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Author
Ross, Nicholas C.

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Three Essays in Accounting

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Management

by

Nicholas C Ross

2012

ABSTRACT OF THE DISSERTATION

Three Essays in Accounting

by

Nicholas C Ross

Doctor of Philosophy in Management

University of California, Los Angeles, 2012

Professor Richard E Saouma, Chair

The three chapters of this dissertation cover a broad spectrum of the accounting literature. The first chapter empirically addresses the question of whether top executives' consistent ability to profit from insider trading indicates talent that translates into superior firm operating performance. We find a short-term positive association between executives relative trading profits and current performance measures. However, this association becomes negative over longer horizons, suggesting that insider trading profits are less a measure of managerial talent and more an exercise in rent extraction. The second chapter complements the ongoing empirical discussion surrounding participative budgeting by comparing a screening model of participative budgeting to a signaling model of top-down budgeting. Our contribution is to show that in the presence of sufficient ex-ante environmental uncertainty, private interim information availability or both, participative budgeting dominates the more centralized, top-down budgeting paradigm. Contrary to common belief, we find that the agency costs associated with participative budgeting largely persist under top-down budgeting; namely that the under either budgeting mode the agents information preferences are single-peaked, while the principal favors either perfect information, or none at all. The final chapter presents a model of strategic intervention, where a principal contracts with an agent to

exert effort and to ask for assistance should the latter receive unfavorable interim information. We find that the principal refrains from using intervention to provide incentives when communication between the two parties is undistorted. In an extension we conclude that the principal may use intervention inefficiently when the communication between the two parties is impeded.

The dissertation of Nicholas C Ross is approved.

David Aboody

Simon Adrian Board

Bruce I. Carlin

John S Hughes

Richard E Saouma, Committee Chair

University of California, Los Angeles

2012

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BIOGRAPHICAL SKETCH

1998-2002   B.A. (Applied Mathematics), University of California, Berkeley

2003-2006   Senior Consultant, Bates White, LLC

2006-2007   M.A. (Economics), University of California, Davis

2007-2012   Graduate Student, University of California, Los Angeles

2011-2012   Director of Analytics, TinyCo

Chapter 1

Executive Talent, Insider Trading, and Firm Performance

1.1 Introduction

In this study, we empirically address the question of whether top executives consistent ability to profit from insider trading indicates talent that translates into superior firm operating performance. It is not difficult to envision that similar information acquisition and processing skills to those employed in trading on ones private account are useful in managing the firm.[1] This perspective on insider trading profitability as a measure of talent that may carry over to firm operating decisions is echoed in recent studies by Gunny et al. [27] and Rubin and Vedrashko [47] that also seek to explore the association of insider trading and firm performance. The former study finds a negative relation between their measure of insider trading and future firm earnings, while the latter finds a positive relation between a similar measure of insider trading and future firm stock returns. Accordingly, the evidence is mixed on the question of whether insider trading connotes managerial talent that manifests in superior firm performance.

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[1]A prominent example of an individual that excels as both a trader and manager would be Warren Buffett who is credited with both astute trading and improving the operating performance of companies acquired by Berkshire Hathaway.

Our approach encompasses both accounting and market measures of firm performance. We employ a proxy for talent based on insider trading profits[2] that makes full use of data from the starting date of our sample, rather than the roll-forward design of Gunny et al. [27] and Rubin and Vedrashko [47]. Specifically, we begin by classifying top executives into quintile portfolios monthly based on the cumulative profitability of their net trades from the starting point of our panel data. Executives are then ranked according to their average portfolio classification over each year for which firm performance is measured by earnings or cash flows, or each month for which firm performance is measured by stock returns. This implies little likelihood that associations of rankings with contemporaneous and future firm performance measures are merely an artifact of a temporary information advantage. If higher ranked insiders possess greater talent which is translatable into superior operating decisions, then we expect to find apositive association between rankings and firm operating performance.[3] We also consider the associations of rankings with investment and financing decisions.

The efficacy of an ability to trade profitably as a proxy for talent as an intrinsic characteristic is supported by Grinblatt et al. [26] who establish a link between an individuals intelligence quotient (IQ) and successful trading. Employing a unique set of data on IQ scores of inductees to military service, they find that high IQ traders display superior market timing and stock-picking skills. Although our trade data is limited to publicly disclosed trades by corporate insiders, it seems reasonable that talent, in the form of IQ, in this domain would also surface in the form of greater profitability. However, counterbalancing the case for profitability of insider trading as a proxy for talent in making firm operating decisions are agency conflicts between executives and shareholders. Such conflicts could lead to suboptimal decisions as suggested by Fried [24], or to an adverse selection problem that raises the firms cost of capital, thereby reducing firm value as depicted by Baiman and Verrecchia [8].[4] Notwithstanding an implied irrationality by not preempting insider

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[2]Throughout the study we will use the phrase insider trading profits and insider profits interchangeably.

[3]Although we consider this inference appropriate, our tests cannot distinguish between talent and whether firms intrinsically differ in the generation of private information that executives may use to enhance firm performance as well as to profit from insider trades.

[4]The converse is that insider trading reduces cost of capital by timely impounding of private information in price (Carlton and Fischel [16]).

trading when it is dysfunctional, the nature of the relation between profitable insider trading and firm performance is an empirical question.[5]

For the purposes of our study, insiders are defined as top executives who collectively bear the principal responsibility of conducting the firms operating activities. They consist of the Chairman of the Board, President, Chief Executive Officer (CEO), Chief Financial Officer (CFO), Chief Operating Officer, and General Counsel. There is substantial evidence that such insiders profit from their trades. Seyhun [49] estimates that insider trades predict up to 60% of future returns. More recent studies linking insider trading to asymmetric information concerning future performance include Lakonishok and Lee [32], Ke et al. [30], Aboody et al. [2], and Piotroski and Roulstone [39]. The underlying presumption is that insiders profit by exploiting a private information advantage leaving moot the question of whether the ability of insiders to profit is a reflection of talent that impacts favorably on firm performance.

Based on a sample of more than 16,000 executives extending over a quarter century concluding in 2010, our results indicate that the earnings of firms of executives who rank high on cumulative insider profits outperform in years during which rankings are determined, and underperform over the subsequent three years. These current (partially overlapping) period associations are strongest for CFOs, as one might anticipate given CFOs comparative advantage in acquiring and exploiting financial information for firm and personal benefit. Results for firm performance, as measured by cash flows, are generally insignificant after the first subsequent year. Similar patterns emerge when stock returns replace earnings as the measure of performance. Having controlled for risk factors and momentum, the predictable under-performance in future stock returns suggests market inefficiency. We further find that both new stock issues and capital expenditures are positively associated with current executive rankings. In concert with future under-performance, the former suggests propitious timing for benefiting current shareholders at the expense of future shareholders

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[5]Yet another view is of insider trading as a form of compensation that aligns managerial incentives with shareholder interests (Manne [35]). If total compensation, inclusive of insider trading profits, was set optimally, then ceteris paribus there should be no cross-sectional relation between such profits and firm performance; the null hypothesis. Consistent with this view, Roulstone [46] reports a negative association between insider trading profits and compensation of CEOs.

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and the latter suggests sub-optimal investment decisions. Last, complementary to the above results, we find that associations of executive rankings and firm performance for firms experiencing at least two consecutive years of earnings increases (decreases) are insignificant (significantly negative).

On the whole, our findings reject the prediction that an executives ability to consistently realize profits from insider trades reflects talent that translates into superior firm performance. Rather, the findings are suggestive of pure rent extraction from current information and foreknowledge of reversals, possibly due in part to sub-optimal investment decisions.

The remainder of the paper is organized as follows: Section 2 details our research design, Section 3 presents our principal findings and Section 4 concludes with a brief summary.

1.2 Research Design

1.2.1 Sample and Measurement of Insider Profits

All stock transactions of corporate insiders, including option exercises, during the period from 1985 to the end of 2010 were obtained from the Thompson Financial Insider Database. For purposes of this study, we limited the set of individuals to the top executives including the Chairman of the Board, CEO, President, CFO, Chief Operating Officer, and General Counsel. The rationale for selecting these executives is that executives at these levels have access to the greatest amount of private information and are likely to have the greatest influence over firm performance. From among the transactions contained in the Database, we selected open market buys, open market sells, and option exercises as the transactions of interest. The initial sample of these transactions is composed of 191,902 transactions pertaining to 13,375 firms (97,396 firm-years) and 47,073 by top executives including 14,445 by CEOs.[6]

In many instances, transactions by the same insider transpire within a matter of days, some of which have a canceling effect. As a consequence, we accumulate insider transactions by month.

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[6]We have 52,756 unique firm-person identification numbers indicating that 5,683 executives switched firms during our sample period.

Months for which some net transactions took place are regarded as active months. Option exercises for which all shares acquired were sold within the month are regarded as sales, while those for which some shares were held are regarded as purchases.

We commence measuring insider trading profits from the first active month net transaction of an individual during the sample period. Returns on the firms stock are accumulated from that transaction until the next active trade month in which the net transaction is in the opposite direction. Returns continue to be accumulated accompanied by a reversal in sign for returns following the change in direction until the next active trade month in which the net transaction again changes direction, and so on. For example, suppose the first active month net transaction is a buy. Returns are accumulated for a long position until the active month net transaction is a sell. Returns following the sell are accumulated for a short position until the next active month net buy. This process continues until six months beyond the last active month net transaction. The choice of six months is based on the legal requirement regarding disgorgement of short-swing profits and the common finding that returns to insiders are generally insignificant beyond this length of time. The combined accumulated returns for the buy and sell positions over the sample period represent the insider profits for that individual.

A caveat to testing for an association between insider trading profits and contemporaneous firm performance as measured by returns is that, by definition, they are equivalent for executives while assumed to be exploiting long positions and precisely opposite for those holding short positions. Accordingly, we remove observations on 21,562 executives whose active transaction months display no change in direction and a further 9,507 observations for other data limitations leaving a usable sample of 16,004 (16,611 unique firm-person id) top executives having at least one change of direction in active month net transactions (6,506 CEOs).[7]

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[7]Consistent with prior insider trading studies, we do not consider the numbers of shares traded in our calculation of the insider trading profit.

1.2.2 Portfolio Formation and Accounting Measures of Performance

Our objective is to investigate whether a greater ability to profit from insider trades reflects talent that translates to superior operating performance and to financing and investing decisions consistent with shareholder interests. We consider future performance, as well as partially overlapping current performance,[8] to assess consequences of operating decisions the impact of which manifests in periods subsequent to those in which profits are obtained from insider trading.

Specifically, we begin by assessing whether the profits from insider trading are positively associated with current and future firm performance, as measured by changes in net income and cash flows, using the following empirical model:

$$\Delta \text{NI}_{t+\tau,i} = \sum_{y=1986}^{2008} \alpha_{oY} \text{YR}_{Yti} + \sum_{N=1}^{48} \alpha_{oN} \text{IND}_{Nti} + \alpha_1 \text{EXEC\_RANK}_{ti} + \alpha_2 \Delta \text{NI}_{ti}$$

$$+ \alpha_3 \text{MB}_{ti} + \epsilon_{1ati}, \qquad \tau = 1, 2, 3 \tag{1a}$$

$$\Delta \text{CFO}_{t+\tau,i} = \sum_{y=1986}^{2008} \alpha_{oY} \text{YR}_{Yti} + \sum_{N=1}^{48} \alpha_{oN} \text{IND}_{Nti} + \alpha_1 \text{EXEC\_RANK} + \alpha_2 \Delta \text{CFO}_{ti}$$

$$+ \alpha_3 \text{MB}_{ti} + \alpha_4 \text{ASSETS}_{ti} + \epsilon_{2ati}, \qquad \tau = 1, 2, 3 \tag{1b}$$

The dependent variable in (1a), $\Delta \text{NI}_{t+\tau}$, is net income in year $t + \tau$ minus net income in year t, deflated by beginning-of-year $t-2$ market value of equity.[9] Net income is defined as income before extraordinary items, discontinued operations, and accounting changes. Similarly, the dependent variable in (1b), $\Delta \text{CFO}_{t+\tau}$, is operating cash flows in year $t + \tau$ minus operating cash flows in year t, deflated by beginning-of-year $t - 2$ market value of equity. We examine performance over three years subsequent to the insider profits to allow for the prospect that top executives operating, investment, and financing decisions have an impact beyond the period during which these decisions are made.

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[8]Recall that insider trading profits are accumulated from the start of our study suggesting that contamination from overlapping with current year firm performance becomes less a concern as we move forward in time. Nonetheless, we acknowledge throughout that such overlap may be contributing to a positive association.

[9]The specification of these models follows prior research that investigates the association between firms financial reporting decisions and subsequent operating performance (see, e.g., Aboody et al. [1]).

EXEC_RANK is insider profits calculated using the accumulated returns for the alternating net buy and net sell positions over the entire period up to time t and ranked into quintiles. Finally, the quintile ranking is averaged over the 12 months of the fiscal year leading to fractional ranks between 1 and 5. If insiders trading profits are an indication of talent in managing the firm, and if these effects are sufficiently large to have a measurable effect on operating income and cash flows, α_1 in (1a) and (1b) will be positive.

The change in net income (operating cash flows) from year $t - 1$ to year t, $\Delta NI_t(\Delta CFO_t)$, controls for the time-series properties of earnings (cash flows). We deflate the ΔNI and ΔCFO variables (both the dependent and independent variables) by beginning-of-year $t - 2$ market value of equity. The market-to-book ratio, MB, controls for the potential effects of firm risk and growth opportunities, and the logarithm of total assets, ASSETS, controls for firm size effects. To control for omitted time- and industry-specific effects, we permit the regression intercept to vary across years and industries. Specifically, YR_Y equals one if the observation is from year Y, and zero otherwise, and IND_N equals one if the firm is in industry N (based on Fama-Frenchs 1997 classification), and zero otherwise.

We estimate equations (1a) and (1b) separately for the year over which insider profits are measured and each of three future horizons; i.e., from year t to year $t + \tau$, where τ = 1, 2, or 3. The parameter of interest in our tests is the coefficient estimate on EXEC_RANK. Similarly, we investigate the relation between EXEC_RANK and contemporaneous financing and investing decisions by estimating the relation between EXEC_RANK and common stock issues, major acquisitions, and changes in firms capital expenditures.

1.2.3 Portfolio Formation and Risk-Adjusted Returns

Quintile portfolios are formed monthly over all but the last 36 months of the sample period based on rankings of executives ranked by cumulative insider profits to date. The motivation for this roll-forward procedure is to allow for changes in CEO rankings as more of their trading activity unfolds. Returns on portfolios of firms corresponding to executives are employed in the following

time series regressions, initially over the 12 months corresponding to the period over which insider profits are measured (prior to the portfolio formation date), and subsequently over the 36 months following the period over which insider profits are measured:

$$R_{p,t} - R_{f,t} = \alpha_p + \beta_p(R_{m,t} - R_{f,t}) + \chi_p\text{SMB}_t + \delta_p\text{HML}_t + \phi_p\text{MOM}_t + \epsilon_p \qquad (2)$$

where $R_{p,t}$ is the return for portfolio p in month t, $R_{m,t}$ is the return on the CRSP value-weighted index, $R_{f,t}$ is the return on a one-month U.S. Treasury Bill, and SMB_t, HML_t, and MOM_t, are, respectively, the Fama and French [20] size and market-to-book factor and Carhart [15] momentum factor mimicking portfolio returns. Separate regressions are run for each portfolio-month configuration commencing July, 1986 through December, 2008. Further tests using the above regression are augmented by a short-term reversion factor based on the returns for the previous month and a long-term reversion factor based on returns for the 48 months ending one- year earlier.

The intercept in (2) represents an estimate of portfolio abnormal returns that serve as a measure of either current or future firm performance. Our tests of an association between insider trading profits and future firm performance are based on the hedge returns from going long and shorting the extreme quintile portfolios. As noted above, a finding of higher current returns for executives in the highest quintile of insider trading profits as compared with those in the lowest quintile would be consistent with executive talent in making operating decisions. A finding in the opposite direction would be more consistent with rent extraction as a diversion of shareholder wealth. On one hand, working with future returns as the measure of firm performance would be vacuous if the market is efficient. On the other hand, a finding of an association between insider profits and future returns would imply market inefficiency.

1.3   Empirical Findings

1.3.1   Descriptive Statistics

Table 1.1[10] presents descriptive statistics on insider trading activity for the initial sample of 16,611 executives including 6,506 CEOs. The average number of trades by all executives over the sample period is approximately 66.5, while the average number of active trading months is 7.68. CEOs are less active in terms of active trading months averaging 2.19 compared with 3.41 for other top executives. The average number of months between active trading months is about 6.05 months for CEOs and 7.61 for others. There are 127,568 active trading months with 59,330 net buys and 68,238 net sells. The number of transactions increases over the sample period peaking in 2004; the number of buys peaks between 1999 and 2001, while the number of sells steadily increases. The increase in buys during the late 1990s may be a reflection of the bull market over that time span. Sells are more likely to be influenced by a diversification motive.

The average number of changes in direction for all executives is 3.52; 3.89 for CEOs and 3.38 for others. Average (median) numbers of months between changes in direction are 15.88 (8.1) and 19.37 (9.17) for CEOs and others, respectively. The average dollar value of insider trades rises slightly in active months for which there is a change in direction, the effect being driven by changes earlier in the data set. There are 28,616 active trading months in which there is a change in net transactions from buys to sells and 29,388 months in which the change is from sells to buys.

Table 1.2 provides descriptive statistics on the 13,375 firms and insider profits of all top executives from the 102,103 firm years (1,900,743 total observations) during the sample period. The upper panel provides statistics without regard to rankings of executives by insider profits. Overall, top executives realized mean profits (returns) of 19.48% while future firm annual returns ranged from 14.08% for the first subsequent year to 14.61% for the third such year. The lower panel provides statistics for quintile portfolios from rankings of executives by insider trading profits (lowest to highest). Mean insider profits are by construction steadily increasing from -73.07% to 206.98%.

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[10]All tables follow the text.

We also note that executive rankings are sticky. The person (Spearman) correlation between an executives ranking over the first half of tenure at the firm and the second half of tenure at the firm is 0.729 (0.736).[11] Firms for executives realizing the highest insider profits compared to those realizing the lowest tend to have somewhat larger market capitalizations, lower market-to-book ratios, and lower future accounting performance and stock returns. Also, we note that firms in the highest versus lowest quintiles have higher sales, operating cash flows, and net income, though in all cases the middle quintiles contain the peaks.

Notwithstanding the qualifications that apply to these simple statistics, there is the suggestion of an inverse association between insider trading profits and future firm performance as measured by raw returns.

Insider Profits and Accounting Performance

Tables 1.3 and 1.4 present regression summary statistics from estimating (1a) and (1b) relating top executives rankings based on profits from insider trading in year t to current and future changes in the firms operating performance. We conduct our analyses separately for CEOs, Presidents, and CFOs. We also provide test results by averaging all the top executives rankings at the firm level.

We estimate all equations using a robust regression technique, pooling data across years. The procedure begins by calculating Cooks D statistic and excluding observations with $D > 1$. Then, the regression is re-estimated, weights for each observation are calculated based on absolute residuals Huber weights and bi-weights and the estimation is repeated iteratively using the weighted observations until convergence in the maximum change in weights is achieved (Berk [12]). Our significance tests are based on standard errors calculated using the pseudo values approach described in Street et al. [54], after adjusting them to be heteroskedasticity-consistent White [57].

Results reported in Table 1.3 indicate that the coefficient on EXEC_RANK is positively significant for all four groups in the current association specification. These findings suggest that insider

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[11]In addition, an executive that is in the upper quintile of insider profit ranking during the first half of tenure at the firm has a 55.27% chance of remaining in that ranking during the second half of tenure at the firm (27.48%, 9.58%, 5.43% and 2.24% chance of dropping to the fourth, third, second and first quintile, respectively).

profits are associated with talent that translates into improved earnings, albeit in a period partially overlapping with the time frame for measuring insiders profits. We further observe that the largest and most significant coefficient is for the CFOs group consistent with the conjecture that CFOs are best placed to exploit an information advantage in both insider trading and influencing firm operating performance. In contrast, we find that EXEC_RANK is negatively associated with future changes in earnings. Across all three time horizons, the coefficient on the insider profits ranking variable, EXEC_RANK, is significantly negative in all specifications. Moreover, except for the president-only specification, the decline in earnings is steadily increasing for the entire three year period. These further findings suggest that the ability to profit from insider trading does not translate into talent relevant to managing the firms operating activities in any lasting sense. Indeed, firms managed by executives who rank high on insider trading profits exhibit inferior future earnings performance.

Table 1.4 presents regression summary statistics from the cash flow from operations specification, equation (1b). In contrast to results reported in Table 1.3, the current and future associations between EXEC_RANK and changes in operating cash flows are, in general, insignificant. This result indicates that the improvement of performance in the current period is mainly due to accruals and that the future decreases in earnings are mainly driven by these accrual reversals (although we do find a negative change in operating cash flows in year $t + 1$). Moreover, the qualitative results in Tables 1.3 and 1.4 are robust when we measure the insiders profits over the first half of the executives tenure in the firm, and observing the firm performance over the second half of the executives tenure in the firm.

Table 1.5 reports results of tests on associations of EXEC_RANK with current period financing and investing decisions, and future earnings and operating cash flows when partitioned on beating prior years earnings for at least two consecutive years. Panel A results indicate that the coefficient on EXEC_RANK is positively significant for three out of the four groups with respect to the current period association between insider profits and common stock issuing (when only presidents are included, the association is insignificant). As in Table 1.3, the strongest association is for the CFO

only group. This result can be interpreted as the stock issuing timed to benefit current shareholders, implicitly at the expense of future shareholders.

Panel B results indicate that insider profits are not accompanied by a significant increase in major acquisitions. Since prior research indicates that major acquisitions generally lead to deterioration of subsequent performance, we find no evidence for such activity being associated with top executives insider trading profits.

As reported in Panel C, we find a significant association between EXEC_RANK and an increase in the firms current capital expenditures. Given the results documented in Table 1.3, one interpretation is that the current increase in both the firms operating performance and insider trading profits leads to over investment in capacity. That is, in light of future operating performance, it appears that current period investment decisions concurrent by insiders profiting most from insider trading are inefficient.

Finally, in Panels D and E there is no discernible pattern to the association between our executive ranking variable, EXEC_RANK, and current or future performance in either earnings or cash flows when the sample is composed of firms that beat prior years earnings in at least two consecutive years. In contrast, we observe significant negative associations of EXEC_RANK with both future earnings and cash flows for firms that fail to beat prior years earnings for two or more consecutive years. Again, the results favor insider trading as pure rent extraction possibly to the detriment of shareholders.[12]

1.3.2 Insider Profits and Abnormal Returns

We next investigate the relation between EXEC_RANK and current and future stock returns after controlling for risk factors and momentum. We present our findings in the following sections, again, subject to the caveat that results in the current period results suffer from a contamination effect as both firm returns and insider profits are measured over a partially overlapping window.

