What does the market know?*

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Abstract

I measure how much information the market knows about firms' fundamentals and managers' incentives to misreport on these fundamentals. The market knows 76.5% of current earnings and 36.8% of managers' incentives to misreport in a current report before the current earnings report arrives. 40.0% of this fundamental and 88.5% of this misreporting incentives information is learned about one year in advance, concurrently with the previous earnings report. A 1% increase in the market's fundamental information will increase earnings quality by 0.885% and improve price efficiency by 1.254%. A 1% increase in the market's misreporting incentives information will reduce earnings quality by 0.158% and improve price efficiency by 0.067%.

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Introduction

Financial misreporting is a product of managers' incentives (i.e., the extent to which the manager's welfare depends on the firm price) and price responsiveness to firms' reports (i.e., the extent to which the manager can move the price by biasing her report). Price responsiveness, in turn, is a function of the information that market participants have. When investors know more about firm fundamentals, firm price is less responsive to financial reports, reducing misreporting. In contrast, investors that are better informed about managers' incentives rely on financial reports more, increasing the misreporting (Fischer and Stocken (2004)). Therefore, to study and regulate financial misreporting, it is crucial to understand what market participants know. In this paper, I estimate how much information investors know about firm fundamentals and managers' misreporting incentives and when investors learn this information.

Potential sources of the market's information are very diverse and almost impossible to count: they include filings of a focal firm and other firms, financial analysts' reports, mass media, managers' and other employees' social media accounts, conference calls, and private meetings with companies' executives. My goal in this paper is not to analyze a particular source, but to estimate the total amount of fundamental and misreporting incentives information that market participants know and understand when they learn it. Because information sources are almost indefinite and some of them are unobservable, a reduced-form approach that must use a proxy for information, which by definition means choosing a certain source, cannot provide complete estimates. The reduced-form approach also cannot provide correct estimates about the marginal effects of changes in the market's information on accounting quality.[1] I use structural estimation – the method that uses observed data and a theoretical model to estimate unobserved theoretical parameters.

To estimate the parameters of interest – the amount of fundamental and misreporting incentives information that the market knows – using the structural approach, I need to find data moments that are sensitive to these parameters and thus help identify them. I use the movement of firm prices to identify the amount of fundamental information that investors know. To measure the market's misreporting incentives information, I assume that when financial analysts predict the next earnings report, they aim to predict the number that will be reported as close as possible (Mikhail et al. (1999), Hilary and Hsu (2013)). This implies that ana-

[1] In the reduced-form approach, a researcher needs to use a plausibly exogenous shock that changes on the type of information (e.g., misreporting incentives) that the market has but not the other (e.g., fundamental). However, it is often easy to argue why one informational shock can provide investors with both types of information. For example, the introduction of the Compensation Disclosure and Analysis section in 2006 arguably improved investors' understanding of managers' incentives to misreport. At the same time, since investors learned how managers are compensated, they could infer real decisions that managers would make and thus firms' fundamental performance.

lysts forecast the sum of true earnings and the bias that the manager will add to the report, where the bias is a function of the manager's misreporting incentives.

I estimate how much information the market learns at two periods of a year: (1) on the day of an annual earnings report and (2) on all other days.[2] I use the residual variance of the regression of price changes and analyst forecasts in [-1, 1] day window around an earnings report on the earnings surprise to measure how much information the market learned during this window. Any prices or forecasts' movements that are not explained by the reported number are due to other information that investors learn on the day of the report, for example, from earnings calls. For the second period, I assume that changes in firm prices and analyst forecasts from right after one annual report to right before the next annual report are driven by new information about fundamentals and misreporting incentives that market participants learn during the year between two reporting dates.

I model a manager who governs a firm that is traded in a perfectly competitive market. Firm annual earnings – the fundamental – have two components: a public component, which is observed by both the manager and the investors, and a private component, which is privately observed by the manager. Every year the manager issues an annual report about the firm's book value – the cumulative sum of all firm earnings before and in the current year. The manager can bias her report at a cost which is increasing in distance between the true firm's book value and the manager's report.[3] The manager's misreporting incentives, or the extent to which she cares about firm stock price, change every year and similarly to fundamentals has two components: a public and a private. Investors use their information about the fundamental and the manager's misreporting incentives to interpret the manager's annual report and price the firm at its expected future value.

To estimate when investors learn their information, I further divide the public information components into two parts. The first part arrives one year in advance, concurrently with the previous earnings report.[4] The second part is learned at other times during the year preceding the current report.

In equilibrium, the manager's annual report is a sum of the firm's true book value and a reporting bias. The bias is a product of the price responsiveness to the report and a discounted sum of the manager's

[2]The technique can be easily adjusted for any number of any other periods during the year.

[3]Reporting about book value – the cumulative sum of all earnings – as opposed to about annual earnings naturally restricts the manager's ability to misreport. If the manager restated the book value last year, she would have to pay an even higher cost for overstating the book value today. To bring her cost to zero, the manager would need to understate this year's book value.

[4]Importantly, the first part of public information is from any source concurrent with the previous earnings report, such as earnings calls, but not from the report itself.

current and expected future misreporting incentives. The price responsiveness to the manager's report is decreasing in the amount of the market's fundamental information and increasing in the amount of the market's misreporting incentives information. As a result, when investors know more about firm fundamentals (misreporting incentives), the manager gets a smaller (higher) reward per unit of misreported book value. Financial misreporting is decreasing in the market's fundamental and increasing in the market's misreporting incentives information.

The model yields six theoretical moments that describe variances of earnings reports and changes in analysts' forecasts during a year, the covariance of changes in prices during a year with this year's earnings reports, earnings response coefficient, and residual variance of the regression of changes in firm price in a [-1, 1] window around an earnings report on the earnings.

To compute empirical moments, I gather data on firm prices from the CRSP database and on earnings reports and analysts' forecasts from the IBES database. After removing firms with missing data, a market-to-book ratio below 30,[5] and stock price above $1, I am left with 42,384 U.S. companies from 1992 to 2020.

I use the generalized method of moments (GMM) to estimate the model. The method searches for the model's parameter values that minimize the distance between theoretical and empirical moments. The distance is a quadratic form of the differences between theoretical and empirical moments with an optimal weighting matrix.

The estimation shows that market participants know 76.5% of information about a firm's current-year earnings available to firm managers, 40.0% of which is learned concurrently with the prior-year earnings report. Investors also know 36.8% of the manager's misreporting incentives and learn 88.5% of it when the prior-year earnings report arrives. For an average firm in my sample, a reported earnings number differs from the true earnings number by about 74.1% of the standard deviation of the true earnings. The price of this average firm is by $376.77 million different from what it could be if investors knew all the information that the manager knows.

These parameter estimates allow me to conduct counterfactual analyses. The elasticity of accounting quality (price efficiency) with respect to the market's fundamental information is 0.885 (1.254), and with respect to misreporting incentives information is -0.158 (0.067). If investors were given 1% more informa-

[5]The equilibrium in the model is a steady-state, implying a stable company that does not grow. That is why I restrict my sample to only companies that are not at a growing stage.

tion about firm fundamentals (misreporting incentives), the bias in the reported numbers would be reduced by 0.885% (increase by 0.158%). The difference between an average firm's actual price and its value without information asymmetry would increase by 1.254% (increase by 0.067%). As for larger changes in the market's information, price efficiency is more sensitive to the amount of fundamental information that the market knows, and accounting quality is more sensitive to the amount of the market's misreporting incentives information.

I use the developed technique to measure how much misreporting incentives information investors have learned after the compensation disclosure regulation in 2006. The goal of the Compensation Disclosure and Analysis (CD&A) section in firms' proxy statements was to provide investors with detailed information on executive compensation and potential incentives resulting from it. Before the regulation, investors knew 43.4% of total misreporting incentives information. After the regulation, this number changed to 49.0%.

I estimate the model on different subsamples of firms. Firms that hold earnings calls have more volatile fundamentals: the variance of their earnings shocks is 43% larger than the variance of earnings shocks for firms that do not hold earnings calls. Investors of firms with earnings calls know the greater absolute amount of annual earnings shocks of their firms. For firms that hold (do not hold) earnings calls, the market learns 43% (35.5%) of its total fundamental information on earnings report days. Larger firms have more volatile fundamentals and managers' misreporting incentives. The market knows 66.1% (20.8%) of total fundamental (misreporting incentives) information for large companies, 85.8% (39.1%) of total fundamental (misreporting incentives) information for medium-sized companies, and 91.0% (35.3%) of total fundamental (misreporting incentives) information for companies in the lowest size tercile. I also provide evidence of information spillover from companies that report early in the earnings cycle to companies that report later. Investors know 56.0% of fundamental information for early reporters and 67.7% for late reporters in a given year.

The main model of the paper does not include reporting noise introduced by accounting system errors. Prior studies have shown that this reporting noise can be considerable (Beyer et al. (2019)). Investors' uncertainty about accounting systems' errors and managers' misreporting incentives affect the earnings response coefficient in the same direction, implying that if I do not account for reporting noise in my model, I can overestimate investors' uncertainty about misreporting incentives. In the last section of this paper, I extend the model to include accounting system errors as another source of bias in the manager's reports. Interestingly, the estimates of the extended model suggest that accounting system error uncertainty is not distinguishable from zero, or small compared to the misreporting incentives uncertainty.

In the section 1 I describe relevant literature and my contribution. Section 2 describes the model, and section 3 the data, the estimation procedure, and the results. Section 4 shows counterfactual analysis, and section 5 time-series and cross-sectional analyses. In section 6 I test the estimates' robustness to an estimation assumption and the dataset construction. I describe and estimate the extended model in section 7. Section 8 concludes.

1 Literature Review

Since accounting manipulation itself and its determinants (e.g., the fundamental information asymmetry between the market and the manager, the level of regulatory scrutiny, the reporting noise, or the manager's misreporting incentives) are almost impossible to observe directly, the recent trend in the accounting literature has been to employ structural estimation approach to recover the informativeness of accounting numbers observed by investors. The structural estimation technique allows researchers to back out unobservable theoretical parameters using observable empirical data, which can be, in the case of accounting quality, earnings response coefficient, time-series properties of accounting numbers, or misreporting detection.

Nikolaev (2019) is one of the earliest papers to use structural estimation to measure how well accounting accruals fulfill their role of adjusting the reported numbers so that they reflect true economic performance of a firm. Prior studies of accruals fail to distinguish shocks to economic performance from the noise introduced by measurement imperfections. Nikolaev (2019) exploits the idea that shocks to fundamentals are persistent, whereas measurement noise reverses in the following period. The estimates suggest that the variance of accruals is to a large extent explained by the variance of economic performance and thus accruals achieve their main goal.

Zakolyukina (2018) looks at how well regulators control financial misreporting. The author estimates a dynamic model of firm manager who can manipulate an earnings report and potentially mislead investors. However, with a probability that depends on the level of cumulative misstatement, the misreporting can be detected, potentially forcing the manager to leave the firm and pay a fine. The findings suggest that the probability of detection and the damage to the CEO's welfare in case of detection are low, and thus the expected misreporting cost is low. 60% of CEOs misstate earnings at least once in their career. My estimates of the values-weighted biases in market value and in stock price are higher than in Zakolyukina

(2018): for the full sample 1992-2020, the bias in market value (weighted by firms' market values) is \$3,280 millions and the bias in stock price (weighted by firms' market values) is 9.67%. Part of the reason for the big differences in the two papers' estimates could be different time periods used to estimate the model and compute the values-weighted mispricing. Zakolyukina (2018) uses observations from 2003 to 2010.

Two closest papers are Beyer et al. (2019) and Bertomeu et al. (2019). Beyer et al. (2019) quantify two types of uncertainty that give rise to biases in accounting numbers: uncertainty about firm fundamentals and information asymmetry between firm managers and investors due to reporting noise. The modelling approach is similar to mine: the authors assume that firm fundamentals are persistent with a normally distributed random component and look at equilibria with linear prices, which implies closed-form solutions for theoretical moments. Beyer et al. (2019), however, only look at annual changes in market value and estimate overall uncertainties, whereas I also provide insights into how uncertainty evolves during the year: around the release of the annual report and at other times. My estimates of the fundamental variance are close to the estimates in Beyer et al. (2019): for an average small (medium, large) firm in my sample, the standard deviation of innovations to annual earnings is \$22.9 (\$81.3, \$536.7) millions. The values for the small and large firms differ from Beyer et al. (2019) because small firms in my sample are larger than in Beyer et al. (2019) (average market value is \$121 million compared to \$63 million in Beyer et al. (2019)) and large firms are smaller (average market value is \$10,741 million compared to \$15,074 million in Beyer et al. (2019)).

The first concurrent paper that measures investors' uncertainty about managers' reporting incentives is Bertomeu et al. (2019). The study relies on a similar framework – Fischer and Verrecchia (2000), but allows for a non-linear earnings response coefficient, which is more descriptive of the data than a linear function of earnings surprise (e.g., Freeman and Tse (1992), Cheng et al. (1992), Das and Lev (1994)). The first step of the estimation procedure infers a non-parametric form of the earnings response function from empirical data. The next step solves for the optimal misreporting by the manager given the earnings response function derived before. Finally, the combination of the earnings response function and optimal reports is used to recover model parameters.

