line), and the conditional investment incentive, $\omega_t$ (solid line). The bottom row show the difference between the cross-sectional means of the high and low conditional investment incentives, $\omega_H - \omega_L$. Panel A shows the Frydman-Saks sample spanning 1956–2012, and Panel B shows the ExecuComp sample spanning 1993–2012.
Figure 7: Investment response to volatility increases of 1998 and 2008. Shows investment rates following the volatility shocks from $\sigma^L$ to $\sigma^H$ in 1998 and 2008. In the year prior to the volatility increase, 1997 and 2007, firms are sorted in three bins based on their model-estimated $\omega_{it}^{HML} \equiv \omega^H_{it} - \omega^L_{it}$ for those years, and the assignments are maintained through the entire period shown. The bin cutoffs are at the 20th and 80th percentiles for those years, representing low, medium, and high $\omega_{it}^{HML}$. For each year shown, each firm’s investment rate is scaled by its own initial investment rate in year 1997 or 2007, and the mean and median of these scaled investment rates are shown in Panel A and B. The solid line represents the firms in the low-$\omega^{HML}$ bin, dashed for the middle bin, and dotted for the high bin. The investment rates are scaled by the initial pre-shock investment rates to control for heterogeneity in the investment rate levels across the different subsets. Thus, the mean and median rates shown represent percent changes in investment rates and do not reflect the levels. The sample of scaled investment rates is trimmed at the 2.5 and 97.5 percent levels to eliminate the effect of outliers. Firms are required to have data for all years shown to be included in the sample.