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[12]Additionally, we reran the regressions of EXEC_RANK on changes in earnings and cash flows varying the number of executives in calculating EXEC_RANK and found no systematic effects.

Furthermore, the future stock returns results can only be interpreted in the context of market inefficiency given public reporting of insider trades.

Insider Profits and Current Abnormal Returns

Table 1.6 contains the results of the time series regressions specified in section 2.3 for the lowest and highest quintile portfolios from rankings of top executives based on insider profits. Separate regressions are run for cumulative returns on portfolios formed on a basis of insider profits ranging 12 months preceding the ranking of executives on a basis of insider trading profits. For example, we form quintile portfolios based on rankings of insider profits each month from the start of the sample period in July, 1986 to the end in December, 2008,[13] yielding as many portfolios for each quintile as there are months in the data set. The preceding one month returns on these portfolios for each quintile are regressed on the four factors. Jensens alpha for the lowest and highest quintile is reported in the first row of the table. This process is continued such that the second row of the table contains the portfolio returns for month $t - 2$ such as the table spans all the preceding 12 months.

We find that firms of top executives ranked in the highest quintile of insider profits outperform those in the lowest quintile. While this result is consistent with insider trading profits as a proxy for talent in managing the firm, we continue to note that the contamination effect from the partial overlapping of periods for estimating cumulative insider profits may be a contributing factor. Further investigation of results for these quintiles reveals that 52.1% of transactions in the lowest quintile are buys while 62.3% of transactions in the highest quintile are buys.

Hedge returns from shorting the highest quintile portfolio and going long in the lowest quintile portfolio are significantly negative for all time horizons for measuring insider profits, indicating that executives buying shares in firms with rising prices extract greater profits than those that are selling shares in firms with rising prices.

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[13] Although it is possible to extend the time horizon for tests of associations between executive rankings and contemporaneous returns to 2010, this would not be feasible for future returns. Accordingly, in order to facilitate comparisons of the effects of rankings on performance, we only employ data through 2008.

The extent to which these results may be driven by the contamination effect or the talent of top executives profiting the most from insider trades is an open question. Nonetheless, the combination of positive associations between EXEC_RANK and current returns and improvements in earnings might be a reflection of translatable talent cannot be entirely rejected.

Insider Profits and Future Abnormal Returns

Table 1.7 contains the results of the time series regressions specified in section 3.3 for the lowest and highest quintile portfolios from rankings of top executives based on insider profits. Separate regressions are run for future returns on portfolios formed on a basis of insider profits ranging over periods from one month to 36 months. For example, we form quintile portfolios based on rankings of insider profits each month from the start of the sample period in July, 1986 to the end in December, 2008, yielding as many portfolios for each quintile as there are months in the data set. The future one month returns on these portfolios for each quintile are regressed on the four factors. Jensens alpha for the lowest and highest quintile are reported in the first row of the table. The second row in the table uses the similar quintile portfolios and subsequently the future two month returns are regressed on the four factors. This process is continued up to 36 months ahead returns.

We find that Jensens alpha for both the lowest and highest quintile portfolios formed from cumulative insider profits over all periods ranging from one month to 36 months are nearly always statistically significant at the 10% level or higher. Accordingly, buying all firms in months during which top executives are active would have yielded positive abnormal returns. More notably for our purpose, the abnormal returns on hedge portfolios, long in the lowest quintile portfolios and short in the highest quintile portfolio, are positive for every time horizon over which insider profits are measured, and statistically significant in 28 out of 36 of those horizons (24 of the 28 statistically significant are concentrated mainly in quintiles formed over the first two years of accumulation of insider profits). In other words, firms of top executives extracting the lowest insider profits outperform those of top executives extracting the highest insider profits as measured by the

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succeeding months abnormal returns. This result runs counter to the view of insider profits as a proxy for talent for making better operating decisions.

The findings in Table 1.7 are robust to the addition of the short-term and long-term reversion factors. Furthermore, as observed earlier for tests involving earnings and cash flows, the results are robust when we measure the insiders profits over the first half of the executives tenure in the firm, and observing the firm performance over the second half of the executives tenure in the firm.

A concern regarding the t-tests in Table 1.7 is the potential lack of independence in the rankings of executives by insider profits as we roll forward in time. In particular, an executive may continue to be placed in the same quintile portfolio in non-active transaction months. Reinforcing this aspect, the average turnover of executives ranked in the lowest and highest quintiles are 4.5% and 5.5%, respectively. To partially alleviate this problem, we replicate the analysis, only ranking executives in active transaction months. Again, the findings in Table 1.7 prove to be robust.

Insider Profits and Future Returns Partitioned by Buys and Sells

Findings of prior studies indicate that returns following insider sells are small in magnitude. These findings are consistent with the conjecture that insider sells are more likely than buys to be driven by diversification and consumption motives; e.g., Hartzell et al. [28]. To explore how this conjecture and related findings might impact our analysis, we partition our sample of top executive transactions into buys and sells. Given that the last transaction by an executive was a buy (sell), all subsequent months up to a sell (buy) are considered buy (sell) months. We point out that because we accumulate insider profits for an executive from their first transaction, those profits span both buys and sells and, hence, do not represent profits to just buy or sell transactions.

Table 1.8 contains our results for hedge portfolios for the two subsamples. The technology for measuring future returns based on cumulative insider profits described in the discussion of Table 1.7 applies here as well, albeit with the sample partitioned into buy and sell months. Accordingly, within each subsample, we again form quintile portfolios based on rankings of insider profits accumulated over the entire top executives insider trading activity and measure future returns over

one month forward through 36 months forward.

The hedge returns for the buy subsample, long in the lowest quintile and short in the highest quintile, are significantly positive in 33 out of 36 month regressions, while for the sell subsample they are significantly positive in only three out of 36. Furthermore, the three significant hedge returns occur in the first four months, suggesting that underperformance by firms with these executives is short-lived by comparison to executives that buy.

This last finding ameliorates concerns that results may be an artifact of short-term mean reversion. From Table 1.2, we note that lagged annual returns are greater for the highest quintile by comparison with the lowest quintile when the non-partitioned sample is in play. If reversion were at work, then we should expect higher future returns for the lowest quintile than for the highest. While this ordering is evident for the buy subsample where lagged returns are greater for the highest compared to the lowest quintile portfolio (55.7% versus 5.1%) and hedge returns are positive, for the sell subsample lagged returns are greater for the lowest compared to the highest quintile portfolio (58.1% versus 12.5%) and, yet, there are only significant negative hedge returns for this subsample in months fourteen to sixteen. This latter result is inconsistent with short-term reversion.

1.4   Summary

Viewing insider trading profits as a proxy for talent that can be applied to firm operating decisions we test for a positive association between those profits and firm performance. Efficacy of this proxy is supported by evidence from Grinblatt et al. [26] that IQ is positively associated with successful stock trading. Notwithstanding possible contamination effects, we find significant positive associations between executive rankings and current changes in earnings and stock returns. In sharp contrast with current period results, we find significant negative associations between insider profits and future changes in earnings and returns, indicating rent extraction accompanied by inferior firm performance. Further, we find that executive rankings are significantly positively

associated with increases in capital spending that, in light of subsequent changes in earnings, appear to be indicative of inefficient investment decisions. Executive rankings are also significantly associated with stock issues, possibly suggesting wealth transfers from incoming shareholders to current shareholders, though other conclusions might be drawn.

There are caveats to our research design. Our tests cannot distinguish whether firms intrinsically differ in the generation of private information that executives may use to better firm performance as well as to profit from insider trades, or executives differ in talent. Given that insider profits are measured in returns and returns are associated with measures of firm performance, then some degree of positive association between our rankings and firm performance is to be expected by construction. Regarding future returns, the significant negative associations that we find between executive rankings and firm returns after controlling for risk and momentum are inconsistent with market efficiency.

Notwithstanding the limitations implied by the above considerations, the weight of our evidence suggests that talent exhibited by executives to generate profits from insider trading does not translate into superior firm performance beyond the very short-run, and, indeed, suggests that insider trading is more likely an exercise in rent extraction accompanied by inferior firm performance beyond that time frame.

A natural extension of our study would be to investigate why it is that firms exhibiting a decline in firm performance associated with insider profit taking do not restrict insider trading. A recent study in this vein by Jagonlinzer et al. [29] finds that corporate counsel approval of insider trades tends to mitigate both insider trading profits and the predictive content of insider trades with respect to the next quarters operating performance. It remains to distinguish whether the negative association between insider profits and future operating performance that we find from panel data is impacted by governance factors such as counsel approval of trades. [14]

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[14]Somewhat related is the case made by Bebchuk and Fried [11] for expropriation through stock-based compensation as a consequence of weak governance.

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Table 1.1: *Descriptive statistics for the sample of 13,375 firms with top executives' insider trading for the 1986-2010 period*

Year	No. of Firms	No. of Firm-Executives	No. of Transactions		No. of Shares (000)		$ of transactions (000)	
			Buy	Sell	Buy	Sell	Buy	Sell
1986	147	150	41	34	2,370	791	60,552	12,263
1987	779	855	442	344	9,048	16,843	125,577	293,931
1988	1,079	1,233	434	524	10,640	21,226	69,871	356,624
1989	1,261	1,469	508	655	11,771	23,304	118,335	4,191,602
1990	1,596	1,899	1,032	600	26,283	21,472	351,824	380,298
1991	1,876	2,287	745	1,439	26,267	57,914	332,745	1,056,907
1992	2,292	3,016	1,666	1,563	123,793	70,692	3,545,779	1,287,940
1993	2,660	3,645	1,672	1,864	82,851	78,085	1,618,530	1,624,614
1994	3,033	4,221	2,127	1,710	87,998	116,650	1,614,646	2,902,159
1995	3,308	4,767	2,557	2,064	125,833	108,969	3,044,253	2,127,264
1996	3,650	5,667	2,618	2,510	99,178	151,665	3,129,063	2,768,637
1997	3,949	6,501	3,703	3,609	224,365	164,179	4,914,510	4,111,005
1998	4,194	7,353	4,877	3,580	196,867	191,785	5,070,281	6,005,734
1999	4,165	7,408	4,781	3,202	229,279	211,891	6,436,273	7,800,523
2000	4,143	7,560	4,674	4,000	260,493	291,075	7,667,411	8,924,906
2001	3,993	7,319	3,869	4,332	211,670	280,949	4,532,956	6,320,787
2002	3,738	6,888	3,602	3,658	364,386	183,126	5,407,279	4,025,448
2003	3,607	6,620	3,507	4,661	204,828	190,943	4,682,663	4,720,735
2004	3,525	6,573	3,817	6,421	216,849	332,161	5,362,051	7,773,337
2005	3,387	6,206	3,358	6,314	215,483	178,344	5,838,862	4,513,230
2006	3,211	5,729	3,054	6,321	198,395	261,457	6,166,700	8,660,950
2007	2,886	4,953	3,159	5,580	204,406	226,928	6,328,102	6,603,217
2008	2,365	3,747	3,087	3,253	202,326	216,355	4,583,794	4,837,994
2009	2,730	4,897	4,870	4,869	239,081	234,859	3,356,253	5,103,177
2010	2,134	3,709	2,752	3,198	114,261	126,374	2,270,090	3,668,577

Table 1.2: *Descriptive statistics for the sample of 13,375 firms (102,103 firm-years) with top executives' insider trading for the 1986-2010 period*

Top executive profit is the profit to insider trades calculated each month using the prior history of the insider trades. The profits are accumulated from insider trade to trade for insider buys and sells. When an insider purchases a share, a long position in the firm is taken and when an insider sells, a short position is taken. Net income is defined as income before extraordinary items, discontinued operations, and accounting changes. CF is operating cash flows Market value is the market value of equity. Market to Book is the ratio of the market value of equity to the book value of equity. $\Delta NI_{t+\tau}(\Delta CF_{t+\tau})$ is net income (operating cash flows) in year $t + \tau$ minus net income (operating cash flow) in year t, deflated by beginning-of-year $t - 2$ market value of equity. Lagged return is the lagged annual raw stock return. Annual return $t + i$ is the one, two, and three years ahead raw stock return. P1 to P5 denote quintiles based on the top executive profit from insider trading. All variables are calculated each month from 7/86 to 12/10 for active insiders.

	Mean	Median	STD	Q1	Q3
Top executive profit	19%	-4%	293%	-36%	19%
Total sales	1,719.9	166.7	8,659.3	40.5	741.0
Net income	87.3	5.4	1,051.3	-1.5	36.7
CF from operations	198.8	12.3	1,694.4	.2	79.8
Total assets	4,191.1	277.3	38,665.9	60.2	1,228.1
Market value	1,795.0	141.0	10,734.0	37.0	647.0
Market to Book	2.5	1.7	122.0	1.0	2.9
ΔNI_t	0.4%	0.8%	31.8%	-2.4%	4.0%
ΔNI_{t+1}	-0.5%	0.8%	27.0%	-2.9%	4.5%
ΔNI_{t+2}	-0.2%	0.9%	29.1%	-3.2%	4.9%
ΔNI_{t+3}	-0.1%	0.9%	28.5%	-3.4%	5.6%
ΔCF_t	1.0%	1.0%	21.4%	-3.2%	5.8%
ΔCF_{t+2}	1.8%	1.0%	26.3%	-3.6%	6.5%
ΔCF_{t+3}	2.3%	1.0%	20.0%	-3.9%	7.1%
ΔCF_{t+4}	0.4%	1.0%	35.7%	-4.2%	7.6%
Lagged return	17%	5%	94%	-8%	38%
Annual return$_{t+1}$	14%	4%	88%	-27%	35%
Annual return$_{t+2}$	15%	4%	94%	-25%	34%
Annual return$_{t+3}$	15%	2%	83%	-22%	33%

	P1	P2	P3	P4	P5
Top executive Profit					
Mean	-73%	-33%	-7%	16%	207%
Median	-74%	-33%	-6%	13%	93%
STD	18%	13%	8%	13%	654%
Total sales					
Mean	1,196.1	1,864.7	1,936.0	1,837.1	1,667.8
Median	140.7	186.9	172.3	172.9	161.5
STD	5,728.2	9,595.1	9,749.7	8,572.9	8,630.7
Net income					
Mean	40.8	82.4	106.1	102.8	95.5
Median	2.1	5.3	6.8	7.0	5.8
STD	880.9	1173.2	1186.3	840.4	1115.0
CF from operations					
Mean	114.7	205.3	240.6	229.3	192.2
Median	7.1	14.2	15.1	14.8	11.7
STD	1797.7	1758.5	1743.2	1718.2	1395.7
Total assets					
Mean	2,726.5	4,118.4	4,935.4	4,586.6	4,278.8
Median	166.5	298.8	347.5	329.8	246.2
STD	44,990.1	34,460.8	42,277.3	34,497.6	35,779.7
Market value					
Mean	1,460	1,870	1,985	1,834	1,748
Median	94	145	153	160	147
STD	8,328	11,598	11,737	10,426	10,898
Market to Book					
Mean	2.36	4.34	1.72	2.35	1.91
Median	1.67	1.60	1.57	1.68	1.78
STD	61.91	242.92	90.81	37.16	68.91
Lagged return					
Mean	15.15%	9.59%	13.57%	16.90%	31.99%
Median	0.01%	1.15%	6.81%	9.00%	11.21%
STD	109.47%	76.55%	75.51%	79.60%	127.13%
$\Delta\mathbf{NI}_t$					
Mean	0.42%	0.14%	0.29%	0.19%	0.79%
Median	0.80%	0.84%	0.83%	0.71%	0.92%
STD	20.85%	35.88%	52.59%	12.72%	15.20%

	P1	P2	P3	P4	P5
$\Delta\mathbf{NI}_{t+1}$					
Mean	0.23%	0.52%	0.13%	-1.88%	-2.25%
Median	0.99%	0.77%	0.82%	0.88%	0.68%
STD	21.90%	25.18%	21.58%	29.63%	26.72%
$\Delta\mathbf{NI}_{t+2}$					
Mean	0.93%	0.37%	-0.41%	-0.27%	-1.37%
Median	0.91%	0.89%	0.91%	0.89%	0.81%
STD	11.36%	25.80%	49.21%	29.25%	12.88%
$\Delta\mathbf{NI}_{t+3}$					
Mean	0.46%	-0.09%	-0.19%	-0.14%	-0.56%
Median	0.94%	0.92%	0.96%	0.87%	0.66%
STD	10.01%	71.25%	61.26%	15.17%	18.95%
$\Delta\mathbf{CF}_t$					
Mean	1.40%	1.54%	1.10%	0.55%	2.10%
Median	0.89%	0.90%	0.95%	0.95%	1.09%
STD	9.53%	6.75%	15.85%	12.72%	14.76%
$\Delta\mathbf{CF}_{t+1}$					
Mean	1.59%	2.93%	2.73%	1.63%	1.11%
Median	0.94%	0.86%	0.94%	0.84%	0.73%
STD	14.90%	15.35%	25.72%	27.86%	15.34%
$\Delta\mathbf{CF}_{t+2}$					
Mean	3.66%	1.29%	1.87%	1.96%	2.82%
Median	0.91%	0.83%	0.96%	0.90%	0.87%
STD	19.36%	17.47%	33.16%	19.68%	16.28%
$\Delta\mathbf{CF}_{t+3}$					
Mean	0.48%	0.69%	0.33%	0.45%	0.26%
Median	0.90%	1.03%	0.99%	0.97%	1.07%
STD	21.61%	32.12%	40.40%	19.87%	18.44%
Annual return$_{t+1}$					
Mean	18.16%	13.58%	13.14%	12.37%	13.92%
Median	4.19%	0.35%	5.76%	4.19%	2.15%
STD	112.22%	83.93%	75.84%	78.68%	89.87%
Annual return$_{t+2}$					
Mean	17.61%	16.19%	16.42%	14.25%	14.13%
Median	6.13%	1.86%	6.21%	5.14%	3.28%
STD	94.82%	85.29%	352.75%	144.63%	8153%
Annual return$_{t+3}$					
Mean	17.71%	16.27%	14.06%	15.09%	15.40%
Median	5.91%	2.54%	5.97%	5.33%	3.56%
STD	96.70%	97.16%	75.66%	80.03%	80.06%

Table 1.3: *Top executives' profits from insider trading and firms' operating income*

$$\Delta \text{NI}_{t+\tau,i} = \sum_{y=1986}^{2008} \alpha_{0Y} \text{YR}_{Yti} + \sum_{N=1}^{48} \alpha_{0N} \text{IND}_{Nti} + \alpha_1 \text{EXEC\_RANK} + \alpha_2 \Delta \text{NI}_{ti}$$
$$+ \alpha_3 \text{MB} + \alpha_4 \text{ASSETS} + \epsilon_{1ati}$$

The dependent variable, ΔNI_t is net income in year t minus net income in year $t-1$, deflated by market value of equity at the beginning of year $t-2$. $\Delta \text{NI}_{t+\tau}$ is net income in year $t+\tau$ ($\tau = 1, 2,$ and 3) minus net income in year t, deflated by market value of equity at the beginning of year $t-2$. EXEC_RANK is the top-executives profits from insider trading ranked by quintiles and averaged over the 12 months of the fiscal year. MB is the ratio of market value of equity to book value of equity at the end of year t. ASSETS is the natural logarithm of the book value of total assets at the end of year t. The regression equations include untabled year- and 48 industry-specific intercepts (Fama-French 1997).

Panel A: Only CEO

Independent variable	ΔNI_t		ΔNI_{t+1}		ΔNI_{t+2}		ΔNI_{t+3}	
EXEC_RANK	0.080	(4.08)	-0.050	(-2.31)	-0.120	(-3.34)	-0.215	(-4.39)
ΔNI_{t-1}	-0.509	(-908.91)	-0.001	(-414.97)	-0.001	(-170.19)	0.001	(123.55)
MB	0.001	(3.59)	0.001	(1.94)	-0.001	(-2.63)	0.001	(3.19)
ASSETS	0.001	(10.04)	-0.001	(-2.31)	-0.001	(-1.39)	-0.001	(-1.30)
N	35,515		30,701		26,097		21,934	
Adj R^2	98.0%		8.0%		7.0%		38.0%	

Panel B: Only Presidents

Independent variable	ΔNI_t		ΔNI_{t+1}		ΔNI_{t+2}		ΔNI_{t+3}	
EXEC_RANK	0.044	(2.76)	-0.067	(-3.55)	-0.103	(-3.53)	-0.107	(-2.77)
ΔNI_{t-1}	-0.034	(-16.02)	0.001	(53.36)	-0.026	(-190.13)	0.081	(194.15)
MB	0.001	(0.01)	-0.026	(-1.61)	-0.001	(-0.58)	-0.001	(-1.21)
ASSETS	0.001	(3.6)	-0.001	(-2.64)	-0.001	(-1.34)	-0.001	(-0.58)
N	44,782		41,840		38,738		35,621	
Adj. R^2	4.0%		14.0%		18.0%		55.0%	

Panel C: Only CFO

Independent variable	ΔNI_t		ΔNI_{t+1}		ΔNI_{t+2}		ΔNI_{t+3}	
EXEC_RANK	0.214	(9.81)	-0.054	(-2.34)	-0.123	(-3.31)	-0.288	(-5.49)
ΔNI_{t-1}	-0.649	(-978.64)	0.014	(114.49)	-0.005	(-11.06)	0.161	(445.22)
MB	0.001	(2.96)	0.001	(4.18)	-0.001	(-0.83)	0.001	(3.47)
ASSETS	0.001	(11.32)	-0.001	(-1.19)	-0.001	(-0.55)	-0.001	(-2.51)
N	36,552		32,249		28,001		24,058	
Adj. R^2	98.0%		6.0%		6.0%		93.0%	

Panel D: Average ranking of all top executives in the firm

Independent variable	ΔNI_t		ΔNI_{t+1}		ΔNI_{t+2}		ΔNI_{t+3}	
EXEC_RANK	0.069	(4.18)	-0.104	(-5.34)	-0.239	(-7.85)	-0.277	(-6.83)
ΔNI_{t-1}	-0.509	(-623.64)	0.002	(33.29)	-0.001	(-2.24)	0.024	(904.14)
MB	0.001	(0.21)	0.001	(0.26)	-0.001	(-2.13)	0.001	(2.97)
ASSETS	0.001	(7.43)	-0.001	(-2.72)	0.001	(0.01)	0.001	(1.12)
N	78,820		70,853		63,125		55,971	
Adj. R^2	43.0%		4.0%		4.0%		98.0%	

Table 1.4: *Top executives' profits from insider trading and firms' cash flows*

$$\Delta\text{CFO}_{t+\tau,i} = \sum_{y=1986}^{2008} \alpha_{0Y}\text{YR}_{Yti} + \sum_{N=1}^{48} \alpha_{0N}\text{IND}_{Nti} + \alpha_1\text{EXEC\_RANK} + \alpha_2\Delta\text{CFO}_{ti}$$
$$+ \alpha_3\text{MB} + \alpha_4\text{ASSETS} + \epsilon_{2ati}$$

The dependent variable, ΔCFO_t, is operating cash flow in year t minus operating cash flow in year $t-1$, deflated by market value of equity at the beginning of year $t-2$. $\Delta\text{CFO}_{t+\tau}$ is operating cash flow in year $t+\tau$ (τ = 1, 2, and 3) minus operating cash flow in year t, deflated by market value of equity at the beginning of year $t-2$. EXEC_RANK is the top-executives profits from insider trading ranked by quintiles and averaged over the 12 months of the fiscal year. MB is the ratio of market value of equity to book value of equity at the end of year t. ASSETS is the natural logarithm of the book value of total assets at the end of year t. The regression equations include un-tabulated year and 48 industry-specific intercepts (Fama-French 1997).