My paper differs from Bertomeu et al. (2019) in multiple dimensions. First, I use a dynamic model that captures the intertemporal trade-off that firm managers make when they choose the misreporting amount: overstating heavily today will reduce manager's ability to boost price in future. Second, in addition to measuring total market's information, I measure when the market learns its information, on earnings release days or at other times. Third, in Bertomeu et al. (2019) and in my paper the identification of what the market's information about managers' misreporting incentives comes from different sources. Bertomeu et al. (2019) use the observed earnings response from the data to arrive to the manager's optimal misreporting. I rely on the assumption that analyst forecasts include expected misreporting and thus can be used to identify the market's information about misreporting incentives. Finally, I make more restrictive theoretical assumptions: I assume that firm fundamentals and manager's misreporting incentives are normally distributed and that firm price is a linear function, – but can obtain closed-form solutions for theoretical moments. Bertomeu et al. (2019)'s approach is agnostic about the distribution of firm fundamentals and pricing function, but the authors have to use simulated method of moments for estimation.

Our estimates of earnings quality are very close to each other. My results suggest that reported earnings are different from true earnings by 74.1% of standard deviation of true earnings, and Bertomeu et al. (2019) obtain an estimate of 86% for parametric and 40% for semi-parametric model. I obtain a larger estimate of the market's uncertainty about managers' misreporting incentives than Bertomeu et al. (2019): for a median firm, the standard deviation is \$25.06[6] million according to my estimates and \$14.00 million for parametric model in Bertomeu et al. (2019) and \$3.75 million for semi-parametric model.

2 Model

2.1 Setup

In what follows, I denote random variables by $\tilde{}$, and their realizations without $\tilde{}$.

A firm is ruled by a manager. Firm annual earnings have the following structure:

$$\tilde{\varepsilon}_t = \tilde{\varepsilon}_{1,t} + \tilde{\varepsilon}_{2,t}, \tag{1}$$

$$\tilde{\varepsilon}_{1,t} = \tilde{v}_{1,t} + \tilde{v}_{1,t-1} + \tilde{v}_{1,t-2}, \quad \tilde{v}_{1,t} \sim N(0, q_v \sigma_v^2), \tag{2}$$

$$\tilde{\varepsilon}_{2,t} = \tilde{v}_{2,t} + \tilde{v}_{2,t-1} + \tilde{v}_{2,t-2}, \quad \tilde{v}_{2,t} \sim N(0, (1-q_v)\sigma_v^2), \tag{3}$$

where $0 < q_v < 1$. The manager observes both parts, $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$, and the market only observes $\varepsilon_{1,t}$. The market can obtain information about current earnings from any sources other than the manager's report. q_v

[6] The estimated variance of the manager's misreporting incentives is \$39.64 million for a median firm in my sample. The market knows 36.78% of this variance. Thus, the remaining market's uncertainty is $\$39.64 \times (1 - 0.3678)$.

represents the fraction of total fundamental information that the market knows.

The market's fundamental information is divided into two parts:

$$\tilde{\varepsilon}_{1,t} = \tilde{\varepsilon}^0_{1,t} + \tilde{\varepsilon}^1_{1,t}, \tag{4}$$

$$\tilde{\varepsilon}^0_{1,t} = \tilde{v}^0_{1,t} + \tilde{v}^0_{1,t-1} + \tilde{v}^0_{1,t-2}, \quad \tilde{v}^0_{1,t} \sim N(0, q_v q^0_v \sigma^2_v), \tag{5}$$

$$\tilde{\varepsilon}^1_{1,t} = \tilde{v}^1_{1,t} + \tilde{v}^1_{1,t-1} + \tilde{v}^1_{1,t-2}, \quad \tilde{v}^1_{1,t} \sim N(0, q_v(1-q^0_v)\sigma^2_v), \tag{6}$$

where $0 < q^0_v < 1$. $\varepsilon^0_{1,t}$ is the fraction of the market's fundamental information that arrives concurrently with the previous earnings report, $\varepsilon^1_{1,t}$ is the fraction of the market's fundamental information that arrives on other days during the year preceding the current earnings report.

I model firm earnings as a sum of the current and two prior-year shocks for two reasons. First, such representation preserves important properties of earnings such as persistence and mean-reversion (Gerakos and Kovrijnykh (2013)). Second, when the earnings process is truncated, the manager's report in equilibrium is a finite sum of innovations, allowing to derive closed-form solution of the model.

I assume that the firm pays no dividends and define the firm's book value as a cumulative sum of all prior and current earnings:

$$\theta_t = \sum_{k=0}^{k=t} \varepsilon_k \tag{7}$$

Every year, the manager releases a report (potentially biased), r_t, about firm book value and is compensated based on the firm's stock price, p_t, net of personal cost of misreporting. Her utility at time t is

$$U_t = m_t p_t - \frac{(r_t - \theta_t)^2}{2}, \tag{8}$$

where m_t is the sensitivity of the manager's welfare to firm price,[7] or misreporting incentives.[8]

[7]The manager's incentives do not mean exclusively direct compensation, but can include non-monetary benefits such as reputation, happiness from governing a successful company. m_t can be positive or negative. For example, if the manager urgently needs cash, she may prefer the company's price to fall next year so that she can sell her shares today and buy them back in a year for a lower price.

[8]Note that the manager bears 1 unit of cost for the misreporting of size $\frac{(r_t-\theta_t)^2}{2}$. This implies that m_t is the manager's benefit of misreporting relative to the 1 unit of misreporting cost. Alternatively, the cost of misreporting can be modelled as $c\frac{(r_t-\theta_t)^2}{2}$ and the manager's misreporting incentives can be modelled as $M_t = cm_t$.

Misreporting incentives evolve every year and are described by the following process:

$$\tilde{m}_t = \tilde{m}_{1,t} + \tilde{m}_{2,t}, \tag{9}$$

$$\tilde{m}_{1,t} = \tilde{\xi}_{1,t} + \tilde{\xi}_{1,t-1} + \tilde{\xi}_{1,t-2}, \quad \tilde{\xi}_{1,t} \sim N(0, q_\xi \sigma_\xi^2), \tag{10}$$

$$\tilde{m}_{2,t} = \tilde{\xi}_{2,t} + \tilde{\xi}_{2,t-1} + \tilde{\xi}_{2,t-2}, \quad \tilde{\xi}_{2,t} \sim N(0, (1-q_\xi)\sigma_\xi^2), \tag{11}$$

where $0 < q_\xi < 1$. Similarly to earnings, the manager knows both $m_{1,t}$ and $m_{2,t}$, and the market knows only $m_{1,t}$. q_ξ represents the share of total misreporting incentives information that the market has. Public information about misreporting incentives is divided into two parts:

$$\tilde{m}_{1,t} = \tilde{m}_{1,t}^0 + \tilde{m}_{1,t}^1, \tag{12}$$

$$\tilde{m}_{1,t}^0 = \tilde{\xi}_{1,t}^0 + \tilde{\xi}_{1,t-1}^0 + \tilde{\xi}_{1,t-2}^0, \quad \tilde{\xi}_{1,t}^0 \sim N(0, q_\xi q_\xi^0 \sigma_\xi^2), \tag{13}$$

$$\tilde{m}_{1,t}^1 = \tilde{\xi}_{1,t}^1 + \tilde{\xi}_{1,t-1}^1 + \tilde{\xi}_{1,t-2}^1, \quad \tilde{\xi}_{1,t}^1 \sim N(0, q_\xi (1-q_\xi^0)\sigma_\xi^2). \tag{14}$$

where $0 < q_\xi^0 < 1$. $m_{1,t}^0$ is the fraction of the market's misreporting incentives information that arrives concurrently with the manager's report, $m_{1,t}^1$ is the fraction of the market's misreporting incentives information that arrives on other days during the year preceding the current earnings report.

The market prices the firm risk-neutrally at the expectation of its book value and sum of all future earnings given investors' information:

$$p_t = E\left[\tilde{\theta}_t + \sum_{k=t+1}^{k=\infty} \tilde{\varepsilon}_k | I_t^{\text{market}}\right], \tag{15}$$

where $I_t^{\text{market}} = \{r_0, r_1, ..., r_t; \varepsilon_{1,0}, \varepsilon_{1,1}, ..., \varepsilon_{1,t}; m_{1,0}, m_{1,1}, ..., m_{1,t}\}$ is all the information available to the market at time t. It includes all managerial reports, all fundamental, and all misreporting incentives information observed by the market.

The manager faces a dynamic trade-off: on the one hand, by overstating firm book value today, she increases firm price and thus increases her utility if her misreporting incentives is positive ($m_t > 0$). On the other hand, if she heavily overstates firm book value today ($r_t > \theta_t$), she will have little room for overstatement (and boosting firm price) going forward. If the manager reports too conservatively and understates book value today ($r_t < \theta_t$), it will be more costly for him to report a higher number in the future. The manager's problem at time t is

$$\max_{r_t} \quad E\left[\sum_{k=t}^{k=\infty} \delta^{k-t}(\tilde{m}_k p_k - \frac{(r_k-\tilde{\theta}_k)^2}{2})|I_t^{\text{manager}}\right], \tag{16}$$

where $I_t^{\text{market}} = \{\varepsilon_0, \varepsilon_1, ..., \varepsilon_t; m_0, m_1, ..., m_t\}$ is all the information available to the manager at time t: all realizations of earnings and misreporting incentives.

The final element that I define is the market's expectations of annual earnings, or of changes in the managerial report.[9] At the time t, the market expects the change in the annual report to be

$$ME_t = E\left[\tilde{r}_t - r_{t-1}|I_t^{\text{market}}\right]. \tag{17}$$

2.2 Equilibrium

2.2.1 Strategies in Equilibrium

I conjecture the following steady-state equilibrium strategies:

- The manager's report about firm book value is a linear function of firm true book value and the manager's misreporting incentives:

$$r_t = r_0 + r_\theta \theta_t + \sum_{k=0}^{k=t} r_{m_1^0,k} m_{1,t-k}^0 + \sum_{k=0}^{k=t} r_{m_1^1,k} m_{1,t-k}^1 + \sum_{k=0}^{k=t} r_{m_2,k} m_{2,t-k};$$

- Firm price is a linear function of the manager's current and prior reports, and the market's fundamental and misreporting incentives information:

$$p_t = p_0 + \sum_{j=0}^{j=t} \alpha_j^t r_j + \sum_{j=0}^{j=t} \beta_j^{0,t} \varepsilon_{1,j}^0 + \sum_{j=0}^{j=t} \beta_j^{1,t} \varepsilon_{1,j}^1 + \sum_{j=0}^{j=t} \gamma_j^{0,t} m_{1,j}^0 + \sum_{j=0}^{j=t} \gamma_j^{1,t} m_{1,j}^1;$$

- Market expectations of the change in annual reports is a linear function of the manager's current and prior reports, and the market's fundamental and misreporting incentives information:

$$ME_t = ME_0 + \sum_{j=0}^{j=t} a_j^t r_j + \sum_{j=0}^{j=t} b_j^{0,t} \varepsilon_{1,j}^0 + \sum_{j=0}^{j=t} b_j^{1,t} \varepsilon_{1,j}^1 + \sum_{j=0}^{j=t} c_j^{0,t} m_{1,j}^0 + \sum_{j=0}^{j=t} c_j^{1,t} m_{1,j}^1.$$

[9] Since the report in the model is about firm book value, which is a sum of all earnings, the difference between current and prior-year reports of the book value is equal to the earnings report.

α_j^t is price-t response to the managerial report, $\beta_j^{0,t}$ and $\beta_j^{1,t}$ are price-t responses to the fundamental information learned at the time of the manager's report and on other days, $\gamma_j^{0,t}$ and $\gamma_j^{1,t}$ are price-t responses to the misreporting incentives information learned at the time of the manager's report and on other days.

The proposition below describes the optimal report of the manager.

Proposition 1 *In equilibrium, the manager's report is*

$$
\begin{aligned}
r_t &= \theta_t + \alpha_t^t m_t + \sum_{k=1}^{\infty} \delta^k \alpha_t^{t+k} E_t[m_{t+k}] \\
&= \theta_t + \alpha_t^t(\xi_t + \xi_{t-1} + \xi_{t-2}) + \delta \alpha_t^{t+1}(\xi_t + \xi_{t-1}) + \delta^2 \alpha_t^{t+2} \xi_t. \qquad (18)
\end{aligned}
$$

Manager's optimal report is a sum of the firm's true book value (θ_t) and a bias ($\alpha_t^t m_t + \sum_{k=1}^{\infty} \delta^k \alpha_t^{t+k} E_t[m_{t+k}]$). The bias is greater if the current and future price reactions to the report are greater and if the sensitivity of the manager's utility to firm price is greater. The bias is smaller for a more impatient manager, who has a low discount rate δ.

Prices and market expectations in the steady-state are updated due to to information arrivals during a year: (1) the manager's prior-year report and the information about firm earnings and the manager's misreporting incentives that arrives concurrently with the report, and (2) the information about firm earnings and the manager's misreporting incentives arriving on other days preceding the current report. Since the two information components = are independent, I can analyze them sequentially. The propositions below describe price changes after the issuance of the report and the arrival of concurrent information, and after the arrival of information on other days. I denote firm prices before and after the manager's report by $p_t^{\text{pre-report}}$ and $p_t^{\text{post-report}}$, respectively.

Proposition 2 *In the steady-state, the change in firm price after the issuance of manager's report and arrival of* $\varepsilon_{1,t+1}^0$ *and* $m_{1,t+1}^0$ *is*

$$
\begin{aligned}
p_t^{\textit{post-report}} - p_t^{\textit{pre-report}} &= E[\tilde{\theta}_t | I_t^{\textit{market}}] - E[\tilde{\theta}_t | I_t^{\textit{market}} \setminus \{r_t\}] \qquad (19) \\
&= \alpha_0(r_t - E[\tilde{r}_t | I_t^{\textit{market}} \setminus \{r_t\}]) + 3v_{1,t+1}^0, \qquad (20)
\end{aligned}
$$

where α_0*, the solution to the equation* $\alpha_0 = \frac{3(1-q_v)\sigma_v^2}{3\sigma_v^2(1-q_v)+\sigma_\xi^2(1-q_\xi)\alpha_0^2((1+\delta+\delta^2)^2+\delta^4+\delta^2+1)}$*, is current price's response to the managers' report.*

The price change is a function of report surprise, $(r_t - E[\tilde{r}_t | I_t^{\text{market}} \setminus \{r_t\}])$, and the new fundamental information, v^0_{t+1}. In appendix 8 I prove that current, one-year-ahead, and two-year-ahead prices' responses to the current report are all equal to α_0. From the manager's perspective, however, these responses are not equal because she cares about current price more than about next year's price because of discounting.