Panel A: Only CEO

Independent variable	ΔCFO_t		ΔCFO_{t+1}		ΔCFO_{t+2}		ΔCFO_{t+3}	
EXEC_RANK	0.013	(0.56)	-0.036	(-1.26)	-0.039	(-0.94)	0.035	(0.64)
ΔCFO_{t-1}	-0.251	(-77.05)	-0.001	(-55.64)	0.019	(4.34)	0.028	(5.44)
MB	-0.001	(-0.03)	-0.001	(-0.02)	-0.001	(-1.15)	-0.001	(-0.30)
ASSETS	0.001	(7.9)	0.001	(1.47)	-0.001	(-0.94)	0.001	(-0.64)
N	32,481		27,875		23,515		19,552	
Adj. R^2	29.0%		5.0%		4.0%		5.0%	

Panel B: Only Presidents

Independent variable	ΔCFO_t		ΔCFO_{t+1}		ΔCFO_{t+2}		ΔCFO_{t+3}	
EXEC_RANK	0.024	(0.99)	-0.038	(-1.29)	0.06	(1.56)	0.039	(0.8)
ΔCFO_{t-1}	-0.316	(97.49)	-0.003	(-0.86)	0.026	(7.81)	-0.001	(-0.10)
MB	-0.001	(-0.44)	-0.001	(-3.11)	-0.001	(-2.29)	-0.001	(-2.11)
ASSETS	0.001	(8.61)	0.001	(3.69)	0.001	(5.83)	0.001	(4.43)
N	37,639		35,088		32,408		29,664	
Adj. R^2	31.0%		1.0%		2.0%		3.0%	

Panel C: Only CFO

Independent variable	ΔCFO_t		ΔCFO_{t+1}		ΔCFO_{t+2}		ΔCFO_{t+3}	
EXEC_RANK	0.021	(0.82)	-0.08	(-2.64)	-0.04	(-0.90)	0.023	(0.39)
ΔCFO_{t-1}	-0.263	(-294.7)	-0.008	(-172.6)	0.053	(87.18)	0.048	(665.3)
MB	0.001	(1.3)	0.001	(0.98)	-0.001	(-0.21)	-0.001	(-0.04)
ASSETS	0.001	(7.38)	0.001	(1.68)	-0.001	(0.70)	-0.001	(-0.69)
N	33,434		29,361		25,369		21,662	
Adj. R^2	98.0%		5.0%		11.0%		36.0%	

Panel D: Average ranking of all top executives in the firm

Independent variable	ΔCFO_t		ΔCFO_{t+1}		ΔCFO_{t+2}		ΔCFO_{t+3}	
EXEC_RANK	0.025	(1.08)	-0.111	(-4.02)	-0.016	(-0.41)	0.069	(1.4)
ΔCFO_{t-1}	-0.263	(-915.19)	-0.008	(-55.81)	0.027	(9.3)	0.008	(-9.89)
MB	-0.001	(-0.36)	0.001	(0.73)	-0.001	(-1.15)	-0.001	(-1.20)
ASSETS	0.001	(8.96)	0.001	(5.45)	0.001	(6.11)	0.002	(7.32)
N	67,403		60,139		53,163		46,652	
Adj. R^2	94.0%		2.0%		2.0%		3.0%	

Table 1.5: *Top executives' profits from insider trading and firms' financing and investing decisions*
The dependent variable in Panel A is the value of stock issued in year t, in Panel B it is the market value of acquisitions conducted in year t, and Panel C is capital expenditures in year t minus capital expenditures in year $t-1$, deflated by market value of equity at the beginning of year $t-2$. Panels D and E present the results for firms with two consecutive years of past earnings increases and decreases, respectively. EXEC_RANK is the top-executives profits from insider trading ranked by quintiles and averaged over the 12 months of the fiscal year. MB is the ratio of market value of equity to book value of equity at the end of year t. ASSETS is the natural logarithm of the book value of total assets at the end of year t. The regression equations include untabled year- and 48 industry-specific intercepts (Fama-French 1997). The estimation period is from 1986 to 2008.

Panel A: Stock issuing

Independent Variable	Stock Issue CEO only		Stock Issue President Only		Stock Issue CFO only		Stock Issue All executives	
EXEC_RANK	0.23	(-2.07)	0.1	(-0.89)	0.331	(-2.32)	0.167	(-2.92)
MB	-0.001	(-0.14)	-0.001	(-0.03)	-0.001	(-0.04)	-0.001	(-0.16)
ASSETS	1.033	(-12.92)	0.828	(-11.32)	1.067	(-11.37)	0.877	(-23.11)
N	39,191		48,660		40,074		177,684	
Adj. R^2	15.0%		7.0%		11.0%		10.0%	

Panel B: Acquisitions

Independent Variable	Acquisitions CEO only		Acquisitions President Only		Acquisitions CFO only		Acquisitions All executives	
EXEC_RANK	-0.014	(-0.30)	0.04	(0.25)	0.011	(0.05)	0.014	(0.14)
MB	0.001	(0.03)	0.001	(0.1)	0.001	(0.02)	0.001	(0.01)
ASSETS	0.091	(0.27)	-0.167	(-1.59)	-0.231	(-1.64)	-0.11	(-1.76)
N	30,915		38,078		31,594		68,386	
Adj. R^2	3.0%		2.0%		11.0%		10.0%	

Panel C: Change in capital expenditures (CAPEX)

Independent Variable	ΔCAPEX CEO only		ΔCAPEX President Only		ΔCAPEX CFO only		ΔCAPEX All executives	
EXEC_RANK	0.027	(5.03)	0.032	(4.3)	0.036	(5.51)	0.053	(8.63)
ΔCAPEX$_{t-1}$	-0.007	(-52.53)	-0.012	(-6.88)	-0.008	(-10.50)	-0.014	(-10.40)
MB	0.001	(0.03)	-0.012	(-1.74)	-0.001	(-1.61)	-0.001	(-0.77)
ASSETS	0.001	(19.53)	0.001	(15.42)	0.001	(13.8)	0.001	(23.29)
N	32,011		39,955		32,943		70,888	
Adj. R^2	7.0%		4.0%		6.0%		4.0%	

Panel D: Two consecutive years of past earnings increases

Independent Variable	ΔNI_t		ΔNI_{t+1}		ΔNI_{t+2}		ΔNI_{t+3}	
EXEC_RANK	0.001	(1.37)	-0.001	(-0.42)	-0.001	(-3.43)	-0.003	(-0.86)
ΔNI_{t-1}	0.201	(782.53)	0.01	(8.45)	0.015	(27.99)	0.006	(4.04)
MB	-0.001	(-2.99)	0.001	(1.19)	-0.001	(-0.88)	-0.001	(-3.36)
ASSETS	-0.001	(-17.92)	-0.001	(-0.42)	0.004	(2.16)	0.001	(0.34)
N	28,221		26,159		23,662		21,067	
Adj. R^2	92.0%		6.0%		5.0%		6.0%	

Independent Variable	ΔCFO_t		ΔCFO_{t+1}		ΔCFO_{t+2}		ΔCFO_{t+3}	
EXEC_RANK	0.004	(-1.07)	-0.003	(-0.69)	0.001	(-0.25)	0.001	(-0.42)
ΔCFO_{t-1}	-0.241	(-14.74)	0.019	(-7.6)	0.02	(-4.53)	0.036	(-7.59)
MB	-0.001	(-0.25)	0.001	(-3.07)	-0.001	(-0.31)	-0.001	(-0.20)
ASSETS	-0.001	(-14.74)	0.001	(-5.16)	-0.001	(-2.64)	-0.001	(-0.20)
N	28,221		26,159		23,662		21,067	
Adj. R^2	25.0%		2.0%		2.0%		3.0%	

Panel E: Two consecutive years of past earnings decreases

Independent Variable	ΔNI_t		ΔNI_{t+1}		ΔNI_{t+2}		ΔNI_{t+3}	
EXEC_RANK	0.001	(3.5)	-0.002	(-2.50)	-0.003	(-2.75)	-0.003	(-2.7)
ΔNI_{t-1}	0.153	(27.84)	-0.008	(-8.95)	-0.198	(-17.33)	-0.073	(-8.78)
MB	0.001	(1.03)	-0.001	(-14.24)	-0.001	(-13.15)	0.001	(0.45)
ASSETS	0.002	(3.5)	-0.002	(-4.44)	-0.001	(-2.07)	-0.003	(-2.28)
N	12,728		10,841		9,435		8,296	
Adj. R^2	16.0%		7.0%		45.0%		28.0%	

Independent Variable	ΔCFO_t		ΔCFO_{t+1}		ΔCFO_{t+2}		ΔCFO_{t+3}	
EXEC_RANK	-0.008	(-1.71)	-0.023	(-3.70)	-0.033	(-3.70)	-0.002	(-1.68)
ΔCFO_{t-1}	-0.286	(-48.82)	-0.033	(-4.98)	-0.041	(-4.55)	-0.064	(-5.97)
MB	0.001	(0.57)	-0.001	(-0.36)	0.001	(0.78)	-0.003	(-1.95)
ASSETS	0.003	(11.74)	0.001	(0.19)	0.001	(0.95)	0.001	(1.04)
N	12,728		10,841		9,435		8,296	
Adj. R^2	28.0%		3.0%		4.0%		6.0%	

Table 1.6: *Top executives' profits from insider trading and past stock returns*

Time series regression results are obtained using the Fama-French four-factor model:

$$R_{p,t} - R_{f,t} = \alpha_p + \beta_p(R_{m,t} - R_{f,t}) + \chi_p\text{SMB}_t + \delta_p\text{HML}_t + \phi_p\text{MOM}_t + \epsilon_{j,t}.$$

Where $R_{p,t}$ is portfolio stock return, where the return is one month to 12 months prior to the portfolio formation date. $R_{m,t}$ is market portfolio return, measured using CRSP value weighted index, $R_{f,t}$ is the risk free rate, measured as the one-month treasury bill rate; SMB_t, HML_t and MOM_t respectively, are the Fama-French (1993) and Carhart (1997) size, market-to-book and momentum factor returns. The return window is monthly, and factor loadings are estimated using a time series regression based on 270 months of data, from 7/86 to 12/08 (firm numbers range from 16 to 1,523 firms per month). T-statistics are next to the coefficient estimates. We report results for top executives insider profits for three portfolios based on the cumulative top executives profits from insider trading: the quintile of insider firms with the lowest top executives profit, the quintile of insider firms with the highest top executives profit, and a hedge portfolio where we buy the low quintile and sell the high quintile. Only months where at least 15 firms are present are included.

	Executive profit lower quintile		Executive profit upper quintile		Hedge Return	
	Monthly (α)	t-stat	Monthly (α)	t-stat	Monthly (α)	t-stat
1 month before	0.21%	(0.48)	1.19%	(3.04)	-0.98%	(-7.62)
2 months before	0.41%	(0.92)	1.31%	(3.33)	-0.90%	(-7.11)
3 months before	0.94%	(2.18)	1.72%	(4.45)	-0.78%	(-6.48)
4 months before	1.01%	(2.38)	1.77%	(4.66)	-0.76%	(-6.18)
5 months before	1.11%	(2.62)	1.85%	(4.98)	-0.75%	(-6.41)
6 months before	1.09%	(2.56)	1.82%	(4.82)	-0.74%	(-6.09)
7 months before	1.22%	(2.89)	2.05%	(5.42)	-0.83%	(-7.28)
8 months before	1.24%	(2.95)	2.12%	(5.70)	-0.88%	(-7.75)
9 months before	1.41%	(3.35)	2.18%	(5.84)	-0.78%	(-6.94)
10 months before	1.28%	(3.06)	1.98%	(5.32)	-0.71%	(-6.32)
11 months before	1.20%	(2.88)	1.93%	(5.25)	-0.73%	(-6.70)
12 months before	1.26%	(3.02)	1.93%	(5.27)	-0.67%	(-6.23)

Table 1.7: *Top executives' profits from insider trading and future stock returns*

Time series regression results are obtained using the Fama-French four-factor model:

$$R_{p,t} - R_{f,t} = \alpha_p + \beta_p(R_{m,t} - R_{f,t}) + \chi_p\text{SMB}_t + \delta_p\text{HML}_t + \phi_p\text{MOM}_t + \epsilon_{j,t}.$$

Where $R_{p,t}$ is portfolio stock return, where the return interval is one month to 36 months subsequent to the portfolio formation date. $R_{m,t}$ is market portfolio return, measured using CRSP value weighted index, $R_{f,t}$ is the risk free rate, measured as the one-month treasury bill rate; SMB_t, HML_t and MOM_t respectively, are the Fama-French (1993) and Carhart (1997) size, market-to-book and momentum factor returns. The return window is monthly, and factor loadings are estimated using a time series regression based on 270 months of data, from 7/86 to 12/08 (firm numbers range from 16 to 1,523 firms per month). T-statistics are next to the coefficient estimates. We report results for top executives insider profits for three portfolios based on the cumulative top executive profits from insider trading: the quintile of insider firms with the lowest top executives profit, the quintile of insider firms with the highest top executives profit, and a hedge portfolio where we buy the low quintile and sell the high quintile. Only months where at least 15 firms are present are included.

	Executive profit lower quintile		Executive profit upper quintile		Hedge Return	
	Monthly (α)	t-stat	Monthly (α)	t-stat	Monthly (α)	t-stat
1 month ahead	1.01%	(2.28)	0.79%	(2.06)	0.23%	(1.87)
2 months ahead	1.09%	(2.39)	0.82%	(2.08)	0.27%	(2.22)
3 months ahead	1.33%	(2.99)	1.00%	(2.60)	0.33%	(2.59)
4 months ahead	1.30%	(2.82)	0.89%	(2.22)	0.41%	(3.16)
5 months ahead	1.19%	(2.57)	0.81%	(2.04)	0.38%	(3.04)
6 months ahead	1.21%	(2.62)	0.84%	(2.12)	0.38%	(3.04)
7 months ahead	1.08%	(2.33)	0.76%	(1.90)	0.32%	(2.52)
8 months ahead	1.00%	(2.17)	0.69%	(1.73)	0.31%	(2.78)
9 months ahead	1.08%	(2.37)	0.70%	(1.72)	0.38%	(3.47)
10 months ahead	0.97%	(2.13)	0.60%	(1.46)	0.38%	(3.79)
11 months ahead	1.04%	(2.26)	0.69%	(1.69)	0.35%	(3.27)
12 months ahead	1.07%	(2.34)	0.70%	(1.69)	0.37%	(3.60)
13 months ahead	0.97%	(2.11)	0.70%	(1.67)	0.28%	(2.66)
14 months ahead	1.14%	(2.47)	0.87%	(2.09)	0.27%	(2.48)
15 months ahead	0.94%	(2.06)	0.66%	(1.58)	0.28%	(2.80)
16 months ahead	1.17%	(2.65)	0.91%	(2.32)	0.26%	(2.39)
17 months ahead	1.33%	(3.05)	1.08%	(2.76)	0.25%	(2.31)
18 months ahead	1.26%	(2.89)	1.02%	(2.62)	0.24%	(2.52)
19 months ahead	1.05%	(2.40)	0.85%	(2.16)	0.19%	(2.11)
20 months ahead	0.70%	(1.62)	0.42%	(1.09)	0.28%	(3.09)
21 months ahead	0.96%	(2.21)	0.80%	(2.02)	0.17%	(1.72)
22 months ahead	1.25%	(2.87)	0.95%	(2.42)	0.30%	(3.20)
23 months ahead	1.12%	(2.57)	0.91%	(2.33)	0.21%	(2.34)
24 months ahead	1.11%	(2.51)	0.80%	(2.00)	0.31%	(3.08)

25 months ahead	0.91%	(2.05)	0.67%	(1.70)	0.24%	(2.40)
26 months ahead	0.83%	(1.90)	0.70%	(1.77)	0.13%	(1.29)
27 months ahead	0.86%	(1.93)	0.76%	(1.90)	0.10%	(0.94)
28 months ahead	0.91%	(2.07)	0.66%	(1.65)	0.25%	(2.53)
29 months ahead	0.84%	(1.91)	0.71%	(1.77)	0.13%	(1.22)
30 months ahead	0.97%	(2.23)	0.74%	(1.83)	0.23%	(2.16)
31 months ahead	0.95%	(2.18)	0.79%	(1.97)	0.17%	(1.64)
32 months ahead	0.98%	(2.22)	0.79%	(1.94)	0.19%	(1.86)
33 months ahead	1.12%	(2.52)	1.04%	(2.51)	0.09%	(0.69)
34 months ahead	0.74%	(1.66)	0.67%	(1.62)	0.07%	(0.55)
35 months ahead	0.85%	(1.92)	0.83%	(1.98)	0.03%	(0.19)
36 months ahead	1.18%	(2.62)	1.18%	(2.67)	0.11%	(0.69)

Table 1.8: *Top executives' profits from insider trading and future stock returns separated by buys and sells*

Time series regression results are obtained using the Fama-French four-factor model:

$$R_{p,t} - R_{f,t} = \alpha_p + \beta_p(R_{m,t} - R_{f,t}) + \chi_p\text{SMB}_t + \delta_p\text{HML}_t + \phi_p\text{MOM}_t + \epsilon_{j,t}.$$

Where $R_{p,t}$ is portfolio stock return, where the return interval is one month to 36 months subsequent to the portfolio formation date. $R_{m,t}$ is market portfolio return, measured using CRSP value weighted index, $R_{f,t}$ is the risk free rate, measured as the one-month treasury bill rate; SMB_t, HML_t and MOM_t respectively, are the Fama-French (1993) and Carhart (1997) size, market-to-book and momentum factor returns. The return window is monthly, and factor loadings are estimated using a time series regression based on 270 months of data, from 7/86 to 12/08 (firm numbers range from 16 to 1,523 firms per month). T-statistics are next to the coefficient estimates. We report results for top executives insider profits for three portfolios based on the cumulative top executive profits from insider trading: the quintile of insider firms with the lowest top executives profit, the quintile of insider firms with the highest top executives profit, and a hedge portfolio where we buy the low quintile and sell the high quintile. Only months where at least 15 firms are present are included.

	Buy		Sell	
	Monthly (α)	t-stat	Monthly (α)	t-stat
1 month ahead	0.27%	(1.09)	0.26%	(1.23)
2 months ahead	0.28%	(1.18)	0.33%	(1.94)
3 months ahead	0.45%	(1.97)	0.28%	(2.36)
4 months ahead	0.50%	(2.16)	0.28%	(2.35)
5 months ahead	0.50%	(2.28)	0.19%	(0.98)
6 months ahead	0.39%	(1.84)	0.28%	(1.46)
7 months ahead	0.36%	(1.93)	0.20%	(1.09)
8 months ahead	0.59%	(3.00)	0.01%	(0.06)
9 months ahead	0.65%	(3.37)	0.05%	(0.31)
10 months ahead	0.54%	(3.01)	0.07%	(0.40)
11 months ahead	0.41%	(2.23)	0.09%	(0.48)
12 months ahead	0.76%	(4.19)	0.10%	(0.52)
13 months ahead	0.71%	(3.72)	-0.02%	(-1.10)
14 months ahead	0.87%	(4.72)	-0.42%	(-2.18)
15 months ahead	0.94%	(4.83)	-0.46%	(-2.44)
16 months ahead	0.74%	(4.06)	-0.43%	(-2.37)
17 months ahead	0.77%	(4.50)	-0.29%	(-1.46)
18 months ahead	0.73%	(4.37)	-0.25%	(-1.24)
19 months ahead	0.59%	(3.64)	-0.22%	(-1.74)
20 months ahead	0.61%	(3.58)	-0.23%	(-1.39)
21 months ahead	0.50%	(3.11)	-0.24%	(-1.48)
22 months ahead	0.48%	(3.05)	-0.17%	(-1.05)
23 months ahead	0.51%	(3.08)	-0.19%	(-1.20)
24 months ahead	0.58%	(3.56)	-0.12%	(-1.09)

25 months ahead	0.48%	(2.65)	-0.11%	(-1.11)
26 months ahead	0.61%	(3.50)	-0.20%	(-1.31)
27 months ahead	0.63%	(3.71)	-0.12%	(-0.99)
28 months ahead	0.40%	(2.39)	-0.12%	(-0.70)
29 months ahead	0.48%	(3.09)	-0.17%	(-1.04)
30 months ahead	0.32%	(2.08)	-0.17%	(-1.11)
31 months ahead	0.50%	(3.37)	-0.19%	(-1.18)
32 months ahead	0.43%	(2.91)	-0.10%	(-0.53)
33 months ahead	0.40%	(2.65)	-0.20%	(-0.89)
34 months ahead	0.27%	(1.70)	-0.16%	(-0.84)
35 months ahead	0.30%	(2.04)	-0.21%	(-1.20)
36 months ahead	0.34%	(2.26)	-0.32%	(-0.93)

Chapter 2

On the Optimality of Participatory Budgeting

2.1   Introduction

A key element of any firm's organizational design is the choice of budgeting system with which information is communicated. Consistent with the decentralization trend over the past two decades (Rajan and Wulf [43] and Roberts [45]), recent surveys suggest that firms are increasingly engaged in bottom-up, or so-called "participative" budgeting, wherein senior-managers solicit information from lower levels of the firm (Stout and Shastri [53]). However, transitioning to such systems can be costly since, as Baiman and Evans III [7] warn, truthful solicitation of subordinates' private information requires paying agents informational rents. In this paper we propose a stylized model of a firm's budgeting decision, providing conditions in which participative budgeting dominates top-down budgeting and characterize how the underlying information system must vary for the optimal choice of budgeting regime to change. Empiricists have also studied the trade-offs involved with participate budgeting, though they have largely focused on how firm attributes such as performance (Brownell [14], Frucot and Shearon [25]), budgetary slack (Dunk [17]) and budget emphasis (Young [58]), vary with the adoption of bottom-up budgeting. Accounting literature

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surveys including Shields and Shields [50], Shields and Young [51] and Brown et al. [13] have concluded that the evidence to date is mixed. As Shields and Shields [50] point out; "Studies have reported, for example, that participative budgeting has linear positive, linear negative, ordinal and disordinal interaction (with other independent or moderating variables), and no effect on motivation and performance." By analyzing a formal model of the firm's budgeting process, we provide an economic rationale for such choices and provide a possible explanation for the mixed empirical results to date.

We model a firm who jointly optimizes all organizational design decisions, including the choice of budgeting paradigm, in response to the underlying informational setting: ex-ante environmental uncertainty and the availability of private interim information. Private interim information can be procured by either a superior (the "principal") or her subordinate (the "agent"), as asking both parties to acquire private information would prove excessively costly. Costly information gathering may include client visits, working with marketing consultants, or inspecting off-site facilities to acquire information such as local or future demand estimates, or the likelihood of supply-chain delays. In each of these instances, the acquired information is privately observed; i.e., the information is soft. Interim information serves two purposes: the agent uses it to choose an appropriate level of costly effort, and the principal uses it to better structure the agent's compensation. Consistent with practice (Parker and Kyj [38]), budgeting enables private information to flow vertically within the firm. Our primary contribution characterizes the optimal information flow: from principal to agent (top-down budgeting) or from agent to superior (bottom-up budgeting).

We find that top-down budgeting outperforms bottom-up budgeting when either there is insufficient interim information available or the firm's range of ex-ante environmental uncertainty is sufficiently small. In such settings, the principal optimally retains all information gathering responsibilities, and later signals his findings to the agent. Absent these conditions, the principal optimally delegates information gathering and reporting duties to the agent. While bottom-up budgeting forces the principal to pay informational rents to the agent directly, top-down budgeting proves costly as well, since the principal may opt to strategically misreport her information

so as to raise her payoffs. To credibly relay information in a top-down setting, the principal optimally concedes an announcement-contingent share of her ex-post profits to the agent, analogous to informational rents faced under bottom–up budgeting.

To motivate credible communication, the contract under each budgeting mode must undermine the informed party's benefit to misrepresentation. Under bottom-up budgeting, the optimal contract provides the agent rents to prevent him from unanimously reporting unfavorable news, which is his preferred information state, while the optimal top-down contract pays the agent rents to prevent the principal from unanimously reporting favorable news, her preferred state. This distinction leads to production inefficiencies in unproductive (productive) states under bottom-up (top-down) budgeting. Because the agent's productivity is unknown when he chooses effort, additional ex-ante environmental uncertainty or additional interim information both drive up (down) the cost of inefficient production in favorable (unfavorable) states. While inefficiencies are always less costly in unfavorable states,[1] bottom-up budgeting may still incur greater agency costs than top-down paradigms, due to the presence of additional "control losses." The principal incurs additional control losses under bottom-up budgeting because the agent reports his signal and selects an effort, whereas under top-down budgeting, the agent need only choose his effort. The expanded action-space allows the agent to optimize his effort concomitantly with strategic misreporting. Therefore, when there is relatively little acquirable information, environmental uncertainty, or both, the principal favors top-down budgeting, as the resulting inefficient production in favorable states proves less costly than the control loss associated with participative budgeting and the associated inefficiencies in the unfavorable state. However, as the cost of inefficient production increases with either additional environmental uncertainty, interim information, or both, the cost of inefficient production in favorable states begins to outweigh those associated with control loss, eventually causing the principal to favor bottom-up budgeting.

In spite of the inherent control loss and subsequent rents associated with bottom-up budgeting,

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[1] A price discriminating monopolist faces a similar decision in choosing whether to impose inefficiencies on high-versus low-willingness to pay consumers. From Maskin and Riley [36], the monopolist optimally screens customers by distorting all but the highest value customers.

the principal and agent's payoffs to misreporting are *qualitatively identical* across top-down and bottom-up budgeting respectively. More surprisingly, we find that the principal's preferences for interim information and environmental uncertainty are themselves qualitatively identical across the two budgeting regimes, and the same is true of the agent's preferences. Put differently, parametric shocks resulting in additional informational rents for the agent under bottom-up budgeting are likely to result in analogous rent increases for the agent under top-down budgeting as well. Combined, these results suggest that many of the concerns surrounding bottom-up budgeting; e.g., Baiman and Evans III [7], apply not only to circumstances of adverse-selection, but more generally to any setting featuring asymmetric information and moral hazard.

After characterizing the principal's preferred budgeting regime, we provide comparative statics linking the choice of budgeting paradigm to the firm attributes most frequently discussed in the empirical literature. Our proxies for budgetary slack, budget emphasis and incentive strength largely behave non-monotonically over interim information availability and environmental uncertainty. Although we have abstracted away from behavioral considerations, these results provide a possible economic explanation for the mixed empirical evidence to date.

The foundation for the two analyzed budgeting modes have each been thoroughly studied in the Economics literature. Bottom-up budgeting shares many common features with the adverse-selection model introduced in Baron and Myerson [10]. Common to both paradigms, the principal contractually screens the agent's private information. In contrast, in top-down budgeting, the principal herself signals information to the agent, much like the informed principal model from Maskin and Tirole [37]. An excellent survey of both the signaling and screening literatures can be found in Riley [44]. Surprisingly, very little research explicitly compares the two communication mediums or more generally, the firm's internal allocation of private information. One notable exception is Eso and Szentes [19], where the principal cannot decipher the favorableness of information, but nonetheless must decide how much information to provide the agent directly, and how much to make contingent on the agent's interim report. Our work differs, as our principal can interpret information, therefore, absent costly contractual constraints, the principal may strategically misin-

form the agent in top-down budgeting, akin to the temptations facing the agent under bottom-up budgeting.

To characterize the firm's preferred budgeting regime, we compare the principal's payoff under each mode while holding the level fixed the level of available interim information. The Information Systems literature, beginning with Antle and Fellingham [4], has already analyzed information preferences within an adverse-selection paradigm; though no work to date has studied such preferences as the information recipient varies. To parameterize information quantity, we borrow from Rajan and Saouma [42] where the authors find the principal and agent's preferences to vary non-monotonically over the agent's allocation of private information. Similar informational preferences arise in Arya et al. [6], where the principal can contribute to output, though she cannot commit to contributing. Therein, the authors find that information system improvements can aggravate the principal's commitment problem, thereby reducing her expected profits. In our top-down model, the principal holds private information, though she cannot commit to truthfully disclosing it, and analogous to Arya et al. [6], introducing additional information can lower the principal's payoff.

Most importantly, our model addresses the extant empirical budgeting research. Brown et al. [13] provide a thorough survey of the budgeting literature, both analytical and empirical, classifying studies on the basis of their underlying ideology: economics, psychology, and sociology. Our research falls within the broader field of economics as we model both a self-interested principal and agent. The majority of the empirical studies have focused on the consequences of bottom-up budgeting adoptions, including slack (Dunk [17], Fisher et al. [23]), incentive contracts (Young [58]) and firm performance (Brownell [14], Frucot and Shearon [25]). Both Shields and Shields [50] and Shields and Young [51] argue that the mixed empirical evidence may have resulted from researchers commingling the antecedents and consequences of participative budgeting. In response, we have provided an economic model which relates potential participative-budgeting antecedents (interim information and environmental uncertainty) to the firm's choice of budgeting paradigm, and the associated consequences.

We present the model below in Section 2. Section 3 studies the optimal contracts under both

top-down and bottom-up budgeting, whereas Section 4 characterizes the relative attributes of each mode. Section 5 discusses the results and concludes.

2.2 Model

We model a risk-neutral principal (she) and an agent[2] (he) who will incur either high-, θ_H, or low-, θ_L, productivity in the upcoming period with probability $1 > p > 0$ and $1 - p$ respectively, where $\theta_H > \theta_L > 0$ and $\mathrm{E}[\theta] = \overline{\theta}$. We denote the ex-ante range in the firm's profitability, or so-called environmental uncertainty, with $j = \frac{\theta_H}{\theta_L}$. The agent's productivity, θ, denotes the efficiency of his private effort, $e \geq 0$ in generating profits, $\pi = \theta e + \epsilon$ where ϵ is mean zero, idiosyncratic noise with finite variance. The agent's private cost of effort is given by $c(e) = T\frac{e^2}{2}$, with $T > 0$. The agent's cost of effort, T, the likelihood of high productivity, p, and the underlying productivity support, $\{\theta_H, \theta_L\}$, are all common knowledge, albeit the true productivity, θ, is unknown to everyone.

Both the principal and agent are equally capable of collecting interim information,[3] $\sigma \in \{\sigma_H, \sigma_L\}$, to estimate the agent's forthcoming productivity, θ. To capture the cost of gathering information, such as meeting with clients or visiting production facilities, we assume that the firm can only justify having either the principal *or* the agent gather information. The decision as to who ought to collect information is made formally at the outset of the game when the agent is hired at time $t = 0$. The *act* of collecting information, while costly to the researcher, is contractible and thus not subject to moral hazard; e.g., visiting a client or touring factories are both costly, yet contractible (i.e., the researcher can seek reimbursement for his or her costs). Collected information provides insight into the agent's marginal productivity, examples include a client's estimated demand or a plant's ability to manufacture products according to schedule. Such soft information is unlikely to be verifiable, therefore we assume that the any acquired information cannot be verifiably recorded. Instead, the researcher communicates their signal during the budgeting process:

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[2]One possible interpretation is that the principal manages the division, whereas the agent is a manager within the division, and the principal is the residual claimant to any divisional profits.

[3]We use the terms "collecting information" and "research" synonymously, as well as "informed party" and "researcher".

when the principal reports her findings, we label the process top-down budgeting, whereas when the agent reports, the process is labeled bottom-up or participating budgeting. Interim information availability, and the accuracy with which it predicts future productivity are exogenously determined by the nature of the firm's business. To capture both facets we define, $a \in [0, 1]$, as the level of interim information available, though one may also interpret a as the quality of available interim information. Without loss of generality, the acquired signal σ fully reflects all available information, a. Given a signal, σ_i with $i = H, L$, we label the expected productivity, $\hat{\theta}_i(a) = \mathrm{E}[\theta|\sigma_i; a]$, though for compactness, we refer to the expected productivity as $\hat{\theta}_i$. To operationalize the level of information available, a, let:

$$Pr[\theta_i|\sigma_i] = a + (1 - a) \cdot Pr[\theta_i] \quad i = H, L \quad a \in [0, 1]$$

$$Pr[\theta_{-i}|\sigma_i] = (1 - a) \cdot Pr[\theta_{-i}] \quad i = H, L \quad a \in [0, 1].$$

Note that the level of information, a, formally measures the correlation between the signal, σ, and the agent's productivity, θ. As $a \to 1$, our setting approaches the perfectly-informed agent paradigm found in the adverse selection literature (Baron and Myerson [10]), while as $a \to 0$, all members of the firm become symmetrically (un)informed, regardless of whether one party or the other has engaged in research. Using the parametrization above, the informed party's signal-contingent expectation of θ, can be seen in Figure 2.1 as a function of a.

Whereas the level of information collected, a, measures the fraction of uncertainty resolved, it does not capture the nominal uncertainty surrounding the agent's productivity, or identically, the firm's ex-ante environmental uncertainty, $j = \frac{\theta_H}{\theta_L}$. For the purpose of our analysis we only consider linear-mean preserving spreads of j. We do so both for reasons of tractability (linear) and to avoid commingling information and productive effective (mean preserving). To measure the informativeness of the acquired signal, σ, or equivalently the level of information asymmetry, a metric must consider both the environmental uncertainty, j and the level of interim information, a. Since the agent bases his effort on the conditional productivity, $\hat{\theta}_i$, the ratio of high- to low-conditional

productivity provides a natural proxy. From Figure 2.1, the ratio $\frac{\hat{\theta}_H}{\hat{\theta}_L}$ (signal informativeness) increases both in the level of interim information, a, and the underlying ex-ante uncertainty, j. For the duration of our analysis, references to increases (decreases) in signal informativeness can be interpreted as increases (decreases) in the level of interim information, a, the level of ex-ante environmental uncertainty, j, or both. Importantly, we ignore changes in signal informativeness that result from changes in the likelihood of favorable states, p, because by fiat, varying p will simultaneously affect the unconditional mean-productivity, $\bar{\theta}$, preventing us from delineating production effects from information effects.
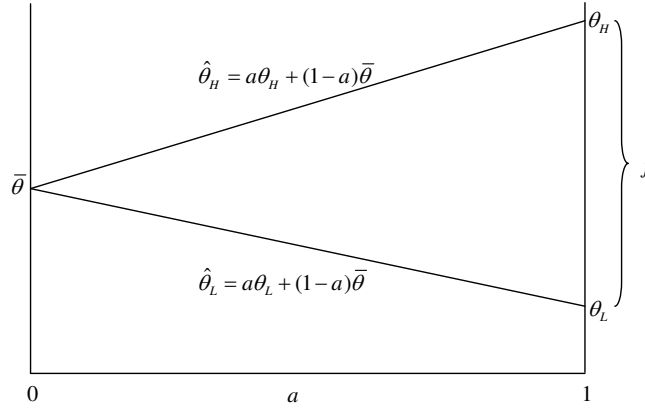
Figure 2.1: Following the receipt of a signal, σ_i, the conditional expectations, $\hat{\theta}_i$, become increasingly distinct from the unconditional expectation, $\bar{\theta}$, as signal informativeness increases, due to increases in the level of interim information, a, the ex-ante environmental uncertainty, j, or both.

Following prior agency literature, the principal holds the majority of the bargaining power: at time $t = 0$, she offers the agent a take-it-or-leave-it menu of contracts which specifies the budgeting mode and the timing thereafter. Under top-down (bottom-up) budgeting, the principal (agent) engages in research and obtain σ at time $t = 1$. At time $t = 2$, a budgeting meeting takes place where the informed party reports their findings (σ). To credibly communicate the interim signal, σ, the party charged with collecting information selects a contract from the menu of contracts agreed upon at $t = 0$. The individual contracts take the form of (α_i, β_i) with $i \in \{H, L\}$ and $0 \leq \beta_i \leq 1$, where α_i denotes a fixed salary paid to the agent and $(1 - \beta_i)$ his share of the $t = 4$ realized profits, π, leaving the principal with the residual profits, $\beta_i \pi - \alpha_i$.[4]

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[4]While we only consider linear profit sharing contracts, if both the principal and agent could agree on the exact

Without loss of generality, we set the contractible cost of information acquisition to zero.[5] The Revelation Principle allows us to restrict attention to menus with only two individual contracts: contract i is selected if and only if $\sigma = \sigma_i$, though the $t = 0$ menu must satisfy incentive compatibility constraints to prevent misreporting. By virtue of proposing the contract, we assume that the principal must honor her terms offered at $t = 0$ throughout, though the agent's bargaining power entitles him to leave the firm at any time.[6] In particular, the agent may leave upon learning σ, either directly at $t = 1$ under bottom-up budgeting, or indirectly at $t = 2$ in top-down budgeting. If the agent decides to leave the firm, he is reimbursed for any information gathering costs incurred, and the the game ends. We assume the agent faces sufficiently limited liability to prevent him from buying the firm from the principal at time $t = 0$; specifically, the principal cannot "sell the firm" prior to information acquisition.

If the agent stays with the firm, then at time $t = 3$, he chooses his effort, denoted e_i, to maximize his utility given the contract $\{\alpha_i, \beta_i\}$ specified in the budgeting process at time $t = 2$. At time $t = 4$, profits, π, are realized, the agent collects $\alpha_i + (1 - \beta_i)\pi$, and the principal retains the realized, residual profits, $\beta_i \pi - \alpha_i$. Figure 2.2 summarizes the time-line.

Consistent with the sample examined in Fisher et al. [22], the principal and agent effectively renegotiate the agent's compensation contract at the budgeting stage; albeit the renegotiation is restricted to the terms set forth in the $t = 0$ menu. To validate our characterization of information, we first examine the effect of varying the signal informativeness in a benchmark setting where the agent's effort, e, is contractible.

Lemma 1. *When the agent's effort is contractible, the principal is always indifferent between top-down and bottom-up budgeting. Under both modes, the principal instructs the agent to exert effort $e_i = \frac{\hat{\theta}_i}{T}$ and pays him only an effort-contingent wage of $\alpha_i = \frac{\hat{\theta}_i^2}{2}T$ following a report $\sigma_i \in \{\sigma_H, \sigma_L\}$*

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distribution of the noise, ϵ, or if $\epsilon \equiv 0$, then the firm could augment profits via a non-linear contract. We thank Ron Dye for raising the possibility of perfect ex-post measures ($\epsilon \equiv 0$). For a discussion of perfect versus imperfect contracting measures with private information, see Rajan and Saouma [42].

[5]For a discussion on costly research subject to moral hazard, see Lewis and Sappington [34].

[6]In equilibrium, both the principal and agent always abide by the original contract in all periods. Below, we show that the principal's interim individual rationality constraint is always non-binding, though that of the agent will always bind.

Top-Down Budgeting

Principal collects
information,
formulates
σ_i

Principal proposes
(α_i, β_i)
agent accepts
or rejects

$t = 0$
Principal proposes
$\{(\alpha_L, \beta_L), (\alpha_H, \beta_H)\}$
agent accepts
or rejects

1

2

3
Agent selects
hidden effort
e_i

4
π realized
agent paid
$\alpha_i + (1 - \beta_i)\pi$

Agent collects
information,
formulates
σ_i

Agent proposes
(α_i, β_i)
principal accepts
or rejects

Bottom-Up Budgeting
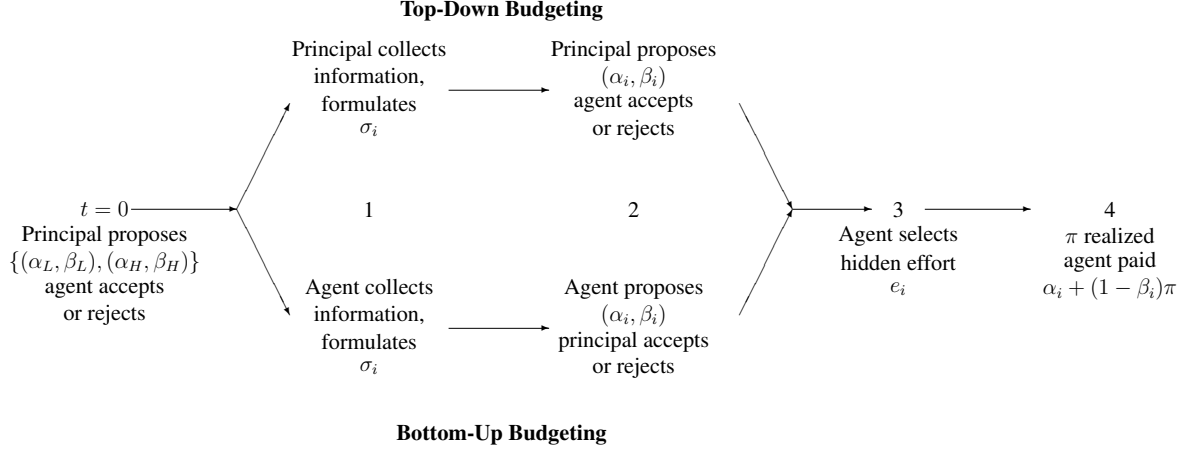
Figure 2.2: Model time-line.

at the budgeting stage, $t = 2$. The principal's expected profits are increasing and convex in signal
informativeness, whereas the agent always earns his reservation utility.

Lemma 1 highlights the fact that absent hidden effort, e, the choice of budgeting mode has no
effect on the principal or agent's payoff. Holding fixed the level of ex-ante environmental uncer-
tainty, additional interim information allows the agent to more efficiently select his level of effort,
e_i, resulting in increased profits. Similarly, holding fixed the level of interim information, increas-
ing the level of ex-ante environmental uncertainty raises (lowers) the expected profits following a
signal σ_H (σ_L). Profits rise nonetheless, as the agent exerts greater effort in favorable states than
in unfavorable states; i.e, $e_H > e_L$, implying that the marginal profits resulting from an increase in
$\hat{\theta}_H$ overpower the negative marginal profits associated with a decrease in $\hat{\theta}_L$; i.e., $\left|\frac{\partial \pi}{\partial \hat{\theta}_H}\right| > \left|\frac{\partial \pi}{\partial \hat{\theta}_L}\right|$.
Profits are convex, because the difference between the two effort levels also expands when $\hat{\theta}_H$ and
$\hat{\theta}_L$ diverge from one another as signal informativeness increases.

2.3 Hidden Effort

In this section the principal can no longer observe and contract on the agent's effort, e. We consider
budgeting equilibria where:

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i. The informed party maximizes its payoffs by truthfully communicating their interim signal.

ii. The uninformed party correctly infers the signal from their opponent's contract choice.[7]

iii. The agent always selects his payoff maximizing effort.

iv. The agent's interim $(t = 3)$ expected payoffs are non-negative.

v. The uninformed party is free to choose a contract from the original $(t = 0)$ menu if the informed party fails to do so at $t = 2$.

The Revelation Principle guarantees that the first equilibrium requirement is without loss of generality. Conditions (ii)-(iv) imply that both the principal and agent are individually rational, while condition (v) specifies the necessary off-equilibrium beliefs required for *any* equilibrium with communication.

2.3.1 Top-Down Budgeting

We first consider the case where the principal collects interim information in accordance with the top-down budgeting paradigm featured in Figure 2.2. The principal thus solves:

$$\max_{\alpha_i, \beta_i} \quad p(\beta_H e_H \hat{\theta}_H - \alpha_H) + (1 - p)(\beta_L e_L \hat{\theta}_L - \alpha_L)$$

$$\text{s.t.} \quad \beta_H e_H \hat{\theta}_H - \alpha_H \geq \beta_L e_L \hat{\theta}_H - \alpha_L \tag{2.1}$$

$$\beta_L e_L \hat{\theta}_L - \alpha_L \geq \beta_H e_H \hat{\theta}_L - \alpha_H \tag{2.2}$$

$$\beta_i e_i \hat{\theta}_i - \alpha_i \geq 0 \qquad i = H, L \tag{2.3}$$

$$(1 - \beta_i)e_i \hat{\theta}_i - \frac{e_i^2}{2} T + \alpha_i \geq 0. \qquad i = H, L \tag{2.4}$$

$$e_i \in \arg\max_e \quad (1 - \beta_i)\hat{\theta}_i e + \alpha_i - \frac{e^2}{2} T \quad i = H, L \tag{2.5}$$

$$0 \leq \beta_i \leq 1 \qquad i \in \{H, L\} \tag{2.6}$$

---

[7]Unless the $t = 0$ menu offered two identical contracts, in which case no information is revealed.

Constraints (2.1) and (2.2) ensure that the principal truthfully reveals her observed signal to the agent. The individual rationality constraints (2.3) and (2.4) guarantee that principal prefers the contract to her reservation payoff at $t = 0$, and that the agent favors the contract over his reservation utility at time $t = 2$ (both set at zero). Finally, (2.5) characterizes the agent's optimal effort. Solving (2.5), the agent puts forth effort $e_i = \frac{(1-\beta_i)}{T}\hat{\theta}_i$ in response to a report of σ_i. Compared with the benchmark setting of Lemma 1, top-down budgeting with moral-hazard causes the agent to distort his effort as his profit-share, $(1 - \beta_i)$, tends away from 1. In other words, any $1 - \beta_i < 1$ induces effort distortions which lower the total expected output. The principal can avoid effort distortions should she sell the agent the firm's entire stream of profits $(1 - \beta_i = 1)$ at time $t = 2$, however the agent will never accept the principal's proposed price. To see why, notice that the agent's valuation of the firm at time $t = 2$ is entirely contingent on the principal's *reported* signal. If the principal's price is independent of her *observed* signal–as is the case when she holds no stake in the firm's realized profits–then she will always claim to have observed favorable information and the agent will not believe her. As the next proposition shows, the optimal contract sells the agent a claim to all firm profits when the principal announces an unfavorable signal and sells the agent a fraction of the firm's profits when the principal acquires favorable news, where the price paid is a function of the principal's payoff to misreporting $\sigma = \sigma_L$.