The second round of price updating happens when the market obtains information on firm earnings and the manager's misreporting incentives on other days. I denote price change due to this information arrival as the difference between prices right before the next report, $p_t^{\text{pre-report}}$, and right after the most recent report, $p_t^{\text{post-report}}$.

Proposition 3 *In the steady-state, the change in firm price after the market learns $\varepsilon^1_{1,t+1}$ and $m^1_{1,t+1}$ is*

$$p_{t+1}^{\textit{pre-report}} - p_t^{\textit{post-report}} = 3v^1_{1,t+1}. \tag{21}$$

The change in prices outside the issuance of the managerial report only depends on new fundamental information received by the market ($v^1_{1,t+1}$).

The two following propositions describe changes in the market's expectations after the arrival of the manager's report and concurrent information, and after the market's information arrival on other days. I denote market expectations before and after the managerial report by $ME_t^{\text{pre-report}}$ and $ME_t^{\text{post-report}}$, respectively.

Proposition 4 *In the steady-state, the change in the market's expectations of change in the manager's report after the current report is issued and $\varepsilon^0_{1,t+1}$ and $m^0_{1,t+1}$ arrive is*

$$ME_t^{\textit{post-report}} - ME_t^{\textit{pre-report}} = v_{1,t} + v_{1,t-1} + v^0_{1,t+1} \tag{22}$$

$$+E[\tilde{\varepsilon}_{2,t+1}|I_t^{\textit{market}}] - E[\tilde{\varepsilon}_{2,t}|I_t^{\textit{market}} \setminus \{r_t\}] \tag{23}$$

$$+\left(\alpha_0(\xi^0_{1,t+1} - \xi_{1,t-2}) + \alpha_0\delta(\xi^0_{1,t+1} - \xi_{1,t-1}) + \alpha_0\delta^2(\xi^0_{1,t+1} - \xi_{1,t})\right) \tag{24}$$

$$+\left(\alpha_0 \sum_{k=1}^{k=\infty} \delta^{k-1} E[\tilde{m}_{2,t+k}|I_t^{\textit{market}}] - \alpha_0 \sum_{k=0}^{k=\infty} \delta^k E[\tilde{m}_{2,t+k}|I_t^{\textit{market}} \setminus \{r_t\}]\right) \tag{25}$$

$$-r_t + r_{t-1} \tag{26}$$

The change in the market's expectations of the next report after the current report is issued and concurrent information arrives are driven by two forces: first, the expectations before the report are of this report, but after the report, they are of the next report; second, the market learns new information about firm fundamentals and the manager's misreporting incentives from the current report and from other sources concurrent with the report. Line 22 in the proposition 4 denotes the expectation of $t+1$ earnings that will be reported in the next report, based on the information that the market observes from other sources. Line 23 denotes the expectation of the unobserved part of $t+1$ earnings based on the manager's report minus the expectation of the unobserved part of t earnings based on the previous report. Lines 24 and 25 are the expected bias at time $t+1$ minus the expected bias at time t. Line 24 is based on the information observed by the market concurrent with the report and on other days, and line 25 is an update in belief about unobserved information based on the manager's report.

Proposition 5 *In the steady-state, the change in the market's expectations of change in the manager's report after the market learns $\varepsilon^1_{1,t+1}$ and $m^1_{1,t+1}$ is*

$$ME^{\textit{pre-report}}_{t+1} - ME^{\textit{post-report}}_{t} = v^1_{1,t+1} + \alpha_0(1+\delta+\delta^2)\xi^1_{1,t+1}. \tag{27}$$

When the market learns $\varepsilon^1_{1,t+1}$ and $m^1_{1,t+1}$, market expectations are a sum of new information about firm earnings, $v^1_{1,t+1}$, and new information about reporting bias based on the new information about misreporting incentives, $\xi^1_{1,t+1}$.

2.2.2 Earnings Quality in Equilibrium

I define earnings quality as the negative ratio of the expected bias in the manager's earnings report to the standard deviation of earnings, which in equilibrium equals

$$EQ_t = \frac{-\sqrt{E[(\varepsilon_t - (r_t - r_{t-1}))^2]}}{\sqrt{Var[\varepsilon_t]}} = \frac{-\sqrt{\sigma^2_\xi \alpha_0^2 2(1+\delta+2\delta^2+\delta^3+\delta^4)}}{\sqrt{3\sigma^2_v}} \tag{28}$$

The market's information – q_v and q_ξ – affect the measure of earnings quality through the current and two future prices' responses to the manager's report, α_0. The proposition and lemma below describe how the price's response and earnings quality change with q_v and q_ξ. As the market's fundamental information increases, prices' responsiveness to the manager's report decreases, implying a smaller reward for the manager per unit of misreported book value and improving earnings quality. The opposite is for the market's misreporting incentives information: it increases prices' reaction to the manager's report and the reward per unit of misreported book value. As a result, earnings quality decreases.

Proposition 6 *In equilibrium, current price's, one-year-ahead price's, and two-year-ahead price's responses to the current report, α_0, decrease (increase) in the market's share of fundamental (misreporting incentives) information, q_ν (q_ξ).*

Lemma 1 *In equilibrium, the earnings quality, EQ_t, increases (decreases) in the market's share of fundamental (misreporting incentives) information, q_ν (q_ξ).*

2.2.3 Price Efficiency in Equilibrium

I define price efficiency as the negative deviation of firm price from its hypothetical value if the market knew all the information that the manager knows:

$$PE_t = -\sqrt{E[(p_t - \text{True Expected Value})^2]} = -\sqrt{E\left[\left(E\left[\tilde{\theta}_t + \sum_{k=t+1}^{k=\infty} \tilde{\varepsilon}_k | I_t^{\text{market}}\right] - E\left[\tilde{\theta}_t + \sum_{k=t+1}^{k=\infty} \tilde{\varepsilon}_k | I_t^{\text{manager}}\right]\right)^2\right]}$$
$$= -\sqrt{(1-q_\xi)\sigma_\xi^2 \alpha_0^2 (2\delta^3 + 4\delta^2 + 4\delta + 3) + 5(1-q_\nu)\sigma_\nu^2} \quad (29)$$

The lemma below describes how price efficiency changes when the market learns more about firm fundamentals (q_ν increases) and about the manager's misreporting incentives (q_ξ increases). In contrast to accounting quality, price efficiency increases with both types of the market's information. As the market knows more about the manager's misreporting incentives, even though from an external observer's perspective the manager's report contains more noise (due to misreporting), from the market's perspective, the report becomes more informative because the market can unravel a greater part of the manager's manipulation.

Lemma 2 *In equilibrium, the price efficiency, PE_t, increases in the market's share of fundamental, q_ν, and misreporting incentives, q_ξ, information.*

2.3 Theoretical Moments

In this section, I describe the theoretical moments from the model that I use to estimate model parameters: variance of innovations in firm earnings (σ_ν^2) and the manager's misreporting incentives (σ_ξ^2), shares of the market's information about them (q_ν and q_ξ), and fraction of the market's information that the market learns concurrently with the manager's report (q_ν^0 and q_ξ^0).

The model is primarily suited to describe the dynamics of annual manager's reports, market expectations, co-movement of the manager's reports and market expectations with firm prices, and firm prices' responses to the manager's reports. I choose the following six moments for the estimation:

1. Variance of one-year change in the annual book value report, or variance of annual earnings report:

$$Var[r_t - r_{t-1}] = 3\sigma_\nu^2 + \alpha_0^2 \sigma_\xi^2((1+\delta+\delta^2)^2 + \delta^4 + \delta^2 + 1) \tag{30}$$

2. Variance of two-year change in the annual book value report, or variance of the sum of two concurrent earnings reports:

$$Var[r_t - r_{t-2}] = 10\sigma_\nu^2 + \alpha_0^2 \sigma_\xi^2((1+\delta+\delta^2)^2 + 2(1+\delta)^2 + (\delta+\delta^2)^2 + 1) \tag{31}$$

3. Variance of change in the market's expectations from after one report to before the next report:

$$Var[ME_{t+1}^{\text{pre-report}} - ME_t^{\text{post-report}}] = q_\nu(1-q_\nu^0)\sigma_\nu^2 + q_\xi(1-q_\xi^0)\alpha_0^2\sigma_\xi^2(1+\delta+\delta^2)^2 \tag{32}$$

4. Covariance of changes in prices from after one report to before the next report with changes in the market's expectations from after one report to before the next report:

$$Cov[p_{t+1}^{\text{pre-report}} - p_t^{\text{post-report}}, ME_{t+1}^{\text{pre-report}} - ME_t^{\text{post-report}}] = 3q_\nu(1-q_\nu^0)\sigma_\nu^2 \tag{33}$$

5. Earnings response coefficient:

$$E[(p_t^{\text{post-report}} - p_t^{\text{pre-report}}) - \alpha_0(r_t - r_{t-1} - ME_t^{\text{pre-report}})] = 0 \tag{34}$$

6. Residual variance of the regression of price changes around the report, $(p_t^{\text{post-report}} - p_t^{\text{pre-report}})$, on earnings surprises, $(r_t - r_{t-1} - ME_t^{\text{pre-report}})$:

$$Var[(p_t^{\text{post-report}} - p_t^{\text{pre-report}}) - \alpha_0(r_t - r_{t-1} - ME_t^{\text{pre-report}})] = 9q_\nu q_\nu^0 \sigma_\nu^2 \tag{35}$$

α_0 is a function of σ_ν^2, q_ν, σ_ξ^2, and q_ξ.

3 Estimation

This section describes the data I use to estimate the model, the estimation procedure, the intuition for parameters' identification, and the results.

3.1 Data

I take annual earnings reports from the I/B/E/S database, and firm prices from the CRSP database. For pre-report prices, I take firms' market values one day before earnings release dates; for post-report prices, I take firms' market values one day after earnings release dates. As a proxy for the market's expectations, I use analyst earnings forecasts from the I/B/E/S database. For pre-report expectations, I take the last analyst forecast before an earnings release; for post-report expectations, I take the first analyst forecast after an earnings release. I multiply variables from I/B/E/S by the number of common shares outstanding on the corresponding date to obtain all the variables on the firm-level. I divide all the variables by firms' book values at the date a firm first appears in my sample to control for firm size as one of the drivers of firm-level volatility of earnings innovations.

The final sample contains 7,410 public firms in the United States with fiscal years from 1992 to 2020; 42,384 observations in total. Table 1 describes the sample selection procedure; table 2 presents the percent of firms in each North American Industry Classification System (NAICS) sector in my sample. A lot of firms (more than a third of the sample) do not have data on their NAICS codes. Manufacturing industry consists the largest share – 20.39%, followed by finance and insurance – 12.84%. The third is information – 4.50%.

Table 1: Sample selection procedure

Sample reduction reason	**Sample size**
Initial sample, containing all the variables needed from I/B/E/S and CRSP	77,843
Non-missing book value in Compustat	74,050
Positive book value	70,572
Market-to-book ratio less than or equal to 30	69,898
Price above or equal to $1	68,177
Truncate sample all variables at 5%	51,556
Firms with non-missing two-year lags of reports	42,384

Summary statistics for the variables I use in estimation are in Table 3. Reported earnings and changes in market values around earnings reports and at other times during a year are positive on average. Analysts'

Table 2: Percent of firms in NAICS sectors in the sample

NAICS	% of total sample
Agriculture, Forestry, Fishing and Hunting	0.13
Mining	2.67
Utilities	2.12
Construction	0.68
Manufacturing	20.39
Wholesale Trade	1.22
Retail Trade	2.92
Transportation and Warehousing	2.31
Information	4.50
Finance and Insurance	12.84
Real Estate Rental and Leasing	2.36
Professional, Scientific, and Technical Services	3.44
Management of Companies and Enterprises	1.18
Administrative and Support and Waste Management and Remediation Services	1.16
Educational Services	0.33
Health Care and Social Assistance	0.98
Arts, Entertainment, and Recreation	0.47
Accommodation and Food Services	1.13
Other Services (except Public Administration)	0.23
Missing NAICS	38.92

forecasts on average go down during a year. This pattern is consistent with the analyst forecast walk-down (e.g., Richardson et al. (2004), Bradshaw et al. (2016)): analysts tend to be more optimistic at the beginning of the forecasting period and gradually reduce their expectations as the date moves closer to the reporting date. This bias can be because of analysts' excessive optimism, analysts' desire to curry favor with companies' managers, or forecasting difficulty. Because I de-mean all my variables for estimation, the existence of the walk-down does not bias my results.

The standard deviation of price changes between two annual reports is about 6 (21) times higher than the standard deviation of changes in reports (analyst forecasts), consistent with the return volatility puzzle (Mehra and Prescott (1985)). Since my model is not primarily about evolution of firms' prices, I do not aim to closely match price changes in the data.