Proposition 1. *The optimal menu of contracts under top-down budgeting is given by:*

$$\alpha_L = \frac{\hat{\theta}_L^2}{2T} \qquad \alpha_H = \begin{cases} \frac{\hat{\theta}_L(2\hat{\theta}_L - \hat{\theta}_H)}{4T} & \text{if } \frac{\hat{\theta}_H}{\hat{\theta}_L} \geq \sqrt{5} - 1 \\ \frac{(1-\beta_H)^2\hat{\theta}_H^2}{2T} & \text{if } \frac{\hat{\theta}_H}{\hat{\theta}_L} \in (1, \sqrt{5} - 1) \end{cases}$$

$$\beta_L = 0 \qquad \beta_H = \begin{cases} \frac{1}{2} & \text{if } \frac{\hat{\theta}_H}{\hat{\theta}_L} \geq \sqrt{5} - 1 \\ \frac{\hat{\theta}_H^2 - \hat{\theta}_H\hat{\theta}_L - \sqrt{2\hat{\theta}_H\hat{\theta}_L^2(\hat{\theta}_H - \hat{\theta}_L)}}{\hat{\theta}_H^2 - 2\hat{\theta}_H\hat{\theta}_L} & \text{if } \frac{\hat{\theta}_H}{\hat{\theta}_L} \in (1, \sqrt{5} - 1) \end{cases}.$$

When the principal reports unfavorable news, σ_L, she concedes that the firm's value cannot be lower. Accordingly, the agent accepts to purchase the firm's entire stream of profits and carry out the benchmark level of effort, e_L^{FB}. The agent's utility will then be given by the benchmark surplus

conditional on unfavorable information $\left(e_L^{FB}\hat{\theta}_L - c\left(e_L^{FB}\right)\right)$, net of the price paid to the principal. The proposition above shows that the principal optimally charges the agent the entire benchmark surplus, leaving the agent at his reservation utility of zero.

Unfortunately, the same mechanism is no longer credible when the principal reports favorable news, because regardless of the principal's announcement, the agent will refuse to pay more than $\left(e_L^{FB}\hat{\theta}_L - c\left(e_L^{FB}\right)\right)$ when the principal's payoff is independent of the firm's realized profits. Instead, Proposition 1 shows that upon observing favorable news, the principal optimally sells the agent a portion of the firm's profits in exchange for salary concessions.

To understand the tradeoffs involved, note that misreporting $\sigma = \sigma_L$ as σ_H misleads the agent into believing that the firm's productivity will be higher than conditionally warranted. Therefore, if the agent believes the principal obtained a signal σ_H, the former will exert excessive effort and accept a compensation package worth less than advertised. While the principal benefits from selling the agent an over-valued share of the firm's profits, her misreporting payoff is penalized since she must reimburse the agent for his excessive effort. The net payoff to the principal's rouse can be traced to the signal's informativeness, $\frac{\hat{\theta}_H}{\hat{\theta}_H}$, which proxies for both the level of private interim information acquired, and the firm's ex-ante uncertainty.

When the principal's private information is relatively uninformative, the difference between correctly- and over-valued firm profits is relatively low. As such, the agent has relatively little to lose from accepting an overvalued share of profits and consequently, the principal has little to gain from misreporting. To mitigate her misreporting payoff, the principal limits the total surplus generated upon announcing a favorable signal via changing $1 - \beta_H$, all of which she keeps. As the informativeness of the principal's signal $(\hat{\theta}_H/\hat{\theta}_L)$ increases, so does the difference between correctly- and over-valued firms profits, therefore the principal must use increasing large effort distortions (decreasing $1 - \beta_H$) to credibly communicate her signal, which, as a byproduct, increases the total surplus forgone due to effort distortions. The principal will continue to use incur these increasingly costly effort distortions until the signal becomes sufficiently informative, $\frac{\hat{\theta}_H}{\hat{\theta}_L} = \sqrt{5} - 1$, at which point, she fundamentally changes how she maintains credibility. In particular, the prin-

cipal switches from leaving the agent with zero rents and distorting his effort, to fixing the effort distortion $(1 - \beta_H = 1/2)$ and paying the agent rents via his salary (α_H). In other words, the surplus lost to lowering $1 - \beta_H$ below 1/2 in response to more a more informative signal proves more costly than mitigated her misreporting payoff by means of transferring a share of her surplus over to the agent via his salary (α_H) in the favorable state. Accordingly, the optimal profit shares sold to the agent under top-down budgeting are shown in Figure 2.3.
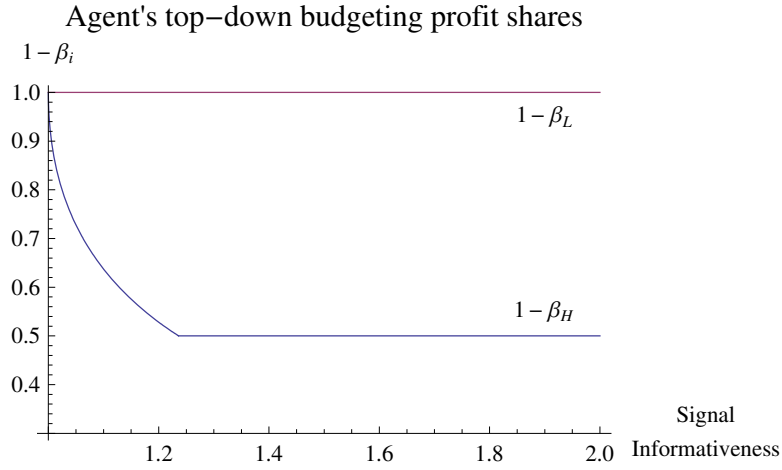
Figure 2.3: Upon announcing the receipt of signal $\sigma = \sigma_H$, the optimal top-down budgeting contract calls for the principal to sell the agent a share $(1 - \beta_H)$ of the firm profits, whereas the constant share $(1 - \beta_L)$. The limit the principal's payoff to misreporting, the optimal contract induced increasingly inefficient production following receipt of a favorable signal until doing so becomes excessively costly, whereupon the contract calls for the principal to transfer surplus to the agent via his salary, α_H.

2.3.2 Bottom-Up Budgeting

In accordance with the time-line in Figure 2.2, the agent is charged with gathering and reporting information under bottom-up budgeting. While we found that the principal may benefit from misreporting unfavorable information as favorable under top-down budgeting, the contrary is true when the agent reports to the principal in a bottom-up budgeting paradigm. When the agent biases his report unfavorably, he causes the principal to undervalue the firm's conditional expected profits, therefore from the principal's perspective, any profit sharing $(1 - \beta_L) > 0$ will overly compensate

the agent. Akin to the top-down problem discussed in the prior subsection, the optimal contract

must limit the agent's payoff to misreporting while maximizing the principal's expected payoff:

$$\max_{\alpha_i, \beta_i} \quad p(\alpha_H + \beta_H e_H \hat{\theta}_H) + (1-p)(\alpha_L + \beta_L e_L \hat{\theta}_L)$$

$$s.t. \quad (1-\beta_i)e_i \hat{\theta}_i - \frac{e_i^2}{2}T - \alpha_i \geq 0 \qquad i \in \{H, L\} \tag{2.7}$$

$$(1-\beta_H)e_H \hat{\theta}_H - \frac{e_H^2}{2}T - \alpha_H \geq (1-\beta_L)e_{HL}\hat{\theta}_H - \frac{e_{HL}^2}{2}T - \alpha_L \tag{2.8}$$

$$(1-\beta_L)e_L \hat{\theta}_L - \frac{e_L^2}{2}T - \alpha_L \geq (1-\beta_H)e_{LH}\hat{\theta}_L - \frac{e_{LH}^2}{2}T - \alpha_H \tag{2.9}$$

$$e_{ij} \in \arg\max_e \quad (1-\beta_j)\hat{\theta}_i e - \frac{e^2}{2}T - \alpha_j \qquad \{i, j\} \in \{H, L\} \tag{2.10}$$

$$0 \leq \beta_i \leq 1 \qquad i \in \{H, L\}. \tag{2.11}$$

Constraint (2.7) ensures that the agent will accept the principal's initial menu of contracts over

his reservation utility of zero at time $t = 0$. The incentive compatibility constraints, (2.8) and (2.9),

require that the agent truthfully report his findings at the budgeting stage in $t = 2$. If the agent

misreports his observation, σ_i as σ_j, then in accordance with equilibrium condition (iii), his choice

of effort, e_{ij}, maximizes his resulting payoffs as determined by (2.10).[8] Although the principal

cannot ensure that the agent's effort is consistent with his announcement, the agent is indirectly

penalized for such inconsistencies. To see how, note that the principal reimburses the agent for his

equilibrium effort, e_{LL} following a report of σ_L, any effort in excess of e_{LL}; e.g., $e_{HL} - e_{LL}$, is

not reimbursed. In equilibrium, the principal rationally anticipates the agent's strategic reporting,

therefore the menu of contracts offered at $t = 0$ provide the agent with informational rents, to

which the agent responds by truthfully revealing his private information.

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[8]To facilitate future exposition, we will refer to the equilibrium bottom-up effort, e_{ii}, as e_i when the connotation is clear.

Proposition 2. *The optimal menu of contracts under bottom-up budgeting is given by:*

$$\alpha_H = \frac{2(1-2p)p\hat{\theta}_H^4\hat{\theta}_L^2 + p(3p-2)\hat{\theta}_H^2\hat{\theta}_L^4 + p2\hat{\theta}_H^6 + (p-1)^2\hat{\theta}_L^6}{2T\left(p\left(\hat{\theta}_H^2 - 2\hat{\theta}_L^2\right) + \hat{\theta}_L^2\right)^2}$$

$$\alpha_L = \frac{(p-1)^2\hat{\theta}_L^6}{2T\left(p\left(\hat{\theta}_H^2 - 2\hat{\theta}_L^2\right) + \hat{\theta}_L^2\right)^2}$$

$$\beta_H = 0$$

$$\beta_L = \frac{p\left(\hat{\theta}_H - \hat{\theta}_L\right)\left(\hat{\theta}_H + \hat{\theta}_L\right)}{p\left(\hat{\theta}_H^2 - 2\hat{\theta}_L^2\right) + \hat{\theta}_L^2}.$$

To keep the agent from misreporting favorable information, the optimal menu of contracts penalizes unfavorable reports with restricted performance pay $((1-\beta_L) < 1)$, leading to an inefficiently low equilibrium effort, e_{LL}. Unlike top-down budgeting, the optimal menu of contracts under bottom-down budgeting retain the same functional form over all information parameters. To understand why this is different between the two modes, recall that inefficient effort is always more destructive when the agent's marginal productivity, θ, is relatively large. Therefore, top-down budgeting induces inefficiencies in the states with the most surplus at stake, whereas bottom-up budgets induce analogous inefficiencies when the surplus at stake is relatively low. As the interim signal becomes more informative, the expected conditional marginal productivity following favorable news $\left(\frac{\partial \pi}{\partial e}\big|_{\sigma=\sigma_H}\right)$ increases, while that following unfavorable news $\left(\frac{\partial \pi}{\partial e}\big|_{\sigma=\sigma_L}\right)$ decreases. In particular, as signal informativeness increases, distortions in the low-state under bottom-up budgeting become less costly in terms of the total output generated while those same distortions in the high-state under top-down budgeting become more costly. As a result, the principal will *always* alter the agent's productivity incentives $(1-\beta_L)$ in response to changes in the level of interim information a and ex-ante environmental uncertainty, j, under bottom-up budgeting. Comparing Figure 2.4 with Figure 2.3, the top-down budgeting regime differs in that the optimal contract finds it excessively costly to assuage the principal's misreporting incentive by means of continuously distorting the agent's favorable state effort as signal informativeness increases indefinitely.
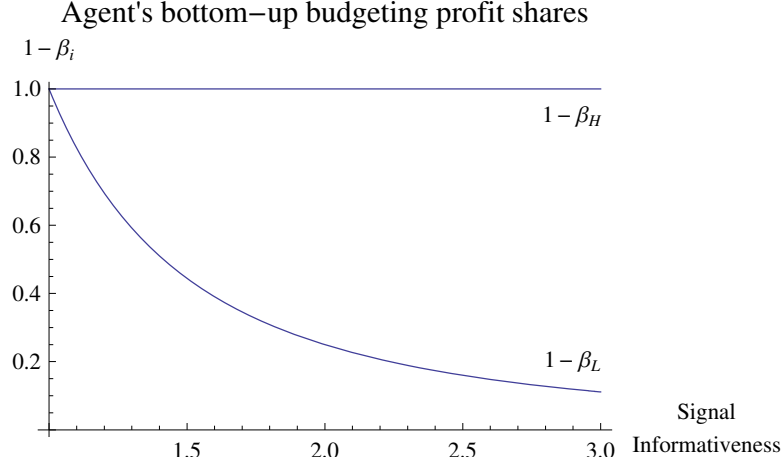
Figure 2.4: To assuage the agent's incentives to misreport $\sigma = \sigma_H$ as σ_L, the optimal contract increasingly decreases the agent's unfavorable state profit share as signal informativeness increases. Consequently, the agent's effort following a report of σ_L becomes increasingly distorted sa signal informativeness rises.

2.4 Results

Each budgeting mode poses a unique set of truth-telling constraints: top-down budgeting requires the agent to distort his effort in favorable productivity states so as to keep the principal honest, whereas bottom-up budgeting imposes a similar distortion in the less productive state in order to keep the agent from misreporting. Pricing theory has shown that a profit maximizing monopolist will avoid imposing inefficient schedules to her most lucrative customers, suggesting that top-down budgeting may never prove efficient. Although the distortions across the two regimes differ, the following proposition demonstrates that total expected surplus *is* always greatest under bottom-up budgeting, where inefficiencies are only imposed in unfavorable states.

Proposition 3. *Total expected surplus is always greater under bottom-up budgeting.*

While the proposition above speaks to total surplus, satisfying incentive compatibility under each budgeting regime frequently requires that the principal partially forfeit surplus to the agent. Therefore the principal's preferred budgeting regime will not always align with the socially optimal outcome. That is, the principal may prefer the overall less efficient top-down paradigm if doing so leaves her with greater expected utility than under bottom-up budgeting. If within a particular

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industry the principal (agent) is better positioned to gather information than the agent (principal), then one would expect firms therein to be that much more inclined to use top-down (bottom-up) budgeting paradigm. However, if both parties are equally adept at research, then the following proposition characterizes the circumstances in which the principal favors one paradigm over the other.

Proposition 4. *When either the principal or the agent can privately observe σ at identical cost, the principal prefers bottom-up budgeting when the privately obtained signal is sufficiently informative. No additional agency costs are incurred if the principal and agent face differing research costs.*

Our main result above speaks directly to the relative costs of signaling (top-down budgeting) versus screening (bottom-up budgeting). When the signal, σ, is relatively uninformative (low levels of information or relatively little uncertainty), neither informed party has much to gain from misreporting. In such a setting, the principal prefers to be privately informed herself, as doing so avoids the "control loss" associated with bottom-up budgeting.[9] However, as the signal becomes more informative (either as the level of interim information, a, or the ex-ante environmental uncertainty, j, increases), both the principal and agent's payoff to misreporting private information increases. Under top-down budgeting, the principal mitigates her misreporting incentives by requiring the agent to exert inefficient effort following favorable news via $(1 - \beta_H) < 1$, and pays the agent non-negative rents via his salary α_H. The principal mitigates the agent's misreporting incentives analogously under bottom-up budgeting, albeit via $(1 - \beta_L) < 1$ instead of $\beta_H > 0$. Because distortions in the favorable state are more costly than those in the unfavorable state, and the difference increases with signal informativeness; when the signal is sufficiently informative $(\frac{\hat{\theta}_H}{\hat{\theta}_L} \gg 1)$, the principal prefers bottom-up budgeting, despite the additional control loss incurred. However, when the signal is relatively uninformative $(\frac{\hat{\theta}_H}{\hat{\theta}_L} \approx 1)$, the surplus losses are approximately equivalent between the favorable and unfavorable distortions and the principal prefers top-down budgeting to

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[9]The phrase "control loss" refers to the losses associated with the fact that under top-down budgeting, the agent can coordinate his efforts to both his realized and reported signal, whereas no such flexibility exists under top-down budgeting.

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avoid paying the control losses associated with bottom-up budgeting.

The proposition also addresses earlier concerns in the Accounting literature suggesting the presence of an additional agency cost with bottom-up budgeting over a top-down paradigm. Regarding the agent's misreporting incentives under bottom-up budgeting, Baiman and Evans III [7] explain: "This suppression and misrepresentation of information could then lead to a budget which is less efficient than the budget which would have been agreed upon if the subordinate's private information were known to the superior." Unlike the top-down setting described in Baiman and Evans III [7], our top-down paradigm assumes that the principal holds an informational advantage over the agent. Surprisingly, the proposition demonstrates that credible communication of the principal's private information generates its own agency costs which may possibly exceed that incurred in soliciting information from the agent in a bottom-up framework.

The second part of the proposition speaks to the possibility that the principal and agent face differing research costs. In particular, if the principal's research cost exceeds that of the agent by δ, then the only penalty above and beyond the production and control costs associated with top-down budgeting is given by δ. Put differently, cost differences between the principal and agent do not affect the underlying hidden-effort problem, as research efforts are not prone to moral hazard.[10]

Each budgeting regime required that the optimal contract allocate surplus across the principal and agent to satisfy the informed party's truth-telling constraint. In the bottom-up regime, the agent's misreporting incentives are offset by informational rents. In the top-down regime, the agent serves as a sink, absorbing the principal's payoff to misreporting her private information. In both settings, the agent benefits from the informed party's misreporting incentives, to the determent of the principal. Combined, these results imply a perpendicular relation between the principal and agent's informational preferences, as we find below.

Proposition 5. *Using the optimal contracts, the agent's rents (principal's payoffs) are single peaked ("U" shaped) over signal informativeness in both top-down and bottom-up budgeting. Over the bounded interval of available interim information, $a \in [0, 1]$, the principal prefers either*

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[10]We thank a seminar participant at UCLA for suggesting that we include a discussion of differing research costs.

the minimal $(a = 0)$ or maximal $(a = 1)$ availability; whereas the agent favors a positive level of availability, $a > 0$.

The agent's rents are initially increasing in signal informativeness, because when $\hat{\theta}_H$ diverges from $\hat{\theta}_L$, misreporting favorable information allows the agent to economize on his misreported costs. However, once the signal becomes sufficiently informative, the principal's asks the agent to exert very little effort following an unfavorable report of $\sigma = \sigma_L$, therefore the agent has very little expected effort upon which to economize, which renders his rents single peaked in the optimized bottom-down regime. Because rents transferred to the agent constitute a zero-sum payment, the principal's payoff is consequently "U" shaped over signal informativeness. More surprising is the fact that, under top-down budgeting, the principal's misreporting incentives are also "U" shaped, which renders her payoffs single-peaked under top-down budgeting as well. Analogous to the case of bottom-up budgeting, misreporting incentives are assuaged by transferring surplus to the agent, implying that his payoffs are "U" shaped over signal informativeness in the top-down budgeting as well. While each participant's payoffs are qualitatively identical across the two budgeting regimes, the choice of bottom-up versus top-town budgeting does impact the ex-ante expected utility of each player, because the total surplus generated varies across the two. Nonetheless, shocks which cause the agent to earn additional rents under bottom-up budgeting are likely to result in additional rents under top-down budgeting as well. Consequently, the principal and agent's utility maximizing level of interim information behaves similarly across each regime.

Proposition 5 also highlights the principal's tenuous trade-off between creating surplus and allocating surplus to the agent. When the overall signal informativeness is relatively small, any perturbation which leaves the signal more informative, such as additional interim information or the underlying economic uncertainty, will raise the researcher's payoff to misreporting. In both regimes, such a perturbation benefits the agent. Similarly, when the level of ex-ante uncertainty is sufficiently large, additional interim information lowers the researcher's payoff to misreporting, causing the agent's payoff to decrease. The principal's profits, however, are not always benefited (harmed) from perturbations which harm (benefit) the agent. To understand why, recall that the

principal and agent are engaged in a zero-sum game for any fixed informational setting, however as the informational setting varies, the level of surplus generated does as well.

Proposition 6. *In both budgeting modes, total surplus is eventually increasing in signal informativeness.*

Unlike the benchmark setting of Lemma 1, additional information can cause overall surplus to decrease in both the bottom-up and top-down budgeting regime. Total expected surplus falls whenever allocating the agent additional rents causes the principal's payoff to fall more than it would have had she instead destroyed both the marginal surplus afforded by the additional information *and* a portion of the ex-ante surplus available prior to the change. Such value destruction is rational whenever the marginal surplus generated induces the researcher to further misreport his or her private information. Surplus eventually increases in signal informativeness, once the researcher's payoff to misreporting begins falling with more informative signals at a rate greater than the surplus being generated, as is the case when signal informativeness is sufficiently large and the optimal contract is employed in either the top-down or bottom-up budgeting regime.

2.4.1   Empirical Discussion

In this section, we briefly provide proxies of firm attributes most commonly studied in the empirical budgeting literature.

Amongst all the firm attributes studied in conjunction with budgeting mode, budgetary slack stands out as the most common. Young [58] defines budgetary slack as "the amount by which a subordinate understates his productive capability when given a chance to select a work standard against which his performance will be evaluated", whereas Dunk [17] measures budgetary slack as the difficulty of attaining budgeted targets. Under bottom-up budgeting, the agent reports her interim information honestly, albeit he collects rents which are equivalent to what he could have obtained had he strategically misreported his findings. Therefore within a bottom-up context, it would seem that the agent's informational rents aline perfectly with Young's definition of budgetary slack. Defining rents as budgetary slack under top-down budgeting agrees with Dunk's

definition of slack. Accordingly, we use the agent's rents, or equivalently, his payoffs to measure budgetary slack.

[17] reports that the choice of participative budgeting alone is unable to explain the presence of slack. Instead, he argues that budgetary slack is largely linked to three firm attributes: the quantity of asymmetric information, the extent to which incentive contracts rely on budgets, and the choice of budgeting mode. When the first two attributes are relatively high, they find that slack may in fact decrease with bottom-up budgeting, though slack increases with participative budgeting when the first two attributes are relatively low. Proposition 5 found rents to be single peaked in the informativeness of the privately observed signal. Therefore if the signal is relatively informative (uninformative), our model predicts that principal ought to employ a top-down (bottom-up) budgeting paradigm. By revealed preference, employing a top-down budgeting when the signal is relatively informative or vice-versa, would leave the principal with fewer payoffs, in large part due to the excessive rents incurred. To the extent that signal informativeness measures asymmetric information, our findings concur with the first finding in Dunk [17].

In a related experimental study, Young [58] rejects the null hypothesis positively correlating private information with budgetary slack under participative budgeting. Comparing firms that employ participative budgeting with those that do not, Proposition 4 predicts that the former contends with greater information asymmetries than the latter, while Proposition 5 predicts single-peaked rents (budgetary slack) over signal informativeness in both regimes. Combined, our results suggest an increase in budgetary slack following the onset of participative budgeting insomuch as the latter was introduced in response to relatively small increases in interim informational availability, ex-ante environmental uncertainty, or both. In response to relatively large increases in signal informativeness, Proposition 5 predicts decreased budgetary slack.

Dunk [17] also finds that the slack-budgeting relationship is affected by the budget emphasis found in compensation contracts. Two budget emphasis measures are commonly used in the literature: incentive strength $(1 - \beta_i)$ and expected performance pay: $(1 - \beta_i)e_i\hat{\theta}_i$. Incentive strength, $(1-\beta_i)$, is somewhat misleading as an emphasis measure, because any gross compensation weight,

$(1 - \beta_i)$, will have little effect on the agent's wages should it be tied to a relatively small (in the sense of first-order stochastic dominance) performance measure. On the other hand, expected performance pay, $(1 - \beta_i)e_i\hat{\theta}_i$, captures the net budget emphasis, though the two measures behave differently as the informational setting varies.

Proposition 7. *Budget emphasis, as measured by expected performance pay:* $E[(1 - \beta_i)e_i\hat{\theta}_i]$, *is initially decreasing and later increasing over signal informativeness. When budget emphasis is measured as incentive strength,* $E[(1 - \beta_i)]$, *then it is always decreasing in signal informativeness.*

Of interest, the proposition shows that budget emphasis, as measured by expected performance pay, may vary non-monotonically under both budgeting regimes while budgeting emphasis, as measured by incentive strength is monotonic. The diverging behavior of these two proxies across alternative budgeting regimes highlight the importance of carefully substantiating empirical measures and controlling for the level of information asymmetry so as not overlook any legitimate statistical relations.[11]

While the extant empirical research has predominantly studied the choice of budgeting mode and consequential budgetary slack, a smaller branch of the literature has studied more tangible firm attributes such as incentive strength. [50] find that strong incentives are correlated with the use of participative budgeting. Addressing incentives within our construct is complicated: both the principal's budgeting choice and the agent's incentives are jointly optimized in response to signal informativeness. Similar to budget emphasis, we provide a relative proxy to measure incentive strength, the agent's performance-pay ratio:

$$\frac{E[(1 - \beta_i)e\theta_i]}{E[(1 - \beta_i)e_i - \alpha_i - \frac{e^2}{2T}\theta_i]}.$$

The performance-pay ratio measures the relative share of the agent's non-salary rents. While Proposition 4 predicts bottom-up budgeting for sufficient signal informativeness we must first re-

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[11]Statistical techniques, such as Cronbach's α are frequently used to validate firm attribute proxies consisting of multiple measures. While Cronbach's α captures set co-variation, it cannot cannot address the consistency of any *individual* measure under consideration.

late the performance-pay ratio with signal informativeness, before forming an empirical prediction.

Proposition 8. *The performance-pay ratio is eventually increasing in the level of signal informativeness.*

As measured by either expected performance pay or the performance-pay ratio, the agent's incentives may initially decline in response to additional information asymmetry, albeit, both measures will eventually increase. To the extent that firms using bottom-up budgeting content with significantly greater information asymmetries than those using top-down budgeting (in accordance with Proposition 4), then our model's predictions agree with those of [50]. because signal informativeness captures the ex-ante environmental uncertainty, our result also aligns with the those found in the Economics literature tying incentives to uncertainty and risk; e.g., Prendergast [40] and [41].

While we have parameterized the firm's preferred budgeting mode and the expected firm attribute levels over the availability of interim information, a and ex-ante environmental uncertainty, j, as [50] point out, very few empirical models consider the presence of participative budgeting antecedents. From the present perspective, the choice of budgeting mode and all firm attributes are driven by the level of information asymmetry, or equivalently, signal informativeness. Whereas the choice of budgeting mode varies at most once over the level of interim information, a, or ex-ante environmental uncertainty, j, we have found that most firm attributes vary non-monotonically in the same dimension. Therefore even within a sample consisting of data-point with very similar levels of information asymmetry, if one omits these levels from their study, then our can justify *any* statistical relation between the choice of budgeting mode and the firm attributes discussed.

2.5   Conclusion

Organizations rely on budgeting to facilitate the sharing of private information. Empirical researchers have documented various budgeting practices and correlated firm attributes over the past three decades; however the literature is fraught with inconsistencies. More recent research (Shields and Shields [50]) has argued that the mixed empirical results to date may have been caused by the

lack of a unifying, analytical model. In this paper, we provided a stylized organizational design model encompassing the two primary budgeting distinctions: top-down and bottom-up budgeting. Our framework captures settings where costly private information can be acquired by either the principal or agent, though asking both parties to collect the same signal would prove prohibitively expensive. Although only one party collects information, both parties stand to gain from the findings: the principal uses the information to minimize the agent's rents, and the agent uses the information to more efficiently select his level of effort. Upon acquiring information, the informed party communicates his or her results via the budgeting mechanism, though they have the option of strategic misreport as well. The principal relies on the agent's compensation contract to commit herself to truthful reporting under top-down budgeting, and analogously to keep the agent honest under bottom-up budgeting. When both parties are equally adept at gathering information, we found that the principal will favor bottom-up budgeting whenever the privately observed signal is sufficiently informative. Surprisingly, we found that the information preferences of both the agent and the principal remained qualitatively identical across the two budgeting regimes; i.e., factors influencing the agent's rents favorably under bottom-up budgeting are likely to have the same impact on his rents in a top-down paradigm. Whereas earlier research had warned of potential rent-seeking behavior accompanying the adoption of participative budgeting, the potential exists for the same behaviors to impact the top-down alternative.

Having parameterized the firm's choice of budgeting mode, the optimal incentive contracts and the resulting surplus, we then provided proxies for budgetary slack, budget emphasis, and incentive strength over the same parameter space. Our predictions all hinged on the implicit assumption that firms jointly select both their budgeting structure and incentives in response to the available interim information and ex-ante uncertainty. To the extent that firms choose their organizational structure with respect to the underlying asymmetric information, we found non-monotone relation between the choice of budgeting mode and budgetary slack, budget emphasis and incentives.

A natural extension to our model would allow both the principal and agent to receive private information. Therein, one could again study the efficacy of having the principal signal her infor-

mation versus screening the agent for his information, and the optimal budgeting sequence if both report their findings. To the extent that either the principal *or* agent be charged with reporting independent information, we suspect that our results will remain largely unchanged. However, if the principal and agent's private information overlap, then the resulting equilibrium will critically depend on the off-equilibrium beliefs. To model overlapping, non-contractible information reporting, one must first settle on a set of reasonable punishments if one party reports information which is inconsistent with that of the other. Unfortunately, the present model cannot support such additional structure without significantly simplifying the informational structure.

Another venue for future research could extent the present analysis to include unobservable, costly information acquisition. In this framework, the principal would either face a dual-moral hazard signalling problem, or a screening problem with two moral hazard tasks. Earlier work in the Economics literature has characterized a solution to this additional friction when only the agent can collect private information. Lewis and Sappington [34] find that "extreme reward structures" can satisfy both the moral-hazard and adverse-selection problems. While it remains unclear what type of contract would commit the principal to both engage in costly research and truthfully reporting her findings, we suspect that the additional agency costs under each budgeting regime may counteract one another, in which case our primary contribution tying information to the choice of budgeting mode, would remain unchanged.

Chapter 3

Strategic Intervention

At the heart of the standard principal-agent relationship lies the idea that a principal delegates a task to an agent. Such a strict definition of task assignment, however, is at odds with many observed principal-agent relationships wherein the principal reserves the right to intervene in the delegated task. For example, sales associates may turn to higher-level management when they feel that they are about to lose a large client while, in consulting firms, partners delegate tasks to managers under the assumption that delegation will continue only as long as the assigned task is succeeding. If a project becomes too costly, or other hurdles are encountered, the manager will return to the partner to ask for assistance. Similarly, within a supply chain, firms often use reserve clauses which surrender previously delegated rights back to the originating party. In each of these circumstances, the principal uses intervention to strategically increase the likelihood a project's success. The purpose of this study is to model how a principal optimally uses intervention in a setting with moral hazard and private information.

There are a number of common features in the above examples. First, both parties agree that the principal has the option of reclaiming the task from the agent. Secondly, there is information asymmetry in the sense that the agent, who is actively working on the task, receives a private signal regarding the usefulness of intervention and, finally, the project's overall success is a function of the agent's effort and any intervention activity. These features imply that intervention may change

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the parties contractual relationship in a number of ways. By allowing for intervention, the principal increases the size of the agent's strategy space because the agent now has two decisions to make: how much effort to put forth and when to ask for assistance. With intervention, the principal must now provide incentives for the agent to exert high-effort *and* to truthfully ask for help. Intervention also changes the association between the agent's actions and the final project outcome. Since the project outcome is the final arbiter of the contract's success, raising or lowering this linkage is akin to increasing or decreasing the signal to noise ratio in a traditional principal-agent model. Finally, the principal must also consider the cost of her own (presumably) costly effort. These factors generate new tensions within the standard principal-agent relationship which the principal must contend with in determining the agent's contract.

What we are most interested in, however, is when and why the principal uses intervention as an incentive mechanism. By an incentive mechanism, we mean a contract which uses the intervention option to change the agent's behavior in the primary moral hazard problem. For example, when intervention yields little benefit, it may prove profitable to forgo the intervention option and, in doing so, reduce the demands placed on the agent to report. The principal may also find it profitable to engage in excessive intervention, provided that the intervention activity does not destroy information about the agent's effort choice.

Our main finding shows that intervention is used as an incentive mechanism if and only if communication between the principal and agent is restricted. If both parties can fully communicate all information about the state of the game when the intervention decision is made, then the agent, who ultimately decides if the principal is called upon or not, requires additional incentives to do so optimally. The least costly method of providing these incentives is to make the agent indifferent between intervention alternatives. Once the agent is made indifferent between the two states (intervention or not), the principal can engage in the economically efficient level of intervention in which intervention is no longer used to provide incentives.

To give a more concrete example, consider the case of a sales associate who can sequester a more senior employee should the former receive private information that a customer may renege

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on a sale. If the sales associate decides to not ask for help, then their expected wage is the product of their commission and the probability of a sale going through despite the negative signal (they get "lucky"). If the associate decides to ask for intervention then the sale may no longer reflect the associate's effort, in which case he is paid a flat fee. To motivate the associate to sequester help efficiently, the principal must equate the total compensation across alternatives such that the agent no longer favors one over the other.

If, on the other hand, there are some restrictions to how the principal and agent communicate then these restrictions may lead to inefficient intervention decisions. As an extension we consider the case where the agent's effort choice is linked to the efficacy of the principal's intervention effort, though the agent can only communicate the current likelihood of the project's success. In this setting we find that the principal may choose to use intervention as an incentive mechanism, thus eschewing the economically efficient level of intervention and engaging in either too much or too little intervention effort.

In other words, if the agent can covey the complete state of the game to the principal, then the principal can isolate the provision of incentives from her intervention activities. If, on the other hand, there is some schism between the principal and agent then the optimal contract may use intervention to strategically provide the agent with adequate incentives. Returning to the case of the sales associate, if the efficacy of the principal's intervention effort is a function of the sales associate's effort choice and private information, and there limitations to the communication between the principal and the agent, then the principal will optimally base the agent's wages on a successful sale, even if the principal intervenes. If there is no such linkage then there is no useful contracting information in the state of the project after the principal intervenes, and thus the agent receives a flat wage contingent on intervention.

There are a number of studies which concern themselves with how a principal can intervene in a project. Our model is most closely related to Levitt and Snyder [33] which considers a setting where the agent exerts costly effort and later receives a signal regarding the likelihood of failure. Because they assume that the principal can abandon the project, the agents interim information is

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valuable. The major difference between our study and their study is that they allow the principal to costlessly distort the agent's report. Such distortions limit the communication channel between the two parties causing the principal to optimally engage in inefficient levels of intervention[1] then warranted in the absence of asymmetric information. As in our model, when the principal engages in inefficient levels of intervention the contract becomes susceptible to commitment issues, which we describe in detail later.

In a similar vein, Arya and Glover [5] consider the case where the principal receives interim information, rather than the agent. As in our model, the signal is discrete, though their principal is allowed to optimally coarsen the information system. They find that the principal may prefer a coarse information system when a finer system is costlessly available, though the principal faces a unique commitment issue because, while she can commit to her own strategy function, the input to her strategy function is private information.

In this study we are concerned with a more fundamental research question: how do intervention activities change the principal-agent relationship. In each of the papers above, the intervention activity is co-mingled with another agency tension. In Levitt and Snyder [33] the principal chooses to destroy information in two places: by freely distorting the signal that the agent reports and by choosing to cancel projects, which destroys all information surrounding the agent's effort choice. In Arya and Glover [5], the principal optimizes over the information destruction inherent in task abandonment in addition to the information system. The purpose of our model is to isolate the primary tensions associated with intervention: what happens when an agent undertakes a hidden action, and in doing so becomes privy to private information determining the efficiency of potentially information destroying intervention activities. Our main finding sheds sheds new light on these previous studies by demonstrating that the inefficient intervention decisions obtained earlier are independent of the information losses incurred with intervention.

Our study also contributes to the literature on strategic delegation. Beginning with Vickers

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[1] For simplicity when comparing this model to other models, we use the phrases "intervention" or "intervention activities" to cover the entire spectrum of activities that the principal can engage in after the agent has begun the project, including when the principal has the option of canceling the project.

[56], Fershtman and Judd [21] and Sklivas [52], this literature studies how delegating decision making can have strategic and competitive ramifications for a firm. This stream of literature, while dealing with delegation issues similar to this study, is more focused on how delegation can overcome commitment issues within a competitive framework, rather than the internal effects of the delegation decision. As in our study, the authors of these papers are concerned with the effect of allowing agent's to make decisions which influence the principals ability to profit. Sengul et al. [48] provides an overview and summary of this literature.

While our model does not directly compare across possible firm organization structures, our results also speak to control right allocation issues. A number of papers concern themselves with how control right should be allocated, including Aghion and Tirole [3], which studies the incentives faced by managers under different authority structures and Baker et al. [9] who study a repeated game where the delegation decision is not contractible. Our paper speaks to these issues by showing that intervention activities only have an effect on control right issues when communication between the principal and agent are limited.

Using a framework similar to our model, Vaysman [55], concerns itself with how an abandonment option changes the pay that a manager receives. The author of this paper is particularly concerned with the structure of the wages that are paid to the agent in the event of project cancellation, as the focus of the study is on how "golden-parachute" wage systems may arise endogenously. As in our study, they find that, contingent on an intervention activity, the agent is paid a wage above his reservation level. Another paper, by Krahmer [31], considers, in an incomplete contracting model where a principal and agent have different preferences, how conditional delegation may outperform unconditional delegation schemes by increasing the incentives for information acquisition.

This chapter proceeds as follows. The next section describes the model and presents a benchmark case. Section 3.2 describes the second-best model and details the main result, while Section 3.3 provides an extension where the signal is no longer a sufficient statistic for the efficacy of the principal's intervention choice. Section 3.4 concludes.

3.1 Model

We model the interaction between a risk-neutral principal (she) and a risk-neutral agent (he) who contract to complete a project. The project is either a success, which generates revenue G or a failure which generates revenue B, where $G > B > 0$. The success or failure of this project is influenced by the agent's effort choice and, if the principal chooses, the principal's intervention effort. After agreeing to a contract, the agent can exert either high- (e_H) or low- (e_L) level effort, incurring private costs c_H and c_L, respectively, where $c_H > c_L = 0$. The agent is then presented a binary signal of the project's quality: σ_i, where $i \in \{H, L\}$. This signal contains all information relevant to evaluating the likelihood of the project's success. To simplify matters we refer to the signal as either "good" or "bad" and the project's final status as either "success" or "failure." After receiving the signal σ_i, the probability of the project being successful is p_i, where $p_H > p_L$. We parameterize the relationship between the signal and the agent's effort in the following manner:

$$Pr(\sigma_H|e_i) = \alpha_i \qquad\qquad i \in \{H, L\}$$

$$Pr(\sigma_L|e_i) = (1 - \alpha_i) \qquad\qquad i \in \{H, L\},$$

where $\alpha_H > \alpha_L$.[2] Higher values of α_i thus increase the relationship between the agent's effort choice and the resulting signal while the variables p_H and p_L define how the signal translates to the likelihood of success.

As an example, reconsider the case of a sales associate trying to land a sale. While working with the client, the agent's effort translates toward the project in two manners. First, high-effort contributes toward having a client respond positively, which is private information of the agent. Secondly, the agent's effort contributes to closing the sale. When the agent exerts high-effort, the likelihood of generating a high signal is equal to α_H, while the probability of the project's success

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[2]Allowing $\alpha_L > \alpha_H$ simply redefines what the "good" and "bad" states are without qualitatively changing the analysis.

is equal to:

$$Pr(G|e_H) = \alpha_H p_H + (1 - \alpha_H)p_L.$$

In other words, while we assume that the signal contains all relevant information in evaluating the project (e.g. after the signal has arrived, knowing the agent's effort has no effect on beliefs surrounding the final output), high-effort is ex-ante valuable, in that it increases the likelihood of the project's success.

After the agent has exerted effort and received a signal, but before the final output is realized, the principal can choose to intervene in the project. By intervening, the principal exerts effort which is costly to her and parameterized by cost c_P. Intervention changes the likelihood of success from p_i to p_P, which we assume is more likely to lead to success than a low-signal, but less likely than following the receipt of a high signal: $p_H > p_P > p_L$.[3] We assume that the principal's effort is both observable and contactable. These stylized facts of intervention are consistent with the sales associate example who can bring in higher-level managers to assure sales, or the law and consulting firm example where managers can bring in a partner to assuage engagement problems.

The time line is specified in Figure 3.1. We assume that the principal has all the bargaining power and therefore proposes a contract at $t = 0$, though we assume that the agent is free to leave the firm at any time. After accepting the contract, the agent selects effort at $t = 1$ and receives a signal of the project's success at $t = 2$. In the third period, $t = 3$, the agent may report the signal to the principal. While we assume that the agent's signal is private information, the principal can incentivize the agent to report his signal; allowing the principal to strategically choose to intervene. When the principal chooses intervention she incurs costly effort at $t = 4$, resulting in output as outlined earlier. If the principal chooses to not intervene, then the agent need not report the signal

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[3]This inequality implies that, contingent upon receiving a good signal, intervention entails two costs to the principal. Not only does the principal pay a direct cost, in the form of c_P, but intervention also lowers the project's expected value (from $p_H G + (1 - p_H)B$ to $p_P G + (1 - p_P)B$). Allowing p_P to be become greater than p_H does not change our analysis as long as we assume that p_P is not so large that the principal wishes to intervene when the good signal is realized. Rather than add another set of inequalities which would complicate this model and leave the tensions studied unchanged, we restrict our parameter space in the simplest manner possible.

Intervention

Agent Reports σ_i → Output based on principal's effort (p_p)

$t = 0$ → 1 → 2 → 3 → 4 → 5

Principal proposes contract | Agent selects hidden effort e_i | Signal σ_i acquired by Agent | No Report → Output based on signal (p_i) | Agent paid game ends
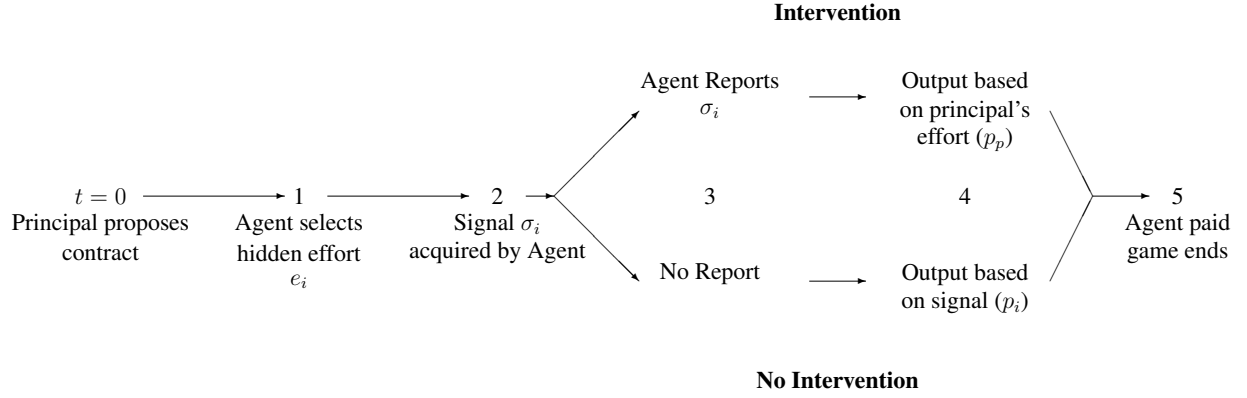
No Intervention

Figure 3.1: The upper path contains events specific to the case where the principal intervenes while the lower path contains events specific to the non-intervention case.

at $t = 3$ and the output generated in the fourth period is solely a function of the agent's effort. At the conclusion of the game, $t = 5$, all accounts are settled between the principal and the agent according to the specified contract.

While our assumption that $p_H > p_P > p_L$ ensures that the principal will never wish to intervene when the high-signal is realized, the personal costs associated with intervention imply that intervention activities may not be efficient following the realization of the low signal. Lemma 2 below summarizes the economically efficient regions where the principal would choose to intervene as well as choose the agent to exert high-effort, absent agency costs.[4]

Lemma 2. *When σ_i and the agent's effort choice are observable and contractible, the principal will only choose to intervene when:*

$$c_P \leq (p_P - p_L)(G - B). \tag{λ^{EE}}$$

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[4]Proofs of all lemmas, propositions and corollaries can be found in the appendix.

When the principal favors intervention, she optimally motivates high-effort when:

$$c_H \leq (\alpha_H - \alpha_L)(c_P + (G - B)(p_H - p_P)),$$

without intervention, she optimally motivates high-effort when:

$$c_H \leq (\alpha_H - \alpha_L)(p_H - p_L)(G - B).$$

Lemma 2 highlights the trade-off the principal faces when there is no private information between the two parties. Without agency costs, the principal chooses to intervene or elicit high-effort only when the marginal benefit outweighs the marginal cost of intervention. In particular, the prinicpal's direct marginal cost of intervention is given by c_p, while her marginal payoff is given by what she receives when intervening $(p_P G + (1 - p_P)B)$ net of her payoff without intervention $(p_L G + (1 - p_L)B)$. Simplification of this difference yields the expression in the lemma above, which we define as λ^{EE} for the economically efficient intervention cost cut-off. Similarly, when deciding between having the agent target high- or low- effort, the principal considers the marginal cost of high-effort, c_H, against the marginal benefit of high-effort. A similar analysis leads to the third inequality in Lemma 2.