3.2 Estimation Procedure

I use the Generalized Method of Moments (GMM) to estimate the model (Hansen (1982)). The method looks for the values of the theoretical model's parameters (σ_v^2, q_v, q_v^0, σ_ξ^2, q_ξ, and q_ξ^0 in my case) that

Table 3: Summary statistics

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
$r_t - r_{t-1}$	42,384	0.209	0.302	−0.646	0.040	0.304	1.890
$ME_t^{\text{pre-report}} - ME_{t-1}^{\text{post-report}}$	42,384	−0.019	0.083	−0.445	−0.041	0.016	0.221
$p_t^{\text{pre-report}} - p_{t-1}^{\text{post-report}}$	42,384	0.363	1.724	−5.174	−0.375	0.902	9.090
$p_t^{\text{post-report}} - p_t^{\text{pre-report}}$	42,384	0.012	0.298	−1.198	−0.078	0.094	1.273
$r_t - r_{t-1} - ME_t^{\text{pre-report}}$	42,384	−0.001	0.029	−0.151	−0.006	0.009	0.105

minimize the distance between theoretical moments (e.g., variance of earnings reports as a function of the theoretical parameters), and empirical moments (e.g., variance of earnings report calculated from the data). The distance is measured as a quadratic form of differences between theoretical and empirical moments with a weighting matrix.

I start with an identity weighting matrix, obtain first estimates of the parameters, then plug them back in the covariance matrix of moments to obtain a new weighting matrix, then use the new matrix to obtain new estimates. This procedure is repeated until the process converges: the value of the objective function does not change with new iterations.

3.3 Identification

My goal is to identify two sets of the model's parameters: (1) the amount of the information that the market knows (fundamental and misreporting incentives information) and (2) the amount of the market's information that is learned concurrently with prior-year earnings reports and on other days of the year preceding the current report.

To identify the amount of fundamental and misreporting incentives information that the market knows, I assume that, first, firms' prices are the firm's expected cash flows given the market's fundamental information and, second, financial analysts aim to forecast a reported earnings number as close as possible. The second assumption implies that an analyst's forecast is a sum of expected firm earnings and an expected bias that a firm manager will add to her report. The bias, in turn, is a function of the manager's misreporting incentives.

Since firm prices only contain fundamental information, the covariance of changes in firm prices with changes in analysts' reports represents the fundamental information that the market has learned during a certain period of time (moment 4). The variance of changes in analysts' forecasts is a function of both fundamental and misreporting incentives information (moment 3). From the "difference" between the two moments, I can identify the amount of misreporting incentives information that the market knows.

The availability of data on firm prices and analyst forecasts at different times during a year allows me to identify which fractions of the market's information are learned concurrently with the prior-year earnings report and which at other times in the year preceding the current report. Since market's beliefs from the day after the prior earnings report to the day before the next earnings report are a function of the information that the market learned from other sources during this year, changes in firms' prices and analysts' forecasts from the prior report to the next show the amount of the market's information learned during the year preceding the current report (moments 3 and 4).

Identifying how much the market learns on the day of the prior-year earnings report is more difficult because firm prices and analysts forecasts change because, first, the market observes the current report and, second, the market learns information from concurrent sources (e.g., earnings calls, analysts' forecasts). To identify the amount of fundamental information learned from the concurrent sources, I use the residual variance of the regression of price changes in the [-1, 1] window around the prior-year report on the prior-year report (moment 6). By regressing prices' changes on the report I first remove the variance in prices due to information contained in the report. The remaining prices' changes are due to other concurrent sources of information.

The model assumes and identification relies on an assumption that firms' prices are efficient and there is no noise in returns due to factors not explained by the information about firm fundamentals.[10] Because prices in the data may contain considerable amount of noise, one might worry that estimates of my model overstate the effect of the firm's reports and investors' information on prices. To avoid this upward bias, I do not use variance of firm prices as a moment in estimation. I only use covariance of price changes with changes in analyst forecasts. To the extent that additional noise in prices (such as discount rate variation) is uncorrelated with analyst forecasts, potential noise in prices in the data does not affect parameter estimates.

3.4 Results

In this section, I present and discuss estimation results and how well the model does its job of matching the targeted variances and covariances of reports, prices, and analysts' forecasts.

[10] One of these factors can be variation in discount rates. For example, Vuolteenaho (2002) finds that 33% of price variation in individual stocks are explained by discount rate variation.

Table 4 presents the estimated parameters. The total variance of annual innovations in firms' earnings is 0.034, which translates into the standard deviation of annual earnings' innovations of $244,822,489 for an average firm in my sample.[11] The market knows 76.5% of this innovation from sources other than the manager's report, and 40.0% of these 76.5% is learned about one year ahead, concurrently with the previous earnings report.

Total variance of innovations in the manager's misreporting incentives is 0.034. The standard deviation of annual innovations to managers' misreporting incentives (or an increase in manager's welfare per $1 increase in firm price) is $247,495,002 for an average firm. The market knows 36.8% of this innovation, and 88.5% of these 36.8% is learned concurrently with the previous earnings report.

Table 4: Estimated model parameters

Parameter estimate	
Fundamental variance, σ_v^2	0.034 (0.001)
Market's total share of fundamental information, q_v	0.765 (0.027)
Market's share of fundamental information received concurrently with the manager's report, q_v^0	0.400 (0.006)
Incentives variance, σ_ξ^2	0.034 (0.010)
Market's total share of incentives information, q_ξ	0.368 (0.180)
Market's total share of incentives information received concurrently with the manager's report, q_ξ^0	0.885 (0.064)

Note: Standard errors are in parentheses. The parameters are estimated assuming a discount rate of $\delta = 0.9$.

The table 5 shows values of the empirical and theoretical moments at the estimated parameters and t-values of differences between the theoretical and empirical moments. The empirical and theoretical values of moments 1, 2, 4, and 6 are close in therms of magnitudes. The model does not match well the variance of changes in analysts' forecasts and the cross-sectional average of earnings response coefficients.

The variance of changes in analyst forecasts can be driven by changes in analyst coverage, which can be a function of firm-specific characteristics and exogenous shocks to financial analytics industry (e.g.,

[11] The average book value at a date a firm first appears in my sample is $1,336,047,000.

brokerage closures). I do not model information sources' endogenous choice of firm coverage, which may result in imperfect fit.

The earnings response coefficient can be fitted badly because I use the simplest version of the ERC regression in my estimation: it is only the regression of price changes on earnings surprises. There may exist omitted variables in this regression, such as earnings persistence (Kormendi and Lipe (1987)) or earnings forecast revisions (Liu and Thomas (2000)).

Table 5: Empirical and theoretical moments

#	Moments	Empirical	Theoretical	t-value of difference
1	**Variance of one-year change in annual reports**	0.13493	0.15583	12.80
2	**Variance of two-year change in annual reports**	0.44913	0.43961	-1.78
3	**Variance of change in market expectations between two reports**	0.00717	0.01718	107.49
4	**Covariance of change in prices with change in market expectations**	0.03602	0.04627	10.54
5	**Earnings response coefficient**	0.00033	0.00116	17.34
6	**Residual variance of the regression of price changes around reports on earnings surprises**	0.08784	0.09240	4.47

Note: The theoretical moments are calculated for estimates assuming $\delta = 0.9$.

The estimates suggest that on average reported earnings differ from true earnings by 74.1% of standard deviation of true earnings. For an average firm in my sample, the price is $376,765,254 different from what it could be if there was no information asymmetry between companies and investors.

4 Counterfactual Analyses

In this section, I look at how earnings quality and price efficiency would respond to potential changes in the market's information.

4.1 Small Changes in the Market's Information

First, I compute the elasticities of earnings quality and price efficiency with respect to two types of the market's information. Elasticities measure the percentage change in earnings quality and price efficiency per 1% change in the market's fubdamental or misreporting incentives information. Since the notion of elasticity assumes linear relation between variables, and earnings quality and price efficiency are not linear functions of the market's information, the measures presented here are only informative for small changes in the shares of the market's information.

The elasticities of earnings quality with respect to the market's share of fundamental and misreporting incentives information are 0.885 and -0.158, respectively, meaning that if the market's share of fundamental information, q_v (misreporting incentives information, q_ξ), increases by 1%, the deviation of the manager's earnings report from the true earnings increases by 0.885% (decrease by 0.158%). At the current levels of the market's information endowment, earnings quality is more sensitive to small changes in fundamental information than to small changes in misreporting incentives information.

The elasticities of price efficiency with respect to the market's fundamental and misreporting incentives information are 1.254 and 0.067. If the market had 1% more fundamental (misreporting incentives) information, price efficiency would increase by 1.254% (0.067%). Price efficiency is notably more sensitive to small changes in fundamental information than to changes in misreporting incentives information.

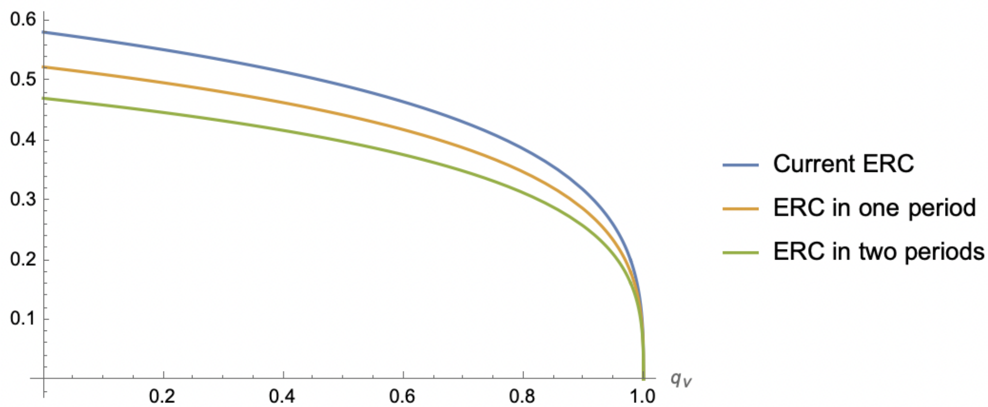
In Figures 1 and 2, I depict ERCs and discounted ERCs, earnings quality, and price efficiency at the estimated parameters as functions of the market's fundamental (q_v) and misreporting incentives (q_ξ) information. The points on the graphs of earnings quality and price efficiency denote the current position on the curve – levels of earnings quality and price efficiency given the current shares of the market's information.

4.2 Large Changes in the Market's Information

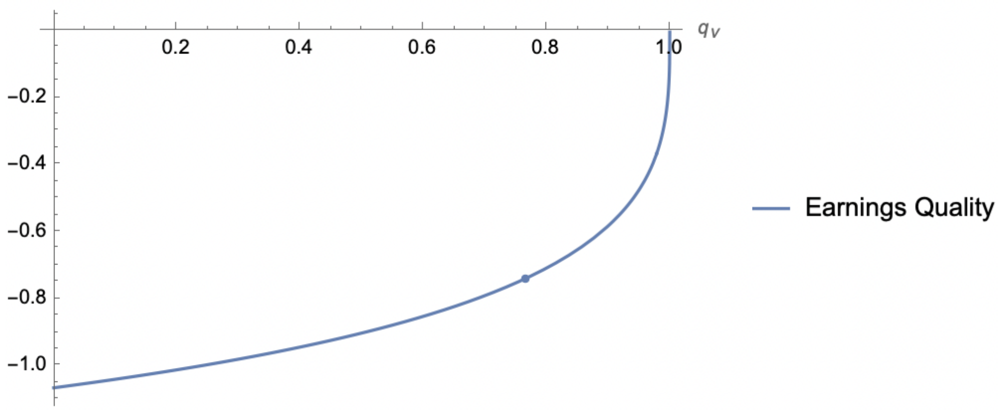
Next, I analyze how earnings quality and price efficiency respond to larger changes in overall uncertainty about firm earnings (σ_v^2) and the manager's misreporting incentives (σ_ξ^2) and in the market's shares of fundamental (q_v) and misreporting incentives (q_ξ) information.

Table 6 summarizes the results for earnings quality, and Table 7 for price efficiency. Both earnings quality and price efficiency are most sensitive to changes in the market's fundamental information: a 10% increase (decrease) in q_v leads to a 10.31% increase (7.86% decrease) in earnings quality and a 13.98%

(a) ERC from the manager’s perspective as functions of q_v



(b) Accounting quality as a function of q_v



(c) Price efficiency as a function of q_v

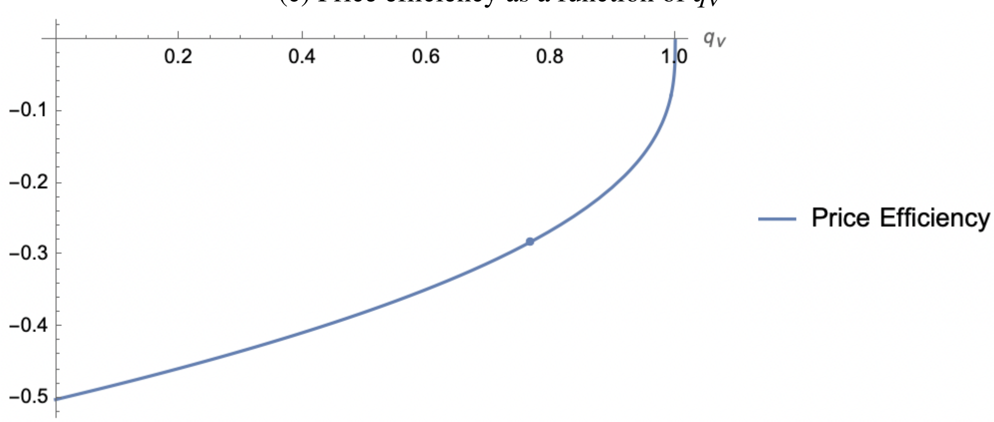
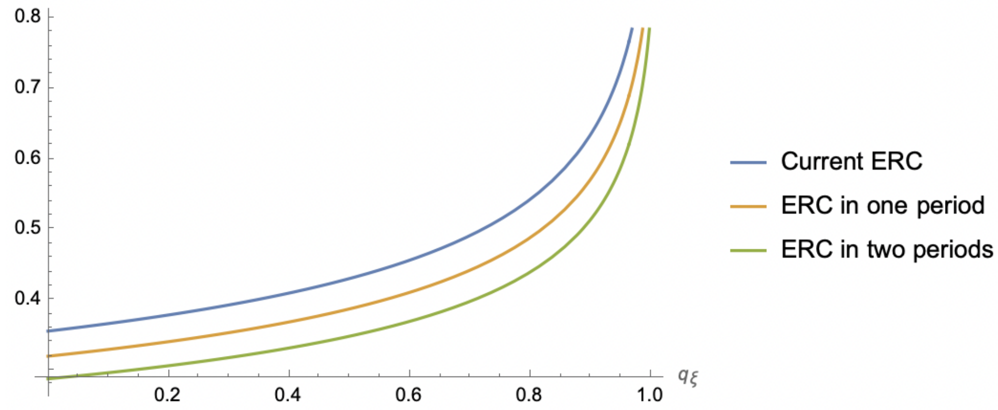
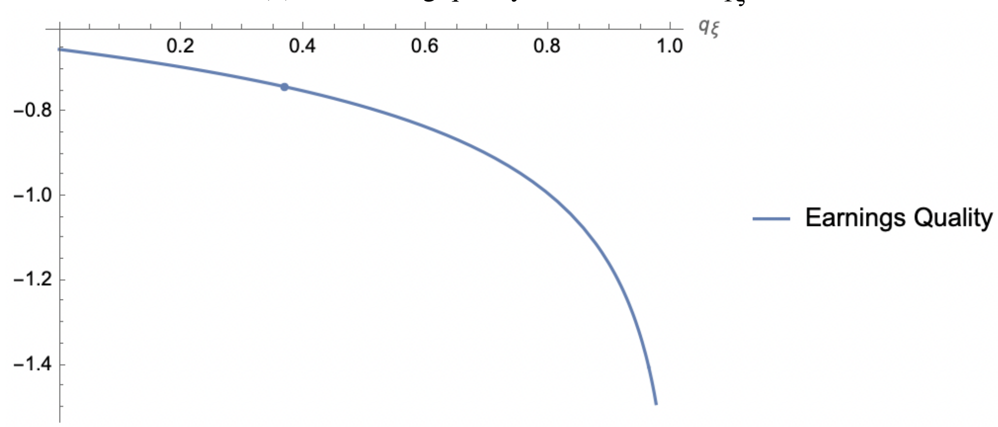


Figure 1: ERC, accounting quality, and price efficiency as functions of the market’s fundamental information

(a) ERC from the manager's perspective as functions of q_ξ



(b) Accounting quality as a function of q_ξ



(c) Price efficiency as a function of q_ξ

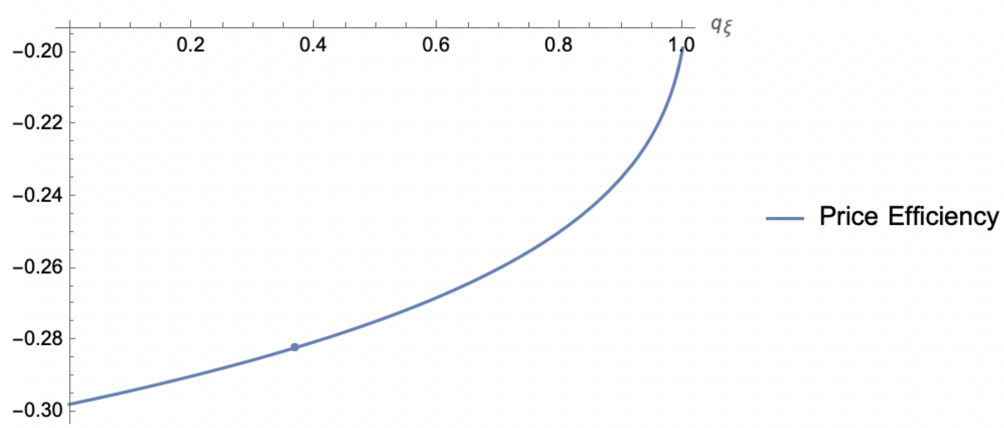


Figure 2: ERC, accounting quality, and price efficiency as functions of the market's misreporting incentives information

increase (11.53% decrease) in price efficiency. Price efficiency is more sensitive to fundamental variance than earnings quality. A change in the market's misreporting incentives information would affect earnings quality stronger than price efficiency.

From a regulator's perspective, the outcome of providing the market with misreporting incentives information is ambiguous. If the regulator is primarily concerned with investors' welfare, she may prefer to increase the provision of misreporting incentives information to make firms' prices closer to their fair value. In contrast, if the regulator prefers the accounting numbers to be more precise about firm performance (i.e., less biased due to misreporting), she will prefer to reduce the amount of misreporting incentives information that investors have.

Table 6: The effects of changes in total uncertainty
and the market's information on earnings quality

Parameter	**Earnings Quality** Current level	10% increase in parameter	10% decrease in parameter
Fundamental variance, σ_v^2	-0.740	-0.724 (2.16% increase)	-0.757 (2.42% decrease)
Market's share of fundamental information, q_v	-0.740	-0.663 (10.31% increase)	-0.798 (7.86% decrease)
Misreporting incentives variance, σ_ξ^2	-0.740	-0.756 (2.19% decrease)	-0.722 (2.39% increase)
Market's share of misreporting incentives information, q_ξ	-0.740	-0.752 (1.64% decrease)	-0.728 (1.53% increase)

Table 7: The effects of changes in total uncertainty
and the market's information on price efficiency

Parameter	**Price Efficiency** Current level	10% increase in parameter	10% decrease in parameter
Fundamental variance, σ_v^2	-0.282	-0.293 (3.74% decrease)	-0.271 (3.97% increase)
Market's share of fundamental information, q_v	-0.282	-0.243 (13.98% increase)	-0.315 (11.53% decrease)
Incentives variance, σ_ξ^2	-0.282	-0.285 (1.11% decrease)	-0.279 (1.20% increase)

Market's share of incentives information, q_ξ	-0.282	-0.280 (0.68% increase)	-0.284 (0.66% decrease)

5 Time-series and cross-sectional analysis

In the first part of this section, I investigate the results of the compensation disclosure regulation of 2006 (Ferri et al. (2018)). I evaluate how much information about managers' misreporting incentives investors learned and how this affected earnings quality and price efficiency. In the second part, I estimate how much information the market knows for firms that do and do not hold earnings calls, firms of different sizes, and from different industries.

5.1 Compensation Disclosure Regulation of 2006

The revision of rules for executive compensation disclosures was proposed by the Securities and Exchange Commission (SEC) in January 2006. The primary goal of the regulation was to provide investors with more information on managerial compensation and its sensitivity to company performance. The revisions were released by the SEC in August 2006 and effective for firms with the fiscal-year ends on or after December 15, 2006.

I divide my sample into two groups: before and after the compensation disclosure regulation. The "before" period is fiscal-year end before the SEC proposal date, January 26, 2006, and the "after" period is fiscal-year end after December 15, 2009.[12]

I estimate the model separately for the two subsamples. Table 8 reports the results. Likely because of the financial crisis, variance of innovations to firm fundamentals increased after 2009 by 74.9%, from 0.021 to 0.037. The market knew 93.9% of fundamental information before the CD&A and financial crisis, and 77.6% after the introduction of the CD&A and financial crisis.

The variance of innovations to managers' misreporting incentives remained unchanged. The introduction of the CD&A section indeed increased the amount of information about misreporting incentives that investors know by about 13.0%, from 43.4% to 49.0%.

[12] Since in my model every shock to firm fundamentals or misreporting incentives persists for three periods, the model needs at least three periods after a shock to converge to a new steady-state.

Using the obtained estimates, I can compute the earnings response coefficients before and after the introduction of CD&A. If I use all the estimated parameters, I find that the ERC increased by 82.63%. This increase is not only because investors learned more about managers' compensation, but also because the fundamental uncertainty increased.

I also compute the change in ERC keeping the fundamental uncertainty and the market's fundamental information at the pre-CD&A level. This approach shows that the ERC increased by only 4.06%. This estimate is lower than obtained by Ferri et al. (2018). First, Ferri et al. (2018) can not fully control for changes in the market's fundamental information, leading to an overestimated change in the ERC due to CD&A. Second, Ferri et al. (2018)'s post-period starts in 2007, and mine in 2009. The ERC could have decreased from 2007 to 2009.

Table 8: Estimated model primitives before and after the introduction of CD&A

Parameter estimate	**Before CD&A**	**After CD&A**
Fundamental variance, σ_v^2	0.021 (0.001)	0.037 (0.002)
Market's total share of fundamental information, q_v	0.939 (0.043)	0.776 (0.046)
Market's share of fundamental information received concurrently with the manager's report, q_v^0	0.399 (0.011)	0.427 (0.009)
Incentives variance, σ_ξ^2	0.123 (0.118)	0.121 (0.078)
Market's total share of incentives information, q_ξ	0.434 (0.527)	0.490 (0.260)
Market's total share of incentives information received concurrently with the manager's report, q_ξ^0	0.913 (0.128)	0.949 (0.032)

Note: Standard errors are in parentheses. The parameters are estimated assuming a discount rate of $\delta = 0.9$.

5.2 Firms that do and do not hold earnings calls

Earnings calls provide investors with a lot of information about firm performance, outlook, and managers' perspectives. That is why I expect that investors of the companies that hold earnings calls learn greater amount of information concurrently with earnings reports. To test this prediction, I divide my sample into two parts: companies with and without earnings calls.

I take dates of earnings calls from Compustat – Capital IQ database. Because the database only contains events starting from 2008, I drop all observations before January, 2008. In the remaining sample, there are 10,291 firms with and 8,691 firms without earnings calls.

Firms that choose to hold and not to hold earnings call may differ on various dimensions: conference calls can be held by larger and more liquid firms with broader investor base and higher analyst coverage. That is why I estimate the full set of parameters (as opposed to just q_v^0 and q_ξ^0) for the two subsamples.

Table 9 presents the results. Earnings of firms that hold earnings calls are more volatile and the market knows 82.7% of these innovations, compared to 87.1% for innovations in the earnings of firms who do not hold earnings calls. The total amount of information about fundamental innovations known by the market is higher for firms that hold earnings calls (0.827×0.043>0.871×0.030). The market learns a bigger fraction of the total fundamental information it knows on the day of earnings report release for firms that hold earnings calls on that day. Firms with and without conference calls do not differ substantially in terms of the variance of innovations to misreporting incentives and the amount of information about misreporting incentives that the market knows.

Table 9: Estimated model primitives for firms that do and do not hold earnings calls

Parameter estimate	**Hold EC**	**Do not hold EC**
Fundamental variance, σ_v^2	0.043 (0.004)	0.030 (0.003)
Market's total share of fundamental information, q_v	0.827 (0.061)	0.871 (0.071)
Market's share of fundamental information received concurrently with the manager's report, q_v^0	0.430 (0.010)	0.355 (0.012)
Incentives variance, σ_ξ^2	0.116 (0.110)	0.116 (0.105)
Market's total share of incentives information, q_ξ	0.657 (0.274)	0.660 (0.281)
Market's total share of incentives information received concurrently with the manager's report, q_ξ^0	0.903 (0.044)	0.907 (0.046)

Note: Standard errors are in parentheses. The parameters are estimated assuming a discount rate of $\delta = 0.9$.

5.3 Early and late reporters

Because different companies' fundamentals are correlated with each other, investors may use one company's report to learn about fundamentals of another company that has not yet issued its report. I test this information spillover, i.e. whether investors anticipate a greater portion of late-reporting firms' fundamentals, by estimating the model separately for early and late reporters.

I classify a company as a late reporter if it reported earnings later than a median company in a given year. My sample has 21,770 early reporters and 20,614 late reporters. Table 10 presents the estimation results.

Table 10: Estimated model primitives for early and late reporters

Parameter estimate	**Early reporters**	**Late reporters**
Fundamental variance, σ_v^2	0.043 (0.002)	0.034 (0.001)
Market's total share of fundamental information, q_v	0.560 (0.024)	0.677 (0.028)
Market's share of fundamental information received concurrently with the manager's report, q_v^0	0.441 (0.009)	0.435 (0.010)
Incentives variance, σ_ξ^2	0.004 (0.001)	0.002 (0.000)
Market's total share of incentives information, q_ξ	0.999 (0.144)	0.746 (0.226)
Market's total share of incentives information received concurrently with the manager's report, q_ξ^0	0.712 (0.045)	0.765 (0.101)

Note: Standard errors are in parentheses. The parameters are estimated assuming a discount rate of $\delta = 0.9$.

First, firms that report their earnings earlier in the reporting cycle are more volatile: their fundamental variance is greater than late reporters' by more than 30%. Second, the estimates support the existence of the information spillover. Investors anticipate 56.0% of early reporters' fundamentals before current reports are announced, and 67.7% of late reporters' fundamentals before the late reporters announce their earnings.

5.4 Industry analysis

In this section, I estimate the model separately for firms in different NAICS industries. I keep only industries for which I have at least 900 firms in the sample. Table 11 presents the results.