While Lemma 2 characterizes the economically efficient outcome, we also consider a benchmark case which will allow us to isolate the information effects of the signal. To do so we consider the case where the signal received by the agent is contractible, but his effort choice is still private. Under these assumptions, the principal is free of the hidden information problem, but the moral hazard problem persists. When the signal is public, the principal will use the signal, rather than the final output to benchmark the agent's performance since the final output contains no additional information beyond what is contained in the signal. Since the signal is both observable and contractible the principal need not incentivize the agent to reveal the private information contained in the signal; the agent therefore only collects rents on the basis of his hidden effort and limited

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liability. In this benchmark setting the principal solves:[5]

Program P_{BM}^{HN}

$$\max_{w_G, w_B} \quad G(p_H \alpha_H + p_L(1 - \alpha_H)) + B((1 - p_H)\alpha_H + (1 - p_L)(1 - \alpha_H))$$

$$- \alpha_H w_G - (1 - \alpha_H)w_B$$

$$s.t. \quad \alpha_H w_G + (1 - \alpha_H)w_B - c_H \geq \alpha_L w_G + (1 - \alpha_L)w_B \qquad \text{(IC)}$$

$$\alpha_H w_G + (1 - \alpha_H)w_B - c_H \geq 0 \qquad \text{(IR)}$$

$$w_i \geq 0 \quad i \in \{G, B\}. \qquad \text{(LL)}$$

While the above program specifies the principal's program when she does not intervene and elicits high-effort, the program below considers the case where the principal targets high-effort and chooses to intervene:

Program P_{BM}^{HI}

$$\max_{w_G, w_I} \quad G(p_H \alpha_H + p_P(1 - \alpha_H)) + B((1 - p_H)\alpha_H + (1 - p_P)(1 - \alpha_H))$$

$$- \alpha_H w_G - (1 - \alpha_H)w_I - (1 - \alpha_H)c_P$$

$$s.t. \quad \alpha_H w_G + (1 - \alpha_H)w_I - c_H \geq \alpha_L w_G + (1 - \alpha_L)w_I \qquad \text{(IC)}$$

$$\alpha_H w_G + (1 - \alpha_H)w_I - c_H \geq 0 \qquad \text{(IR)}$$

$$w_i \geq 0 \quad i \in \{G, I\}. \qquad \text{(LL)}$$

In both programs, the principal is maximizing her profits by varying the agent's signal contingent wages. The wages are labeled, w_G, w_B and w_I which correspond to the project being a success, a failure, and having the principal intervene, respectively. Each of the above programs share three constraints. The first constraint, the incentive compatibility constraint, (IC), guaran-

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[5]For the duration of this paper we define the programs as P_X^Y where $X \in \{BM, SB, L\}$ and $Y \in \{HN, HI, LN, LI\}$. X refers to informational setting, BM is benchmark, SB is second best and L refers to the second-best linked intervention extension found in the final section of this chapter. The variables in Y refer to whether the principal targets high, H, or low, L, effort and whether the principal chooses to intervene, I, or not, N.

tees that the agent exert high-effort, while the individual rationality constraint, (IR), ensures that the agent will choose to enter the contract at $t = 0$ since the principal must provide the agent, in expectation, their reservation payoff, which we have normalized to zero. The final constraint, the limited liability constraint, (LL), guarantees the agent a reservation payoff in each state. The limited liability constraint ensures that the agent will not leave the firm between $t = 0$ and $t = 5$ in all states of the world.[6] Proposition 9 below characterizes the solution to the benchmark setting.

Proposition 9. *When the signal is contractible, the principal will continue to use the efficient cost cut-off to choose between intervention and non-intervention:*

$$c_P \leq (p_P - p_L)(G - B). \qquad (\lambda^{FB})$$

The optimal contract, when the principal targets high-effort is:

$$w_G = \left(\frac{c_H}{\alpha_H - \alpha_L} \right)$$

$$w_I = 0,$$

while the principal simply sets $w_G = w_B = 0$ when she targets low-effort. The principal will motivate high-effort when:

$$c_H \leq \frac{(\alpha_H - \alpha_L)^2}{\alpha_H}(c_P + (G - B)(p_H - p_P)),$$

or

$$c_H \leq \frac{(\alpha_H - \alpha_L)^2}{\alpha_H}(G - B)(p_H - p_L),$$

depending on if the principal chooses to intervene, or not, respectively.

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[6]We will refrain from writing out the program for when the principal targets low-effort, Programs P_{BM}^{LI} and P_{BM}^{LN}, since the solution, pay the agent their reservation wage in all scenarios, will solve any such program.

Because the signal is contractible, the principal can costlessly extract the efficient level of intervention as outlined in Lemma 2 ($\lambda^{FB} = \lambda^{EE}$). To see why, note that in the benchmark setting the agent need only choose how much effort to exert, once the agent has chosen his effort level the principal controls the entire project, therefore she can exert the efficient level of intervention without affecting the underlying moral hazard problem. While the signal is contractible in this benchmark case, the agent's effort choice still provides him the ability to command rents whenever the principal targets high-effort. In the next section we consider non-contractible signals which afford the agent additional rents.

3.2   Hidden Information and Effort

In the second-best regime, the signal is privately observed by the agent and is therefore non-contractible. However, the principal provides the agent with incentives to report his signal and, regardless of the veracity of the signal, reporting is itself contractible. With hidden effort and private information the principal solves the following program when she commits not to intervene and targets high-effort:

Program P_{SB}^{HN}

$$\max_{w_G, w_B} \quad (G - w_G)(\alpha_H p_H + (1 - \alpha_H)p_L) + (B - w_B)(\alpha_H(1 - p_H) + (1 - \alpha_H)(1 - p_L))$$

$$s.t. \quad w_G(\alpha_H p_H + (1 - \alpha_H)p_L) + w_B(\alpha_H(1 - p_H) + (1 - \alpha_H)(1 - p_L)) - c_H$$

$$\geq w_G(\alpha_L p_H + (1 - \alpha_L)p_L) + w_B(\alpha_L(1 - p_H) + (1 - \alpha_L)(1 - p_L)) \quad \text{(ICP)}$$

$$w_G(\alpha_H p_H + (1 - \alpha_H)p_L) + w_B(\alpha_H(1 - p_H) + (1 - \alpha_H)(1 - p_L))$$

$$\geq c_H \quad \text{(IR)}$$

$$w_i \geq 0 \quad i \in \{G, B\}. \quad \text{(LL)}$$

The program, when the principal targets high-effort and chooses to intervene becomes:

Program P_{SB}^{HI}

$$\max_{w_G, w_I, w_B} \quad \alpha_H(p_H(G - w_G) + (1 - p_H)(B - w_B))$$

$$+ (1 - \alpha_H)(p_P G + (1 - p_P)B - c_P - w_I)$$

$$s.t. \quad \alpha_H p_H w_G + \alpha_H(1 - p_H)w_B + (1 - \alpha_H)w_I - c_H$$

$$\geq \alpha_L p_H w_G + \alpha_L(1 - p_H)w_B + (1 - \alpha_L)w_I \qquad \text{(ICP)}$$

$$p_H w_G + (1 - p_H)w_B \geq w_I \qquad \text{(ICR}_H)$$

$$p_L w_G + (1 - p_L)w_B \leq w_I \qquad \text{(ICR}_L)$$

$$\alpha_H p_H w_G + \alpha_H(1 - p_H)w_B + (1 - \alpha_H)w_I \geq c_H \qquad \text{(IR)}$$

$$w_i \geq 0 \quad i \in \{G, I, B\}. \qquad \text{(LL)}$$

As in the benchmark regime, programs P_{SB}^{HN} and P_{SB}^{HI} feature an (IR) constraint that requires that the principal provide the agent, in expectation, his reservation wage at $t = 0$. The (ICP) constraint provides incentives for the agent to exert high-effort at the time of the effort choice, $t = 1$,[7] while the (LL) constraints limits the minimum wage that can be paid in any state. The difference between the two programs above is that the principal provides incentives for the agent to truthfully communicate his signal in the second model. This requirement appears in the secondary incentive compatibility constraints, (ICR$_H$) and (ICR$_L$), which prevent the agent from misreporting a good signal as bad and a bad signal as low, respectively. The following proposition characterizes the optimal contract and constitutes our main result.

Proposition 10. *The optimal second-best contract when the principal targets high-effort and does*

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[7]When referring to the agent's incentive compatibility constraints, we use the connotation "R" for those referring to the reporting game and "P" for primary, those that refer to the effort choice.

not intervene is:

$$w_G = \frac{c_H}{(p_H - p_L)(\alpha_H - \alpha_L)}$$

$$w_B = 0.$$

When the principal targets high-effort and chooses to intervene, the optimal contract becomes:

$$w_B = 0$$

$$w_I = \frac{p_L c_H}{(\alpha_H - \alpha_L)(p_H - p_L)}$$

$$w_G = \frac{c_H}{(\alpha_H - \alpha_L)(p_H - p_L)}.$$

Independently of the intervention choice, when the principal targets low-effort, she pays the agent his reservation wage in all states. The principal will choose high-effort when intervening if and only if:

$$c_H \leq \frac{(p_H - p_L)(\alpha_H - \alpha_L)^2 (c_P + (G - B)(p_H - p_P))}{\alpha_H(p_H - p_L) + p_L}$$

while the cut-off level becomes

$$c_H \leq \frac{(G - B)(p_H - p_L)^2 (\alpha_H - \alpha_L)^2}{\alpha_H(p_H - p_L) + p_L},$$

when not intervening. The optimal contract does not use intervention to influence the underlying moral hazard problem, instead the principal continues to use the economically efficient cost cut-off, λ^{EE}.

The wage structure for the non-intervention game is straightforward – the principal pays the agent a wage if and only if the project is successful. To provide proper incentives to the agent to exert high-effort, the agent's marginal payoff must overcome his marginal cost of effort. Since the limited liability constraint prevents the principal from paying negative wages, the agent collects

rents, despite not holding any reporting duties.

When the principal commits to intervention, she not only contends with the moral hazard problem, but also with an adverse selection problem because the agent must be compensated to truthfully reveal the signal. If the principal employed the non-intervention contract ($w_I = 0$) in the intervention setting then the agent would never reveal their signal because there is always some positive probability that the agent gets lucky and the project succeeds in spite of the unfavorable signal. The principal therefore provides the agent with a positive payment when she intervenes following a bad signal.
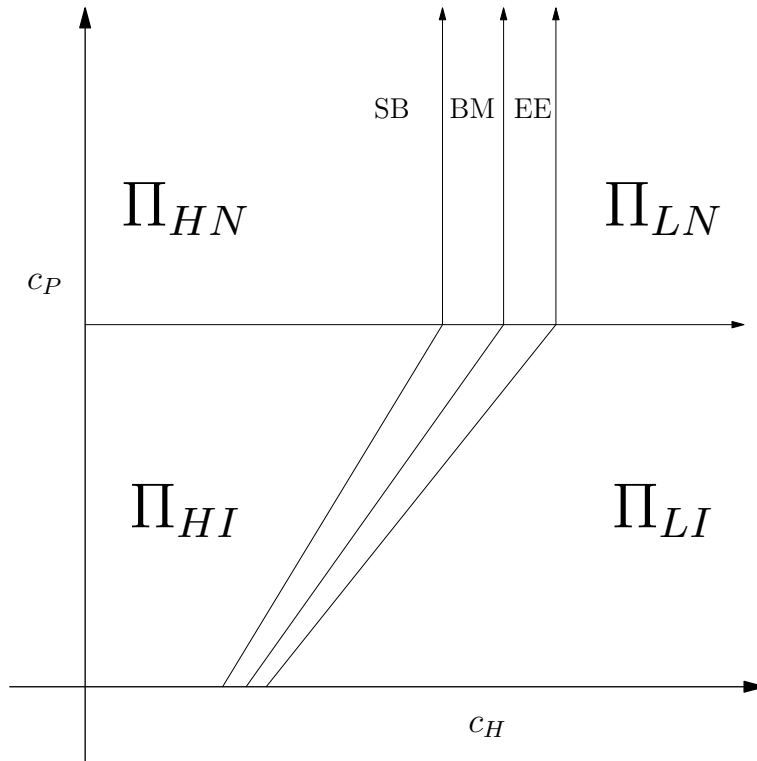
Figure 3.2: The above figure shows the principal's preferred intervention and effort targets as a function of the principal's intervention cost, c_P, and the agent's cost of effort, c_H. The subscript "H" and "L" imply that the principal prefers the agent to exert high- or low- level effort, respectively, while "I" and "N" mark when the principal prefers to intervene or not. Also shown are how the regions change while moving between the economically efficient ("EE"), benchmark ("BM") and second-best models.

Proposition 10 also describes the regions where the principal optimally intervenes, which we illustrate in Figure 3.2. Figure 3.2 highlights a number of intuitive properties. For example, as

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the agent's personal cost of effort, c_H, increases, the principal becomes less likely to induce high-effort. As the cost of intervention decreases, the principal moves begins to favor contracts involving intervention. Finally, Figure 3.2 shows that when the principal chooses to intervene she increasingly favors high-effort as her intervention costs increase. In other words, the principal and agent's efforts are substitutes. The figure also suggests that the principal continues to exert economically efficient intervention in the second-best setting, which the proposition confirms.

Although intervention exacerbates the agency problems faced by the principal, the optimal contract never involves inefficient intervention. To see why, note that the agents report fully encapsulates the information within the game and thus the contract, which determine the agent's rents, pays the agent a uniform bonus if the project is successful regardless of her intervention choice. Within the intervention game, the agent controls the intervention decision, therefore he must be provided incentives to choose the intervention efficiently. In the non-intervention game the expected payment to the agent can be broken down into two parts: the payment received when the agent observes a good signal and the project succeeds and the payment received when the agent "gets lucky"; i.e. the project is successful following the receipt of a bad signal. The intervention game, however, only pays the agent w_G when the agent receives a good signal and the project succeeds. By truthfully revealing the signal the agent loses the opportunity to "get lucky" in this manner. To ensure that the agent truthfully reports, the principal must therefore compensate the agent when the agent asks for assistance, which is why $w_I > 0$.

This can be seen by studying the binding (IC) constraint in each of the scenarios. First consider the case without intervention, and let w_B bet set to zero. The binding (IC) constraint becomes:

$$p_H w_G - p_L w_G \geq \frac{c_H}{\alpha_H - \alpha_L} \tag{3.1}$$

while the (IC) constraint under intervention becomes:

$$p_H w_G - p_L w_I \geq \frac{c_H}{\alpha_H - \alpha_L}. \tag{3.2}$$

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Comparing the two equations, the intervention payment (w_I) must be equal to the option of playing the non-intervention game, which is just the payment associated with the lucky scenario. While the two scenarios represent two functionally different payment schemes, the value of that payment to the agent must be equivelent in expectation since the agent always has the option of playing the non-intervention game. The agent thus receives the same expected rents under each and therefore is indifferent between the regime choices. By being made indifferent between the intervention choices the principal can costlessly choose the regime that maximizes her profits, which is the economically efficient case.

The critical assumption of the above analysis is that the signal fully determines the information within the system. In other models, notably Levitt and Snyder [33], the relationship between the principal and the agent is co-mingled with limitations on information transmission. In their model the agent observes a continuous signal of projects quality. The principal could conceivably learn the true value of the projects quality, but rather than engage in that exceedingly costly project, which would provide for first-best intervention levels, the principal instead chooses to reduce the message space by only incentivizing the agent to report a thumbs-up or thumbs-down with respect to project quality.[8] As shown in the preceding discussion, the reason that the principal in their model engages in inefficient levels of intervention is not due to the intervention activity itself; but rather to the distortions introduced by the principal choosing to reduce the message space. In the following section we demonstrate how limiting communication between the principal and the agent changes the ability of the principal to engage in the economically efficient level of intervention.

3.3   Linked Intervention

In the previous analysis we considered the case where the agent's effort choice had no bearing on the effectiveness of the principal's actions and perfect communication was allowed. In this section

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[8]While our model assumes that the signal is fixed, their main result, that the principal will engage in inefficient levels of project cancellation, or too much intervention in our parlance, is undone when they consider commitment issues associated with having the principal tell the agent not to fully disclose, when full disclosure would result in greater profits.

we relax those assumptions so that the agent's action directly determines the productivity of intervention and limited communication, in that the agent is limited to reporting the signal they receive, σ_i.[9] In doing so, we confirm the intuition in the previous section linking inefficient intervention to agency problems not associated with the underlying moral hazard and adverse selection problems. To study imperfect communication, we first expand the model so that the agent can take advantage of any limited communication. In particular, we now assume that the likelihood that intervention leads to a successful project, formerly defined as p_P, is now parameterized as:

$$i_H = Pr(\text{Successful Intervention}|e_H) > Pr(\text{Successful Intervention}|e_L) = i_L.$$

We also assume that the $p_H > i_H > p_L$, so that there are cost levels at which the principal wishes to partake in intervention and non-intervention. If we allowed $p_L > i_H$ then the principal would never resort to intervention and, similarly, if $i_H > p_H$ the principal may never wish to have the agent engage in any effort. The second change that we introduce in this extension is that we limit communication such that the agent can only report his private signal, σ_i. The actual communication between the principal and the agent is thus just the signal that the agent receives – they are unable to communicate their own effort choice.[10]

As an example, reconsider the case of a sales associate who has the option of bringing in a senior-level associate when they believe that a sale will fall through. The sales associate may have exerted high-effort by keeping in contact with the client and promptly answering questions about the product. Nearing the time of the sale, the agent knows the likelihood of closing the sale, assuming that the principal does not intervene, and can bring in a more senior associate in the case that the sale may fall through. The associate, in this model, is only able to communicate the

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[9]For the rest of this document we will refer to "path dependence" and "linked intervention" to mean the same thing.

[10]There are innumerable communication limiting methods which could be modeled in this situation, rather that collude our analysis by trying to be complete or modeling the exact mechanism by which communication is limited, we choose to focus on the key issue: how limited communication changes the intervention strategy of the principal. We freely acknowledge that other communication limiting mechanisms would change this analysis, but no matter what mechanism is chosen, there are only three things that can happen: under-intervention, over-intervention or economically efficient intervention. Our chosen mechanism breaks out these effects in a simple manner so that underlying tension can be demonstrated.

information that they receive, σ_i.[11]

When the principal target's high-effort and commits to intervening, she solves:

Program P_L^{HI}

$$\max_{w_G, w_B, w_G^I, w_B^I} \alpha_H p_H (G - w_G) + \alpha_H (1 - p_H)(B - w_B)$$

$$+ (1 - \alpha_H)(i_L(G - w_G^I) + (1 - i_L)(B - w_B^I) - c_P)$$

$$s.t. \quad \alpha_H p_H w_G + \alpha_H (1 - p_H) w_B$$

$$+ (1 - \alpha_H)(i_L w_G^I + (1 - i_L) w_B^I) \geq c_H \tag{IR}$$

$$w_G p_H + (1 - p_H) w_B \geq i_H w_G^I + (1 - i_H) w_B^I \tag{ICR$_H$}$$

$$i_H w_G^I + (1 - i_H) w_B^I \geq w_G p_L + (1 - p_L) w_B \tag{ICR$_L$}$$

$$\alpha_H(p_H w_G + (1 - p_H) w_B) + (1 - \alpha_H)(i_H w_G^I + (1 - i_H) w_B^I) - c_H$$

$$\geq \alpha_L(p_H w_G + (1 - p_H) w_B) + (1 - \alpha_L)(p_L w_G + (1 - p_L) w_B) \tag{ICP$_L$}$$

$$\alpha_H(p_H w_G + (1 - p_H) w_B) + (1 - \alpha_H)(i_H w_G^I + (1 - i_H) w_B^I) - c_H$$

$$\geq \alpha_L(p_H w_G + (1 - p_H) w_B) + (1 - \alpha_L)(i_L w_G^I + (1 - i_L) w_B^I) \tag{ICP$_{TT}$}$$

$$w_i^I \geq 0 \quad i \in \{G, B\} \tag{LL}$$

$$w_i \geq 0 \quad i \in \{G, B\} \tag{LL}$$

The principal's program maintains the same fundamental constraints as in previous program; there is still limited liability, the agent must still be induced to truthfully report their signal and the agent's expected pay must still exceed his outside option. However, the form of the incentive compatibility constraints is now complicated due to path dependence.

When the signal fully encapsulates all the information in the problem, as in the prior section, the constraints ((ICR$_H$) and (ICR$_L$)) which guarantee that the agent will not misrepresent his sig-

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[11] If the principal is able to create a signal fully encapsulating the entire history of the agent's actions, then the wedge between the information sets of the two parties would disappear, this tension would evaporate and the problem would reduce to that without path dependence. It is easily shown that if the principal's intervention efficacy varies, but only as a function of the signal, then the results of the previous section hold.

nal conditional on high-effort also ensure that the agent will not misrepresent if he shirks. In other words, the principal is able to avoid having the agent misrepresent in the second period with a single set of incentive compatibility constraints that apply independently of the agent's effort choice. On the other hand, when the agent's action is linked to the efficacy of the principal's effort, the information in the signal is no longer a sufficient statistic for the state of the game. As such, guaranteeing that the agent does not misrepresent when he has engaged in high-effort no longer implies that the agent will tell the truth when he has shirked. Accordingly, the principal must now contend with four possible states defined by the intersections of the agent's effort and signaling strategies. If the agent engages in high-effort, the (ICR_H) and (ICR_L) incentivize the agent to truthfully report his signal. The (ICP_{TT}) and (ICP_L)[12] constraints contend with the cases where the agent shirks and truthfully reports his signal and where the agent shirks and misrepresents. Importantly, we can ignore the constraints associated with the agent misrepresenting after receiving a high signal; the optimal payment schemes costlessly preclude this behavior.[13] For simplicity, we therefore consider the statements "misreporting" and "misreporting a low signal" or "misrepresenting" and "misrepresenting a low signal" to be equivalent, unless otherwise specified.

The program above now also contains four wages: w_G^I, w_B^I, w_G and w_B since the principal may wish to pay different amounts to the agent dependent on whether the project is a success or failure after intervening. Proposition 11 below summarizes the optimal contract.

Proposition 11. *When the principal's intervention productivity is linked to the agent's private signal, the optimal contract takes the following form when the principal targets high-effort and*

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[12]We use subscript TT for truth-telling and L for lying.