Table 11: Estimated model for firms in different NAICS industries

Parameter estimate	Mining *(1,133 firms)*	Utilities *(900 firms)*	Manufacturing *(8,641 firms)*	Retail trade *(1,239 firms)*	Transportation and warehousing *(979 firms)*	Information *(1,909 firms)*	Finance and insurance *(5,442 firms)*	Real estate rental and leasing *(1,002 firms)*	Professional, scientific, and technical servic *(1,456 firms)*
Fundamental variance, σ_v^2	0.025	0.051	0.025	0.052	0.037	0.024	0.027	0.022	0.038
	(0.005)	(0.010)	(0.003)	(0.010)	(0.009)	(0.004)	(0.004)	(0.006)	(0.007)
Market's total share of fundamental information, q_v	0.646	0.035	0.791	0.985	0.962	0.994	0.992	0.992	0.992
	(0.165)	(0.041)	(0.102)	(0.187)	(0.203)	(0.184)	(0.151)	(0.240)	(0.169)
Market's share of fundamental information received concurrently with the manager's report, q_v^0	0.613	0.033	0.787	0.330	0.347	0.490	0.307	0.267	0.497
	(0.114)	(0.341)	(0.034)	(0.018)	(0.030)	(0.030)	(0.011)	(0.029)	(0.028)
Incentives variance, σ_ξ^2	0.013	0.000	1.127	1.942	2.483	1.685	1.973	3.190	1.802
	(0.014)	(0.000)	(2.734)	(2.080×10)	(2.467×10)	(2.400×10)	(7.480)	(4.493×10)	(2.697×10)
Market's total share of incentives information, q_ξ	0.672	0.030	0.461	0.733	0.615	0.804	0.944	0.518	0.790
	(0.478)	(5.623×10^3)	(0.804)	(3.798)	(2.723)	(5.797)	(1.031)	(1.364×10)	(4.833)
Market's total share of incentives information received concurrently with the manager's report, q_ξ^0	0.762	0.037	0.906	0.886	0.830	0.875	0.717	0.747	0.847
	(0.226)	(1.284×10^6)	(0.166)	(0.604)	(0.766)	(0.922)	(0.315)	(6.713)	(0.956)

Note: Standard errors are in parentheses. The parameters are estimated assuming a discount rate of $\delta = 0.9$.

5.5 Size subsample analysis

In this section, I estimate the model separately for firms in different quantiles of the market value of equity. Table 12 presents the results.

Table 12: Estimated model primitives for firms in different size quintiles

Parameter estimate	**Small** *(13,987 firms)*	**Medium** *(13,986 firms)*	**Large** *(14,411 firms)*
Fundamental variance, σ_v^2	0.006 (0.001)	0.014 (0.001)	0.032 (0.003)
Market's total share of fundamental information, q_v	0.910 (0.102)	0.858 (0.076)	0.661 (0.060)
Market's share of fundamental information received concurrently with the manager's report, q_v^0	1.000 (0.081)	0.897 (0.048)	0.692 (0.020)
Incentives variance, σ_ξ^2	1.186 (2.946)	1.173 (2.971)	1.319 (2.738)
Market's total share of incentives information, q_ξ	0.353 (1.114)	0.391 (0.888)	0.208 (0.948)
Market's total share of incentives information received concurrently with the manager's report, q_ξ^0	0.923 (0.026)	0.953 (0.114)	1.000 (0.015)

Note: Standard errors are in parentheses. The parameters are estimated assuming a discount rate of $\delta = 0.9$.

6 Robustness tests

In this section, I examine the sensitivity of the parameters' estimates to the choice of the manager's discount rate and normalization of data.

6.1 Different levels of the manager's discount rate

I follow Zakolyukina (2018) and re-estimate the model assuming two additional levels of the manager's discount rate, $\delta = 0.85$ and $\delta = 0.95$. Table 13 presents the results.

The estimates for $\delta = 0.85$ are similar to the estimates obtained assuming $\delta = 0.9$. For $\delta = 0.95$, the estimates of the misreporting incentives uncertainty and the market's share of misreporting incentives information are notably different.

To understand why the estimated misreporting incentives uncertainty is different, first, note that this variance is primarily identified from the variance of changes in annual reports and the variance of the market's expectations of reporting bias. According to proposition 1, the bias is the product of the (1) price response to the manager's report, (2) misreporting incentives, and (3) the discounting factor. Therefore, for a given variance of reports from the data, if we assume a higher discounting factor, the estimated misreporting incentives uncertainty will be lower.

Another moment that helps identify misreporting incentives uncertainty is the ERC, α_0. α_0 is decreasing in the manager's discounting factor, increasing in the market's share of misreporting incentives information, and decreasing in the market's share of fundamental information. When we assume a higher level of the discounting factor, for a given level of ERC from the data, the estimated market's share of fundamental information decreases and the estimated market's share of misreporting incentives information increases.

Table 13: Parameters' estimates for different levels of the manager's discounting factor, δ

Parameter estimate	$\delta = 0.85$	$\delta = 0.95$
Fundamental variance, σ_v^2	0.034 (0.001)	0.043 (0.001)
Market's total share of fundamental information, q_v	0.749 (0.027)	0.515 (0.015)
Market's share of fundamental information received concurrently with the manager's report, q_v^0	0.407 (0.006)	0.435 (0.007)
Incentives variance, σ_ξ^2	0.034 (0.010)	0.001 (0.000)
Market's total share of incentives information, q_ξ	0.373 (0.172)	0.592 (0.599)
Market's total share of incentives information received concurrently with the manager's report, q_ξ^0	0.890 (0.058)	0.947 (0.119)

Note: Standard errors are in parentheses.

6.2 Data normalization

In the main analysis, I divide all the variables by companies' book values at dates the companies first appear in my sample. Because some companies have very small or negative book values due to buybacks, these companies are excluded, leading to a potentially biased sample of firms. In this section, I change the normalization and divide all the variables by total assets that companies have at the first date they appear in my sample. This new normalization increases my sample by approximately 10,000 companies.

Table 14 shows the summary statistics for the broader sample, and the re-estimated parameters are presented in Table 15.

Keeping companies with negative or very small book value changes the estimates of the market's shares of fundamental and misreporting incentives information. Perhaps because companies with negative or small book values are smaller and harder to analyze for investors, the new estimated market's share of fundamental information is lower. The estimated market's share of misreporting incentives information, on the other hand, is higher for the new sample, suggesting that investors better understand manager's incentives for smaller companies.

Table 14: Summary statistics for the sample with new normalization

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
ACTUAL_total_scaled	52,263	0.073	0.122	−0.386	0.010	0.108	0.790
change_AF_scaled	52,263	−0.008	0.035	−0.217	−0.013	0.004	0.097
change_price_scaled	52,263	0.128	0.713	−2.484	−0.094	0.264	4.283
change_price_EA_scaled	52,263	0.004	0.121	−0.561	−0.020	0.025	0.579
r_AF	52,263	−0.000	0.012	−0.067	−0.002	0.003	0.050

Table 15: Estimated model parameters after new normalization

Parameter estimate	
Fundamental variance, σ_v^2	0.001 (0.000)
Market's total share of fundamental information, q_v	0.534 (0.080)
Market's share of fundamental information received concurrently with the manager's report, q_v^0	0.632 (0.057)
Incentives variance, σ_ξ^2	0.086 (0.057)
Market's total share of incentives information, q_ξ	0.705 (0.140)
Market's total share of incentives information received concurrently with the manager's report, q_ξ^0	0.807 (0.040)

Note: Standard errors are in parentheses. The parameters are estimated assuming a discount rate of $\delta = 0.9$.

7 An extension: accounting noise in the report

In the main model, I assume that absent manipulation, the report is equal to the true book value and there are no errors due to the accounting system's imperfections. Investors' uncertainty about the reporting error may affect prices' and analyst forecasts' moments in a similar manner as investors' uncertainty about misreporting incentives. For example, the price response to the manager's report will be lower when investors have less information about the accounting noise and when investors are more uncertain about the manager's misreporting incentives. To examine to what extent my estimates of the misreporting incentives uncertainty are confounded by the accounting noise, in this section I consider an extension of the model where I include the accounting noise.

Specifically, I assume that the manager's cost of misreporting at time t is $\frac{1}{2}\left(r_t - \theta_t - e_t\right)^2$, where $\tilde{e}_t \overset{\text{i.i.d.}}{\sim} N(0, \sigma_e^2)$ is the noise generated by the accounting system. The manager observes the book value and the realization of e_t before choosing her report. The distribution of e_t is common knowledge. The manager's optimal report at time t will be

$$r_t^* = \theta_t + \alpha_0(\xi_t + \xi_{t-1} + \xi_{t-2}) + \delta\alpha_0(\xi_t + \xi_{t-1}) + \delta^2\alpha_0\xi_t + e_t \tag{36}$$

The report response coefficient will be the solution to

$$\alpha_0' = \frac{3(1-q_v)\sigma_v^2}{3(1-q_v)\sigma_v^2 + (1-q_\xi)\sigma_\xi^2((\alpha_0' + \delta\alpha_0' + \delta^2\alpha_0')^2 + \delta^4\alpha_0'^2 + \delta^2\alpha_0'^2 + \alpha_0'^2) + 2\sigma_e^2} \tag{37}$$

To identify the uncertainty about the accounting noise, σ_e^2, I introduce a new moment – the covariance of two one-year changes in the manager's reports:

$$Cov\left[r_t - r_{t-1}, r_{t-1} - r_{t-2}\right] = 2\sigma_v^2 - \delta^4\alpha_0'^2\sigma_\xi^2 - \sigma_e^2 \tag{38}$$

I use two properties of the accounting system noise and the manager's misreporting incentives to identify the degree of the accounting system noise. First, while a shock to misreporting incentives persists for three period, the accounting system noise only lives for one period. Because of that misreporting incentives variance and accounting system noise variance enter the moments that use variances and covariances of the manager's reports in different forms. Second, since investors do not have any information about the accounting system noise from any sources other than the manager's report, changes in the analyst market's expectations of the next report during the year are not affected by the updated beliefs about the accounting system noise.

The new complete set of moments to estimate the model with accounting noise is

1. Variance of one-year change in the annual book value report, or variance of annual earnings report:

$$Var[r_t - r_{t-1}] = 3\sigma_v^2 + \alpha_0'^2 \sigma_\xi^2((1+\delta+\delta^2)^2 + \delta^4 + \delta^2 + 1) + 2\sigma_e^2 \tag{39}$$

2. Variance of two-year change in the annual book value report, or variance of the sum of two concurrent earnings reports:

$$Var[r_t - r_{t-2}] = 10\sigma_v^2 + \alpha_0'^2 \sigma_\xi^2((1+\delta+\delta^2)^2 + 2(1+\delta)^2 + (\delta+\delta^2)^2 + 1) + 2\sigma_e^2 \tag{40}$$

3. Variance of change in the market's expectations from after one report to before the next report:

$$Var[ME_{t+1}^{\text{pre-report}} - ME_t^{\text{post-report}}] = q_v(1-q_v^0)\sigma_v^2 + q_\xi(1-q_\xi^0)\alpha_0'^2\sigma_\xi^2(1+\delta+\delta^2)^2 \tag{41}$$

4. Covariance of changes in prices from after one report to before the next report with changes in the market's expectations from after one report to before the next report:

$$Cov[p_{t+1}^{\text{pre-report}} - p_t^{\text{post-report}}, ME_{t+1}^{\text{pre-report}} - ME_t^{\text{post-report}}] = 3q_v(1-q_v^0)\sigma_v^2 \tag{42}$$

5. Earnings response coefficient:

$$E[(p_t^{\text{post-report}} - p_t^{\text{pre-report}}) - \alpha_0'(r_t - r_{t-1} - ME_t^{\text{pre-report}})] = 0 \tag{43}$$

6. Residual variance of the regression of price changes around the report, $(p_t^{\text{post-report}} - p_t^{\text{pre-report}})$, on earnings surprises, $(r_t - r_{t-1} - ME_t^{\text{pre-report}})$:

$$Var[(p_t^{\text{post-report}} - p_t^{\text{pre-report}}) - \alpha_0'(r_t - r_{t-1} - ME_t^{\text{pre-report}})] = 9q_v q_v^0 \sigma_v^2 + 2\alpha_0'^2\sigma_e^2 \tag{44}$$

7. Covariance of two one-year changes in the reports:

$$Cov\left[r_t - r_{t-1}, r_{t-1} - r_{t-2}\right] = 2\sigma_v^2 - \delta^4 \alpha_0'^2 \sigma_\xi^2 - \sigma_e^2 \tag{45}$$

Table 16 presents the estimated parameters. The variance of the accounting system error is close to zero, which implies it is very small relative to the fundamental and misreporting incentives variance. However, adding the accounting system error uncertainty to the model alters the values of the other estimated parameters. The total fundamental variance is about 30% larger than for the model that does not account for the uncertainty about the accounting system's noise. The fraction of the fundamental information that investors know is now only 0.481.

The estimate of the misreporting incentives variance has also gone up by roughly 200%. According to the new model, investors know 0.625 of the misreporting incentives information, which is slightly less than twice the estimate for the model without accounting system error uncertainty (0.368). Interestingly, the new model suggests that investors learn nothing about managers' misreporting incentives on the earnings report day.

Table 17 shows the theoretical and empirical moments produced by the model that accounts for the accounting system error uncertainty. The new model matches statistics related to the reports notably better than the model that does not account for the accounting system error uncertainty, however, the new model matches the statistics related to the earnings response coefficient worse than the old model. I let the reader choose the model and thus the conclusions.

Table 16: Estimated parameters of the extended model

Parameter estimate	
Fundamental variance, σ_v^2	0.045 (0.007)
Market's total share of fundamental information, q_v	0.481 (0.079)
Market's share of fundamental information received concurrently with the manager's report, q_v^0	0.518 (0.008)
Incentives variance, σ_ξ^2	0.107 (2.953)
Market's total share of incentives information, q_ξ	0.625 (17.685)

Market's total share of incentives information received concurrently with the manager's report, q_ξ^0	0.023 (51.605)
Accounting system error uncertainty, σ_e^2	0.000 (0.017)

Note: Standard errors are in parentheses. The parameters are estimated assuming a discount rate of $\delta = 0.9$.

Table 17: Empirical and theoretical moments for the extended model

#	**Moments**	Empirical	Theoretical	t-value of difference
1	**Variance of one-year change in annual reports**	0.13493	0.13569	-0.469
2	**Variance of two-year change in annual reports**	0.44913	0.44948	-0.066
3	**Variance of change in market expectations between two reports**	0.00717	0.01123	-43.64
4	**Covariance of change in prices with change in market expectations**	0.03602	0.03102	5.138
5	**Earnings response coefficient**	0.00033	0.00003	23.364
6	**Residual variance of the regression of price changes around reports on earnings surprises**	0.08784	0.09997	11.01
7	**Covariance of two one-year changes in the reports**	0.10520	0.08903	-12.336

Note: The theoretical moments are calculated for estimates assuming $\delta = 0.9$.

8 Conclusion

This paper provides a structural estimation technique to measure the amounts of two types of information – fundamental and misreporting incentives information – that market participants have before the manager issues annual earnings report. I further quantify the effects of the market's information endowment on earnings quality and price efficiency, and current levels of misreporting and mispricing due to information asymmetry.

The estimates suggest that the market knows a lot of fundamental and misreporting incentives information that the manager knows – 81.9% and 70.8%, respectively. Fundamental information has higher effects on earnings quality and price efficiency than misreporting incentives information. Counterfactual analyses consider different scenarios about changes in market's information and overall uncertainty.

The study could be of interest to regulators who are concerned with informational reforms to improve earnings quality and/or price efficiency. In particular, I show that an increase in the market's misreporting incentives information will dramatically decrease earnings quality, but only slightly improve price efficiency.

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Appendix

A.1 Proof of Proposition 1

Let us start with a manager who has finite tenure, that is, works at a firm with certainty up until time T. At time T, the manager's problem is:

$$\max_{r_T} \quad m_T p_T - \frac{(r_T - \theta_T)^2}{2} \tag{A46}$$

$$= m_T(p_0 + \sum_{j=0}^{j=T-1} \alpha_j^t r_j + \sum_{j=0}^{j=T-1} \beta_j^{0,t} \varepsilon_{1,j}^0 + \sum_{j=0}^{j=T-1} \beta_j^{1,t} \varepsilon_{1,j}^1 + \sum_{j=0}^{j=T-1} \gamma_j^{0,t} m_{1,j}^0 + \sum_{j=0}^{j=T-1} \gamma_j^{1,t} m_{1,j}^1) - \frac{(r_T - \theta_T)^2}{2} \tag{A47}$$

The optimal report is:

$$r_T^* = \theta_T + m_T \alpha_T^T \tag{A48}$$

Given the optimal choice at time T, the manager's problem at time $T-1$ is:

$$\max_{r_{T-1}} \quad m_{T-1}p_{T-1} - \frac{(r_{T-1}-\theta_{T-1})^2}{2} + \delta E_{T-1}[U_T] \tag{A49}$$

$$= m_{T-1}p_{T-1} - \frac{(m_T\alpha_T^T)^2}{2} + \delta E_{T-1}[U_T] \tag{A50}$$

The expected utility at time T is

$$\begin{aligned} E_{T-1}[U_T] = E_{T-1}[m_T]((p_0 + \sum_{j=0}^{j=T-1}\alpha_j^t r_j + \sum_{j=0}^{j=T-1}\beta_j^{0,t}\varepsilon_{1,j}^0 + \sum_{j=0}^{j=T-1}\beta_j^{1,t}\varepsilon_{1,j}^1 + \sum_{j=0}^{j=T-1}\gamma_j^{0,t}m_{1,j}^0 + \sum_{j=0}^{j=T-1}\gamma_j^{1,t}m_{1,j}^1) \\ +\alpha_T^T E_{T-1}[m_T]E_{T-1}[\theta_T] + \alpha_T^{T2}E_{T-1}[m_T^2] \\ +\beta_T^T E_{T-1}[m_T]E_{T-1}[\varepsilon_{1,T}] + \gamma_T^T E_{T-1}[m_T m_{1,T}] \end{aligned} \tag{A51}$$

The optimal report at time $T-1$ is

$$r_{T-1} = \theta_{T-1} + m_{T-1}\alpha_{T-1}^{T-1} + \delta E_{T-1}[m_T]\alpha_{T-1}^T \tag{A52}$$

By induction, the manager's optimal report at time t is

$$\begin{aligned} r_t &= \theta_t + m_t\alpha_t^t + \sum_{k=1}^{\infty}\delta^k\alpha_t^{t+k}E_t[m_{t+k}] \\ &= \theta_t + \alpha_t^t(\xi_t + \xi_{t-1} + \xi_{t-2}) + \delta\alpha_t^{t+1}(\xi_t + \xi_{t-1}) + \delta^2\alpha_t^{t+2}\xi_t \end{aligned} \tag{A53}$$

A.2 Proof of Proposition 2

Denote by α_0, α_1 and α_2 the steady-state responses of current, one-year ahead and two-years ahead prices' to a current managerial report. Managerial report in steady-state is then:

$$r_t = \theta_t + \alpha_0(\xi_t + \xi_{t-1} + \xi_{t-2}) + \delta\alpha_1(\xi_t + \xi_{t-1}) + \delta^2\alpha_2\xi_t \tag{A54}$$

Before the current managerial report is issued, price equation is:

$$p_t^{\text{pre-report}} = \sum_{k=0}^{k=t} \varepsilon_{1,k} + E\left[\sum_{k=t+1}^{k=\infty} \varepsilon_{1,k} | I_t^{\text{market}} \setminus \{r_t\}\right] + E\left[\sum_{k=0}^{k=t-1} \varepsilon_{2,k} | I_t^{\text{market}} \setminus \{r_t\}\right]$$
$$+ E\left[\varepsilon_{2,t} | I_t^{\text{market}} \setminus \{r_t\}\right] + E\left[\sum_{k=t+1}^{k=\infty} \varepsilon_{2,k} | I_t^{\text{market}} \setminus \{r_t\}\right] \tag{A55}$$

The difference between current and prior year reports, $r_t - r_{t-1} = \varepsilon_{1,t} + \varepsilon_{2,t} + \text{Bias}_t - \text{Bias}_{t-1}$, is a sum of (1) part of current period earnings that is observed by the market, (2) part of current period earnings that is not observed by the market, (3) difference in biases that is a function of the manager's incentive intensity, m_t. The difference between the reports provides market with information on $\varepsilon_{2,t}$. Following the report, the market's revised expectation of $\varepsilon_{2,t}$ is

$$E[\varepsilon_{2,t} | I_t^{\text{market}}] = E[\varepsilon_{2,t} | I_t^{\text{market}} \setminus \{r_t\}]$$
$$+ (r_t - E[r_t | I_t^{\text{market}} \setminus \{r_t\}]) \frac{(1-q_\nu)\sigma_\nu^2}{3(1-q_\nu)\sigma_\nu^2 + (1-q_\xi)\sigma_\xi^2((\alpha_0 + \delta\alpha_1 + \delta^2\alpha_2)^2 + \delta^4\alpha_2^2 + \delta^2\alpha_1^2 + \alpha_0^2)}, \tag{A56}$$

The expectation of $\varepsilon_{2,t} = \nu_{2,t} + \nu_{2,t-1} + \nu_{2,t-2}$ affects the market's expectations of $\varepsilon_{2,t+1}$ and $\varepsilon_{2,t+2}$ through expectations of $\nu_{2,t}$. Thus, $E[\nu_{2,t} | I_t^{\text{market}}]$ will appear in the pricing function three times. Steady-state price response coefficients can be found by solving the system of equations:

$$\alpha_0 = \frac{3(1-q_\nu)\sigma_\nu^2}{3(1-q_\nu)\sigma_\nu^2 + (1-q_\xi)\sigma_\xi^2((\alpha_0 + \delta\alpha_1 + \delta^2\alpha_2)^2 + \delta^4\alpha_2^2 + \delta^2\alpha_1^2 + \alpha_0^2)} \tag{A57}$$

$$\alpha_1 = \frac{3(1-q_\nu)\sigma_\nu^2}{3(1-q_\nu)\sigma_\nu^2 + (1-q_\xi)\sigma_\xi^2((\alpha_0 + \delta\alpha_1 + \delta^2\alpha_2)^2 + \delta^4\alpha_2^2 + \delta^2\alpha_1^2 + \alpha_0^2)} \tag{A58}$$

$$\alpha_2 = \frac{3(1-q_\nu)\sigma_\nu^2}{3(1-q_\nu)\sigma_\nu^2 + (1-q_\xi)\sigma_\xi^2((\alpha_0 + \delta\alpha_1 + \delta^2\alpha_2)^2 + \delta^4\alpha_2^2 + \delta^2\alpha_1^2 + \alpha_0^2)} \tag{A59}$$

It can be shown that $\alpha_0 = \alpha_1 = \alpha_2$.

In addition to the update about ε_2, the market observes part of fundamental information – a component of next-year earnings, $\nu_{1,t+1}^0$. Thus, change in prices around the report, $p_t^{\text{post-report}} - p_t^{\text{pre-report}}$ is

$$p_t^{\text{post-report}} - p_t^{\text{pre-report}} = (r_t - E[\tilde{r}_t | I_t^{\text{market}} \setminus \{r_t\}])\alpha_0 + 3\nu_{1,t+1}^0 \tag{A60}$$

A.3 Proof of Proposition 3

Firm price after the current report and before the market learns information about next year earnings from other sources is

$$p_t^{\text{post-report}} = \sum_{k=0}^{k=t} \varepsilon_{1,k} + E\left[\varepsilon_{1,t+1}|I_t^{\text{market}}\right] + E\left[\sum_{k=t+2}^{k=\infty} \varepsilon_{1,k}|I_t^{\text{market}}\right] + E\left[\sum_{k=0}^{k=\infty} \varepsilon_{2,k}|I_t^{\text{market}}\right] + 3\nu_{1,t+1}^0 \quad \text{(A61)}$$

$$= \sum_{k=0}^{k=t} \varepsilon_{1,k} + (\nu_{1,t-1} + \nu_{1,t}) + \nu_{1,t} + E\left[\sum_{k=0}^{k=\infty} \varepsilon_{2,k}|I_t^{\text{market}}\right] + 3\nu_{1,t+1}^0 \quad \text{(A62)}$$

After the market learns information from other sources, $\varepsilon_{1,t+1} = \nu_{1,t+1} + \nu_{1,t} + \nu_{1,t-1}$, it updates its expectation on $\nu_{1,t+1}$ from 0 to its realized value. The price becomes

$$p_{t+1}^{\text{pre-report}} = \sum_{k=0}^{k=t} \varepsilon_{1,k} + (\nu_{1,t-1} + \nu_{1,t} + \nu_{1,t+1}) + (\nu_{1,t} + \nu_{1,t+1}) + \nu_{1,t+1} + E\left[\sum_{k=0}^{k=\infty} \varepsilon_{2,k}|I_t^{\text{market}}\right] \quad \text{(A63)}$$

The change in price is, therefore:

$$p_{t+1}^{\text{pre-report}} - p_t^{\text{post-report}} = 3\nu_{1,t+1}^1 \quad \text{(A64)}$$

A.4 Proof of Proposition 4

Change in market expectations of the next report after the issue of a current report are driven by two forces: first, the expectations before the report are of this report, but after the report, they are of the next report; second, the market learns new information about firm fundamentals and the manager's incentive intensity from the current report and from other sources concurrent with the report. Before current report comes out, market expectations of the current report are:

$$\begin{aligned} ME_t^{\text{pre-report}} = &\sum_{k=0}^{k=t} \varepsilon_{1,k} + E\left[\sum_{k=t+1}^{k=\infty} \varepsilon_{1,k}|I_t^{\text{market}} \setminus \{r_t\}\right] + E\left[\sum_{k=1}^{k=\infty} \varepsilon_{2,k}|I_t^{\text{market}} \setminus \{r_t\}\right] - r_{t-1} \\ &+ \alpha_0((\xi_{1,t} + \xi_{1,t-1} + \xi_{1,t-2} + E[m_{2,t}|I_t^{\text{market}} \setminus \{r_t\}]) \\ &+ \delta(\xi_{1,t} + \xi_{1,t-1} + E[m_{2,t+1}|I_t^{\text{market}} \setminus \{r_t\}]) + \delta^2(\xi_{1,t} + E[m_{2,t+2}|I_t^{\text{market}} \setminus \{r_t\}])) \end{aligned} \quad \text{(A65)}$$

After the report is issued, the market (1) updates its beliefs about unobserved information (ε_2 and m_2), (2) incorporates newly observed information ($\nu_{1,t+1}^0$ and $\xi_{1,t+1}^0$), (3) forms new expectations about the next report.

$$ME_t^{\text{post-report}} = \sum_{k=0}^{k=t} \varepsilon_{1,k} + E\left[\sum_{k=t+1}^{k=\infty} \varepsilon_{1,k}|I_t^{\text{market}}\right] + E\left[\sum_{k=1}^{k=\infty} \varepsilon_{2,k}|I_t^{\text{market}}\right] - r_t$$
$$+\alpha_0((\xi_{1,t+1}^0 + \xi_{1,t} + \xi_{1,t-1} + E[m_{2,t+1}|I_t^{\text{market}} \setminus \{r_t\}]) +$$
$$\delta(\xi_{1,t+1}^0 + \xi_{1,t} + E[m_{2,t+2}|I_t^{\text{market}} \setminus \{r_t\}]) + \delta^2(\xi_{1,t+1}^0 + E[m_{2,t+3}|I_t^{\text{market}} \setminus \{r_t\}])) \tag{A66}$$

Change in the market's expectations is

$$ME_t^{\text{post-report}} - ME_t^{\text{pre-report}} = \nu_{1,t} + \nu_{1,t-1} + \nu_{1,t+1}^0 \tag{A67}$$
$$+E[\tilde{\varepsilon}_{2,t+1}|I_t^{\text{market}}] - E[\tilde{\varepsilon}_{2,t}|I_t^{\text{market}} \setminus \{r_t\}] \tag{A68}$$
$$+\left(\alpha_0(\xi_{1,t+1}^0 - \xi_{1,t-2}) + \alpha_0\delta(\xi_{1,t+1}^0 - \xi_{1,t-1}) + \alpha_0\delta^2(\xi_{1,t+1}^0 - \xi_{1,t})\right) \tag{A69}$$
$$+\left(\alpha_0 \sum_{k=1}^{k=\infty} \delta^{k-1} E[\tilde{m}_{2,t+k}|I_t^{\text{market}}] - \alpha_0 \sum_{k=0}^{k=\infty} \delta^k E[\tilde{m}_{2,t+k}|I_t^{\text{market}} \setminus \{r_t\}]\right) \tag{A70}$$
$$-r_t + r_{t-1} \tag{A71}$$

A.5 Proof of Proposition 5

$$ME_t^{\text{post-report}} = \sum_{k=0}^{k=t} \varepsilon_{1,k} + E\left[\sum_{k=t+1}^{k=\infty} \varepsilon_{1,k}|I_t^{\text{market}}\right] + E\left[\sum_{k=1}^{k=\infty} \varepsilon_{2,k}|I_t^{\text{market}}\right] - r_t$$
$$+\alpha_0((\xi_{1,t+1}^0 + \xi_{1,t} + \xi_{1,t-1} + E[m_{2,t+1}|I_t^{\text{market}} \setminus \{r_t\}]) +$$
$$\delta(\xi_{1,t+1}^0 + \xi_{1,t} + E[m_{2,t+2}|I_t^{\text{market}} \setminus \{r_t\}]) + \delta^2(\xi_{1,t+1}^0 + E[m_{2,t+3}|I_t^{\text{market}} \setminus \{r_t\}])) \tag{A72}$$

When the market learns $\nu_{1,t+1}^1$ and $\xi_{1,t+1}^1$ from other sources, it updates its expectation of $\xi_{1,t+1}$ from $\xi_{1,t+1}^0$ to $\xi_{1,t+1}^0 + \xi_{1,t+1}^1$. Pre-next report market expectations are:

$$ME_{t+1}^{\text{pre-report}} = \sum_{k=0}^{k=t} \varepsilon_{1,k} + \nu_{1,t+1} + \nu_{1,t} + \nu_{1,t-1} + E\left[\sum_{k=1}^{k=\infty} \varepsilon_{2,k}|I_t^{\text{market}}\right] - r_t$$
$$+\alpha_0((\xi_{1,t+1} + \xi_{1,t} + \xi_{1,t-1} + E[m_{2,t}|I_t^{\text{market}} \setminus \{r_t\}]) +$$
$$\delta(\xi_{1,t+1} + \xi_{1,t} + E[+m_{2,t+1}|I_t^{\text{market}} \setminus \{r_t\}]) + \delta^2(\xi_{1,t+1} + E[m_{2,t+2}|I_t^{\text{market}} \setminus \{r_t\}])) \tag{A73}$$

Change in market expectations is

$$ME_{t+1}^{\text{pre-report}} - ME_{t}^{\text{post-report}} = v_{1,t+1}^{1} + \alpha_0(1+\delta+\delta^2)\xi_{1,t+1}^{1} \tag{A74}$$

A.6 Proof of Proposition 6

Recall that α_0 is a solution to

$$\alpha_0 - \frac{3(1-q_v)\sigma_v^2}{3\sigma_v^2(1-q_v)+\sigma_\xi^2(1-q_\xi)\alpha_0^2((1+\delta+\delta^2)^2+\delta^4+\delta^2+1)} \equiv f(\alpha_0, q_v, q_\xi) = 0 \tag{A75}$$

From implicit function theorem, $\frac{\partial\alpha_0}{\partial q_v} = -\frac{\frac{\partial f}{\partial q_v}}{\frac{\partial f}{\partial \alpha_0}}$ and $\frac{\partial\alpha_0}{\partial q_\xi} = -\frac{\frac{\partial f}{\partial q_\xi}}{\frac{\partial f}{\partial \alpha_0}}$.

$$\frac{\partial f}{\partial \alpha_0} = 1 + \frac{3(1-q_v)\sigma_v^2(1-q_\xi)\sigma_\xi^2(((1+\delta+\delta^2)^2+\delta^4+\delta^2+1))}{(3\sigma_v^2(1-q_v)+\sigma_\xi^2(1-q_\xi)\alpha_0^2((1+\delta+\delta^2)^2+\delta^4+\delta^2+1))^2} > 0 \tag{A76}$$

$$\frac{\partial f}{\partial q_v} = -\frac{3\sigma_v^2(3\sigma_v^2(1-q_v)+\sigma_\xi^2(1-q_\xi)\alpha_0^2((1+\delta+\delta^2)^2+\delta^4+\delta^2+1))+3\sigma_v^2 3(1-q_v)\sigma_v^2}{(3\sigma_v^2(1-q_v)+\sigma_\xi^2(1-q_\xi)\alpha_0^2((1+\delta+\delta^2)^2+\delta^4+\delta^2+1))^2} > 0 \tag{A77}$$

$$\frac{\partial f}{\partial q_\xi} = \frac{-3(1-q_v)\sigma_v^2\sigma_{\alpha 0}^{22}((1+\delta+\delta^2)^2+\delta^4+\delta^2+1)}{(3\sigma_v^2(1-q_v)+\sigma_\xi^2(1-q_\xi)\alpha_0^2((1+\delta+\delta^2)^2+\delta^4+\delta^2+1))^2} < 0 \tag{A78}$$

Thus, $\frac{\partial\alpha_0}{\partial q_v} < 0$ and $\frac{\partial\alpha_0}{\partial q_\xi} > 0$.

A.7 Proof of Lemma 1

Earnings quality is

$$EQ_t = \frac{-\sqrt{\sigma_\xi^2\alpha_0^2 2(1+\delta+2\delta^2+\delta^3+\delta^4)}}{\sqrt{3\sigma_v^2}} \tag{A79}$$

$\frac{\partial EQ}{\partial q_v} = \frac{\partial EQ}{\partial \alpha_0}\frac{\partial\alpha_0}{\partial q_v}$, $\frac{\partial EQ}{\partial q_\xi} = \frac{\partial EQ}{\partial \alpha_0}\frac{\partial\alpha_0}{\partial q_\xi}$.

$$\frac{\partial EQ}{\partial \alpha_0} = \frac{-\sqrt{\sigma_\xi^2 2(1+\delta+2\delta^2+\delta^3+\delta^4)}}{\sqrt{3\sigma_v^2}} < 0 \tag{A80}$$

Given Lemma 6, $\frac{\partial EQ}{\partial q_v} > 0$ and $\frac{\partial EQ}{\partial q_\xi} < 0$.

A.8 Proof of Lemma 2

$$PE_t = -\sqrt{(1-q_\xi)\sigma_\xi^2\alpha_0^2(2\delta^3+4\delta^2+4\delta+3)+5(1-q_\nu)\sigma_\nu^2} \tag{A81}$$

$$\begin{aligned}\frac{\partial AQ}{\partial q_\nu} &= -\frac{1}{\sqrt{(1-q_\xi)\sigma_\xi^2\alpha_0^2(2\delta^3+4\delta^2+4\delta+3)+5(1-q_\nu)\sigma_\nu^2}} \\ &\quad \times\left((1-q_\xi)\sigma_\xi^2(2\delta^3+4\delta^2+4\delta+3)2\alpha_0\frac{\partial\alpha_0}{\partial q_\nu}-5\sigma_\nu^2\right) \end{aligned}\tag{A82}$$

$$\begin{aligned}\frac{\partial AQ}{\partial q_\xi} &= -\frac{1}{\sqrt{(1-q_\xi)\sigma_\xi^2\alpha_0^2(2\delta^3+4\delta^2+4\delta+3)+5(1-q_\nu)\sigma_\nu^2}} \\ &\times\left(-\sigma_\xi^2\alpha_0^2(2\delta^3+4\delta^2+4\delta+3)+(1-q_\xi)\sigma_\xi^2(2\delta^3+4\delta^2+4\delta+3)2\alpha_0\frac{\partial\alpha_0}{\partial q_\xi}\right)\end{aligned}\tag{A83}$$

(A61) is positive for all $\alpha > 0$, (A62) is positive iff

$$|\sigma_\xi^2\alpha_0^2(2\delta^3+4\delta^2+4\delta+3)| > |(1-q_\xi)\sigma_\xi^2(2\delta^3+4\delta^2+4\delta+3)2\alpha_0\frac{\partial\alpha_0}{\partial q_\xi}|, \tag{A84}$$

which is true for all $0 < q_\nu < 1$, $0 < q_\xi < 1$, $\sigma_\nu^2 > 0$, $\sigma_\xi^2 > 0$, $0 < \delta < 1$.

A.9 Equilibrium of the extension with accounting noise

Denote by α_0, α_1 and α_2 the steady-state responses of current, one-year ahead and two-years ahead prices' to a current managerial report. Managerial report in steady-state is then:

$$r_t = \theta_t + \alpha_0(\xi_t+\xi_{t-1}+\xi_{t-2}) + \delta\alpha_1(\xi_t+\xi_{t-1}) + \delta^2\alpha_2\xi_t + e_t \tag{A85}$$

Before the current managerial report is issued, price equation is:

$$\begin{aligned}p_t^{\text{pre-report}} &= \sum_{k=0}^{k=t}\varepsilon_{1,k} + E\left[\sum_{k=t+1}^{k=\infty}\varepsilon_{1,k}|I_t^{\text{market}}\setminus\{r_t\}\right] + E\left[\sum_{k=0}^{k=t-1}\varepsilon_{2,k}|I_t^{\text{market}}\setminus\{r_t\}\right] \\ &\quad + E\left[\varepsilon_{2,t}|I_t^{\text{market}}\setminus\{r_t\}\right] + E\left[\sum_{k=t+1}^{k=\infty}\varepsilon_{2,k}|I_t^{\text{market}}\setminus\{r_t\}\right]\end{aligned}\tag{A86}$$

The difference between current and prior year reports, $r_t - r_{t-1} = \varepsilon_{1,t} + \varepsilon_{2,t} + \text{Bias}_t - \text{Bias}_{t-1} + e_t - e_{t-1}$, is a sum of (1) part of current period earnings that is observed by the market, (2) part of current period earnings that is not observed by the market, (3) difference in biases that is a function of the manager's incentive intensity, m_t, (4) difference in the accounting noise at times t and $t-1$. The difference between the reports provides market with information on $\varepsilon_{2,t}$. Following the report, the market's revised expectation of $\varepsilon_{2,t}$ is

$$E[\varepsilon_{2,t}|I_t^{\text{market}}] = E[\varepsilon_{2,t}|I_t^{\text{market}} \setminus \{r_t\}]$$
$$+(r_t - E[r_t|I_t^{\text{market}} \setminus \{r_t\}])\frac{(1-q_\nu)\sigma_\nu^2}{3(1-q_\nu)\sigma_\nu^2 + (1-q_\xi)\sigma_\xi^2((\alpha_0+\delta\alpha_1+\delta^2\alpha_2)^2+\delta^4\alpha_2^2+\delta^2\alpha_1^2+\alpha_0^2)+2\sigma_e^2}, \tag{A87}$$

The expectation of $\varepsilon_{2,t} = \nu_{2,t} + \nu_{2,t-1} + \nu_{2,t-2}$ affects the market's expectations of $\varepsilon_{2,t+1}$ and $\varepsilon_{2,t+2}$ through expectations of $\nu_{2,t}$. Thus, $E[\nu_{2,t}|I_t^{\text{market}}]$ will appear in the pricing function three times. Steady-state price response coefficients can be found by solving the system of equations:

$$\alpha_0 = \frac{3(1-q_\nu)\sigma_\nu^2}{3(1-q_\nu)\sigma_\nu^2 + (1-q_\xi)\sigma_\xi^2((\alpha_0+\delta\alpha_1+\delta^2\alpha_2)^2+\delta^4\alpha_2^2+\delta^2\alpha_1^2+\alpha_0^2)+2\sigma_e^2} \tag{A88}$$

$$\alpha_1 = \frac{3(1-q_\nu)\sigma_\nu^2}{3(1-q_\nu)\sigma_\nu^2 + (1-q_\xi)\sigma_\xi^2((\alpha_0+\delta\alpha_1+\delta^2\alpha_2)^2+\delta^4\alpha_2^2+\delta^2\alpha_1^2+\alpha_0^2)+2\sigma_e^2} \tag{A89}$$

$$\alpha_2 = \frac{3(1-q_\nu)\sigma_\nu^2}{3(1-q_\nu)\sigma_\nu^2 + (1-q_\xi)\sigma_\xi^2((\alpha_0+\delta\alpha_1+\delta^2\alpha_2)^2+\delta^4\alpha_2^2+\delta^2\alpha_1^2+\alpha_0^2)+2\sigma_e^2} \tag{A90}$$

It can be shown that $\alpha_0 = \alpha_1 = \alpha_2$.