[13]The proof of Proposition 11 cover this more in-depth.

intervenes:[14]

$$w_B = w_B^I = 0$$

$$w_G = \begin{cases} \frac{c_H}{(1-\alpha_L)(p_H-p_L)} & \frac{i_H}{i_L} < \frac{p_H}{p_L} \\[12pt] \frac{c_H i_L}{p_L(i_H(1-\alpha_H)+i_L(\alpha_L-1))+i_L p_H(\alpha_H-\alpha_L)} & \frac{i_H}{i_L} \geq \frac{p_H}{p_L} \; and \; \frac{i_H}{i_L} < \frac{\frac{\alpha_H}{(1-\alpha_H)}}{\frac{\alpha_L}{(1-\alpha_L)}} \\[12pt] \frac{c_H i_H}{p_H(1-\alpha_L)(i_H-i_L)} & \frac{i_H}{i_L} \geq \frac{p_H}{p_L} \; and \; \frac{i_H}{i_L} \geq \frac{\frac{\alpha_H}{(1-\alpha_H)}}{\frac{\alpha_L}{(1-\alpha_L)}} \end{cases}$$

$$w_G^I = \begin{cases} \frac{c_H p_H}{i_H(1-\alpha_L)(p_H-p_L)} & \frac{i_H}{i_L} < \frac{p_H}{p_L} \\[12pt] \frac{c_H p_L}{p_L(i_H(1-\alpha_H)+i_L(\alpha_L-1))+i_L p_H(\alpha_H-\alpha_L)} & \frac{i_H}{i_L} \geq \frac{p_H}{p_L} \; and \; \frac{i_H}{i_L} < \frac{\frac{\alpha_H}{(1-\alpha_H)}}{\frac{\alpha_L}{(1-\alpha_L)}} \\[12pt] \frac{c_H}{(1-\alpha_L)(i_H-i_L)} & \frac{i_H}{i_L} \geq \frac{p_H}{p_L} \; and \; \frac{i_H}{i_L} \geq \frac{\frac{\alpha_H}{(1-\alpha_H)}}{\frac{\alpha_L}{(1-\alpha_L)}} \end{cases}$$

If the principal targets any other effort and intervention strategy, the contract retains the same form as in Proposition 10, with the proper substitution of i_H and i_L for p_P.

Note that in a number of instances the contract with linked and without linked intervention is the same. For example, anytime the principal targets low-effort, she pays the agent his reservation wage in all states, independent of her intervention choice. The agent therefore has no incentive to misreport and will comply with the principal's targeted actions. Similarly, when the principal targets high-effort, but decides not to intervene, the linkage between the agent's actions and the efficacy of the principal's effort plays no part in the program and hence fails to change the contract form.

On the other hand, when the principal targets high-effort and wishes to intervene, the contractual form becomes complicated because the principal's intervention strategy is used to increase the probability of success *and* motivate the agent to report truthfully. The reason for this is that when the efficacy of the principal's action are tied to the agent's effort choice, the truthfully reported

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[14]For simplicity, the contracts below ignore some wage-payment multi-equilibrium complexities. In particular, in some circumstances the principal can shift some of agent's wages from one state, w_G^I, to another state, w_B^I, while maintaining the same profits. To simplify the exposition, we present the contracts above while ignoring this feature and leave the details to the appendix.

signal no longer contains all the information regarding the agent's effort choice. Therefore, the principal intervenes sub-optimally to assuage the moral hazard problem encountered in the first stage of the game. In other words, the state-space at the time of the signal, $t = 2$, now involves both the agent's effort and the private signal, σ_i.

The intuition behind why the contractual form varies over the parameter space is straightforward. Because of the limited liability constraint, the principal will always set the worst outcomes, w_B and w_B^I to the lowest value that she can, which is zero. Since there are only two more degrees of freedom left with respect to the contract (the wages the agent receives in the high states) the principal's profit maximization program is transformed as a decision over which two incentive constraints will bind. First, consider the case when i_H and i_L are sufficiently small so that we are in the contract region where $\frac{i_H}{i_L} \leq \frac{p_H}{p_L}$. When this is the case the split between the efficacies of the principal's actions is so small that the contract takes on the same basic structure as that with the unlinked case. While there are some minor differences between the functional forms of the linked and unlinked cases in this region, the expected payment conditional on intervention remains the same. In this region, the binding constraints are the (ICR$_H$) constraint and the (ICP$_L$) constraint, or those constraints associated with a high signal agent wanting to misrepresent at the second stage and an agent deciding to shirk and then misrepresent. As i_H and i_L move further apart, however, the agent finds the alternative strategy of shirking and then telling the truth more enticing since the wage payments associated with w_G^I are relatively large. Therefore the principal, to maintain incentive compatibility must lower the expected payments associated with this strategy and, in doing so, moves to binding the constraint associated with this strategy (ICP$_{TT}$). As $\frac{i_H}{i_L}$ increases even more to the point where $\frac{i_H}{i_L} \geq \frac{p_H}{p_L}$ and $\frac{i_H}{i_L} \geq \frac{\frac{\alpha_H}{1-\alpha_H}}{\frac{\alpha_L}{1-\alpha_L}}$, the contract associated with this second region will fail to provide proper incentives since the agent never wishes to misrepresent at the second stage because the payment at this point, w_G^I, is too large, though the agent who exerted high-effort will now misrepresent if they receive the high signal since the payoff associated with this strategy is too large. Thus the third contract region specifics that the binding constraints are those associated with (ICP$_{TT}$) and (ICR$_H$). In other words, when the ratio of i_H to i_L is small, the contract is the

same as in the unlinked case and, as this ratio increases, or as the game becomes more and more unlike the unlinked case, the principal must incentive the agent to not strategically shirk. As the game becomes significantly different from the unlinked game, the agent will never wish to shirk and then lie about the low state; the final contract region thus has the principal binding the (ICP_{TT}) and (ICR_H) constraints.

Independent of the contractual form, the principal may now optimally use intervention as an incentive mechanism, as described by Proposition 12 below.

Proposition 12. *When the agent's initial action choice and the efficacy of the principal's intervention effort are linked, the principal uses intervention as an incentive mechanism. In particular, the principal may find it optimal to over- or under- intervene, depending on the parameters.*

As suggested in the introduction and outlined in the preceding proposition, the principal may optimally over- or under-intervene, depending on the signal value of the post-intervention effort. In particular, when the signal is no longer a sufficient statistic for the agent's effort at the time of transmission, two factors arise which change the costs associated with intervention. The first factor is that the principal may find it more expensive to ensure that the agent engages in truthful communication. The second factor influencing the costs associated with the choice of intervention is that there is an additional useful signal that the principal can leverage in assuaging the initial moral hazard problem.

In essence, the principal faces two problems: preventing the agent from shirking and having the agent truthfully report the signal he has received. When the principal was engaging in unlinked intervention the same constraints that prevented the agent from misrepresenting when the agent shirked also applied to the case when the agent exerted high-effort. With linked intervention this is no longer the case and the principal must use additional constraints to ensure the veracity of the signal. To state it another way, when there is no path dependence, even if the principal could somehow see the agent's action choice, the incentive compatibility constraints that the principal needs to create to ensure truthful revelation would not change.

The second factor changing the costs associated with linked intervention is that the project's

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outcome is now a useful signal of the agent's actions, which allows the principal to use it to provide incentives. When the model did not exhibit path dependence the post project intervention outcome was not used in the agent's contract, but with path dependence, the principal uses the outcome to combat the underlying moral hazard problem. Accordingly, the principal uses intervention to generate more information about the agent's prior effort choice, whenever the outcome without intervention proves excessively noisy of informative. The principal now finds it optimal to intervene and then use the project's outcome as a contractible variable to ascertain if the agent had originally shirked or not, which will weakly lower the principal's expected costs.

Because of these factors, the principal can use intervention as an incentive mechanism; the principal can use the choice of when to intervene as a means to change the agent's behavior. The surprising result of our model is that either of these factors can dominate and the principal may find it optimal to either over- or under-intervene, as can be seen in Figure 3.3.

The highlighted areas in Figure 3.3 are areas where the principal varies from the economically efficient decision. Starting at the bottom, the first region, between Π_{HI} and Π_{LI} still has first best intervention, since she still chooses to intervene in either region, though the principal targets high-effort less than the economically efficient level (the cross-hatched portion of the graph is where the principal has the agent under-exerting in this manner).

The region between Π_{HN} and Π_{HI}, on the other hand, has the principal choosing to intervene more than the economically efficient level. As described earlier, the intuition behind this is that the principal can use the project's final outcome as a contracting variable, which lowers the rents that the she has to pay to the agent. The overall costs associated with intervention are therefore lower than those generated when the principal chooses to not intervene. Since the costs are lower, the principal finds it beneficial to over-intervene in this region.

The final highlighted area shows where the principal chooses to under-intervene since intervention requires the use of additional (costly) constraints to ensure truth-telling. When the principal chooses to neither intervene nor target high-effort, she incurs the lowest possible costs since she doesn't pay any rents to the agent. With linked intervention there is a boundary between this choice
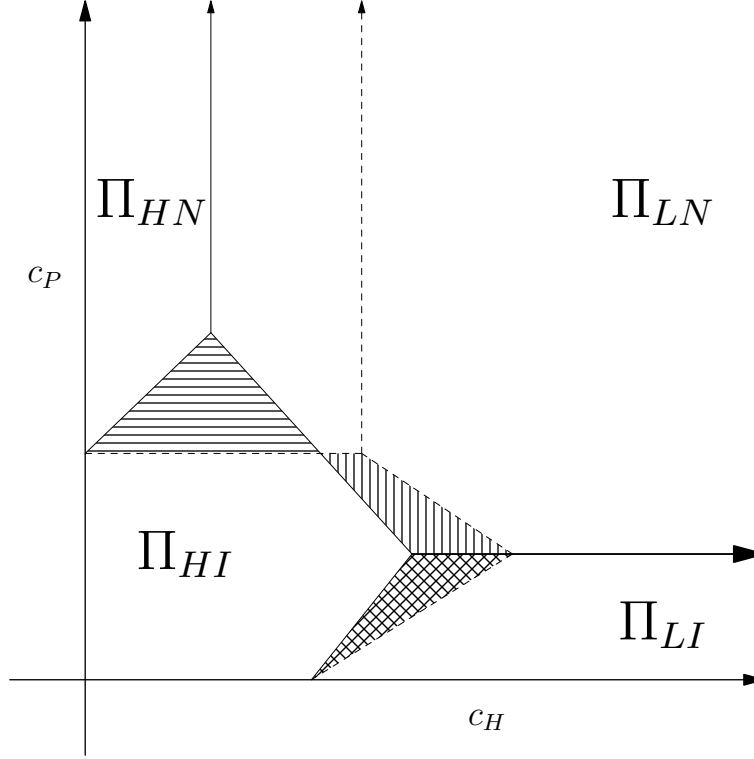
Figure 3.3: The figure demonstrates where, given the linked intervention scenario, the principal chooses to use intervention as an incentive mechanism. The dashed lines represent the boundary between different regions for the economically efficient scenario while the solid lines represent the same boundaries for the second best scenario. The bold line represents lines where they overlap. Vertical lines represent areas where the principal uses too little intervention while horizontal lines represent areas where the principal uses too much intervention. The region with cross-hatching has the principal preserving his intervention decision, but changing the targeted effort level. The figured labels are as defined in Figure 3.2

and choosing to target high-effort and intervene. This later choice, however, involves providing incentives against each of the agent's possible strategy and therefore requires paying costly rents. The principal thus finds it optimal to refrain from incurring these costs and instead chooses to have the agent target low-event and not intervene in this region.

3.4   Conclusion

Task assignment in a standard principal-agent model is generally a one-way street in that the principal contracts with the agent to do a task, the outcome is realized, people are paid and the game

ends. Many employment relationships, however, are built on the idea that the principal or manager may be more skilled, have better abilities or command of more resources when compared to the agent being managed. In this case, the principal may find it beneficial to have the agent relinquish the task back to the principal when the positive outcome is in jeopardy. The agent, however, is often more likely to know if the project is in a good or bad state, since he is the one working on it, therefore the principal must provide incentives to have the agent properly report such private information. The purpose of this chapter is to study how intervention changes incentives and when to optimally intervene in the presence of additional agency problems.

We found that, when there is perfect communication between the principal and the agent then the principal does not use the intervention choice as an incentive mechanism to assuage the underlying moral hazard problem. This is because the agent effectively controls the choice as to whether intervention should occur or not. Thus, if the principal wishes to have the agent ask for assistance in some state, the principal must pay the agent a wage which makes him indifferent between asking for assistance and not asking for assistance when reaching that state. Because the agent is made indifferent, the expected costs to the principal (and the expected wages to the agent) are independent of the intervention decision therefore the principal can engage in the economically efficient level of intervention.

However, the above analysis relies on the ability of the agent and principal to fully communicate the state of the world to each other. If there is some limitation, as in the case when the agent's effort determines the efficacy of the principal's intervention activity, yet the agent can only report his private information, then this analysis no longer applies. In the final section of this chapter we demonstrate, in an extension, how slight perturbations to the base model quickly translate into strategic intervention. In our model found that the principal may engage in either over- or under-intervention, depending on how the intervention activity influenced the ability of the principal to learn information about the agent's effort choice.

In particular, we found that the principal may engage in too little intervention because it becomes costlier to provide the necessary incentives to ensure truthful reporting at the second stage,

while the she may also engage in too much intervention, since, by intervening, the principal may learn more about the agent's initial action choice and assuage the initial moral hazard problem. Depending on the parameter choice, each of these factors could dominate.

Our study highlights a number of features around intervention in moral hazard problems and also raises questions for future research. For instance, do we still observe efficient intervention absent communication frictions in multi-agent settings? Depending on how the relationship between the agents is structured, the principal may be able to play the agents off each other to increase the overall efficiency of the system, but, if not done correctly, could easily lead to collusion. Another area for future research would be to consider the case where the principal's intervention effort is not observable and contactable. In such a model, there would be dual moral-hazard, which would fundamentally change the underlying tensions.

As a final note, in each of the regions where the principal deviates from the optimal intervention level, the principal will face commitment issues at the time when the agent decides if intervention should be attempted or not. If the parameters are such that the agent is making an intervention decision which is not economically efficient there are gains to additional communication at the time to make the economically efficient decision. As noted in Levitt and Snyder [33], among others, the only commitment-issue free intervention scheme is having the agent engage in the economically efficient level.

Appendix A

Proofs of Lemmas and Proposition

In the proofs associated with chapter 2, we simplify the exposition by defining $k = \frac{\hat{\theta}_H}{\hat{\theta}_L}$, our proxy for signal informativeness. Note that k is increasing in both the level of information, a, and with respect to arbitrary mean preserving spreads which enlarge j. Additionally, let Π_P^n denote the principal's expected payoff and Π_A^n that of the agent with $n \in \{FB, BU, TD\}$ denoting the first-best benchmark, bottom-up and top-down regime respectively.

Proof of Lemma 1

The principal maximizes:

$$\max_{e_H, e_L} \quad p \cdot E\left[\theta_H e_H - T\frac{e_H^2}{2}\bigg|\sigma_H\right] + (1-p) \cdot E\left[\theta_L e_L - T\frac{e_L^2}{2}\bigg|\sigma_L\right],$$

thus the optimal processing efforts are $e_H^{FB} = \frac{\hat{\theta}_H}{T}$ and $e_L^{FB} = \frac{\hat{\theta}_L}{T}$, where the FB superscript denotes the optimal first-best benchmark solution. The principal's first-best profits are hence:

$$\Pi_P^{FB} = \frac{p\hat{\theta}_H^2 + (1-p)\hat{\theta}_L^2}{2T} = \frac{\bar{\theta}^2 + a^2(1-p)p(\theta_H - \theta_L)^2}{2T}.$$

By inspection, Π_P^{FB} is increasing and convex in a. Mean preserving spreads, on the other hand, will only increase the difference $\theta_H - \theta_L$. Because θ_H and θ_L appear only with a positive coefficient via $\theta_H - \theta_L > 0$ in the principal's profits, mean preserving spreads will induce positive and convex

gains to the principal's profits as well. The contractibility of the agent's effort allows the principal to pay the agent conditionally on his efforts, therefore by providing the agent with a menu of contracts consisting of $\alpha_i = \frac{\hat{\theta}_i^2}{2}T$, for $i = H, L$, the agent is indifferent between the each contract and we assume that he resolves his indifference according to either his signal, or in the case of top-down budgeting, the principal's report.

Proof of Proposition 1

The principal solves:

$$\max_{\alpha_H, \alpha_L, \beta_H, \beta_L} \quad p\left(\beta_H e_H \hat{\theta}_H + \alpha_H\right) + (1-p)\left(\beta_L e_L \hat{\theta}_L + \alpha_L\right)$$

$$\text{s.t.} \quad \mathrm{E}[\beta_H e_H \theta + \alpha_H | \sigma_H] \geq \mathrm{E}[\beta_L e_L \theta + \alpha_L | \sigma_H] \quad (\text{ICP}_H)$$

$$\mathrm{E}[\beta_L e_L \theta + \alpha_L | \sigma_L] \geq \mathrm{E}[\beta_H e_H \theta + \alpha_H | \sigma_L] \quad (\text{ICP}_L)$$

$$\mathrm{E}[\beta_i e_i \theta + \alpha_i | \sigma_i] \geq 0 \qquad i = H, L \quad (\text{IRP}_i)$$

$$e_i \in \arg\max_e \quad \mathrm{E}[(1 - \beta_i)\theta e - \alpha_i - \frac{e^2}{2}T | \sigma_i] \quad i = H, L \quad (\text{ICA}_i)$$

$$\mathrm{E}[(1 - \beta_i)e_i \theta - \frac{1}{2}T e_i^2 - \alpha_i | \sigma_i] \geq 0 \qquad i = H, L \quad (\text{IRA}_i)$$

$$0 \leq \beta_i \leq 1 \qquad i = H, L$$

In accordance with (ICA$_i$) the agent exerts effort $e_i = \frac{(1-\beta_i)\hat{\theta}_i}{T}$ for $i = H, L$. We ignore constraints (ICP$_H$), (IRP$_H$) and (IRP$_L$), and later verify that the solution to the relaxed program satisfies these constraints. (IRA$_L$) will always bind, for otherwise α_L and profits could be increased, while generating slack in (ICP$_L$). Simplifying (IRA$_L$) with the agent's optimized processing effort yields:

$$\alpha_L = (1 - \beta_L)e_L \hat{\theta}_L - T\frac{e_L^2}{2} = \frac{(1 - \beta_L)^2 \hat{\theta}_L^2}{2T}. \quad (\text{A.1})$$

The principal's program thus becomes:

$$\max_{\alpha_H, \beta_H, \beta_L} \quad p \cdot \left(\alpha_H + \frac{\beta_H(1 - \beta_H)\hat{\theta}_H^2}{T} \right) + (1 - p)\left(\frac{(1 - \beta_L^2)\hat{\theta}_L^2}{2T} \right)$$

$$s.t. \quad \frac{(1 - \beta_H)^2\hat{\theta}_H^2}{2T} \geq \alpha_H \qquad\qquad\qquad\qquad (\text{IRA}_H)$$

$$\frac{(1 - \beta_L^2)\hat{\theta}_L^2}{2T} - \frac{\beta_H(1 - \beta_H)\hat{\theta}_H\hat{\theta}_L}{T} \geq \alpha_H \qquad (\text{ICP}_L)$$

$$0 \leq \beta_i \leq 1 \qquad i = H, L.$$

Both the objective function and the left hand side (LHS) of constraint (ICA_L) are decreasing in $|\beta_L|$ while the rest of the program is independent of β_L. To maximize profits, β_L is set to 0, implying, from (A.1), that $\alpha_L = \frac{\hat{\theta}_L^2}{2T}$. The program thus further reduces to:

$$\max_{\alpha_h, \beta_h} \quad p\left(\alpha_H + \frac{\beta_H(1 - \beta_H)\hat{\theta}_H^2}{T} \right) + (1 - p)\left(\frac{\hat{\theta}_L^2}{2T} \right) \qquad (\text{A.2})$$

$$s.t. \quad \frac{(1 - \beta_H)^2\hat{\theta}_H^2}{2T} \geq \alpha_H \qquad\qquad\qquad (\text{IRA}_H)$$

$$\frac{\hat{\theta}_L^2}{2T} - \frac{\beta_H(1 - \beta_H)\hat{\theta}_H\hat{\theta}_L}{T} \geq \alpha_H \qquad (\text{ICP}_L)$$

$$0 \leq \beta_H \leq 1$$

We claim that (ICP_L) must bind. To see this, note that the principal's profits are increasing in α_H, though α_H is bounded above by either (IRA_H) or (ICP_L). If the (LHS) of (ICP_L) is less than that of (IRA_H), then (ICP_L) binds. Otherwise, (IRA_H) binds and $\alpha_H = \frac{(1-\beta_H)^2\hat{\theta}_H^2}{2T}$. However, if $\alpha_H = \frac{(1-\beta_H)^2\hat{\theta}_H^2}{2T}$, then the principal maximizes her profits by lowering β_H until (ICP_L) binds. Thus (ICP_L) always binds, admitting the equivalent equations:

$$\beta_H(\alpha_H) = \frac{\hat{\theta}_H\hat{\theta}_L \pm \sqrt{\hat{\theta}_H\hat{\theta}_L \left(\hat{\theta}_L \left(\hat{\theta}_H - 2\hat{\theta}_L \right) + 4\alpha_H T \right)}}{2\hat{\theta}_H\hat{\theta}_L} \qquad (\text{A.3})$$

$$\alpha_H(\beta_H) = \frac{\hat{\theta}_L \left(2\left(\beta_H - 1 \right)\beta_H\hat{\theta}_H + \hat{\theta}_L \right)}{2T}. \qquad (\text{A.4})$$

The principal's objective function, (A.2), is maximized when β_H is equal to $1/2$, since substituting (A.4) into Π_P^{TD} yields:

$$\frac{\partial \Pi_P^{TD}(\beta_H, \alpha_H(\beta_H))}{\partial \beta_H} = \frac{p\,(1 - 2\beta_H)\,\hat{\theta}_H\left(\hat{\theta}_H - \hat{\theta}_L\right)}{T} \geq 0, \tag{A.5}$$

therefore Π_P^{TD} is concave in β_H. Using $\beta_H = 1/2$ and α_H defined by (A.4), constraint (ICP$_H$) is satisfied, as it is equivalent to $\frac{\hat{\theta}_H\left(\hat{\theta}_H - \hat{\theta}_L\right)}{4T} \geq 0$. Similar substitution and algebraic manipulation reveals that both (IRP$_H$) and (IRP$_L$) are satisfied with the candidate solution. However, the candidate solution sets (IRA$_H$) to $\frac{(k(k+2)-4)\hat{\theta}_L^2}{8T}$, which is only non-negative for $k \geq \sqrt{5} - 1$. When $k < \sqrt{5} - 1$, the principal will set β_H as large as possible without violating (IRA$_H$), since her profits are increasing in β_H when $\beta_H < 1/2$. The contract will therefore have a second form when $k < \sqrt{5} - 1$; i.e., when (IRA$_H$) binds: $\alpha_H = \frac{(1-\beta_H)^2\hat{\theta}_H^2}{2T}$, which combined with (A.3) implies $\beta_H = \frac{\hat{\theta}_H^2 - \hat{\theta}_H\hat{\theta}_L - \sqrt{2}\sqrt{\hat{\theta}_H\hat{\theta}_L^2\left(\hat{\theta}_H - \hat{\theta}_L\right)}}{\hat{\theta}_H^2 - 2\hat{\theta}_H\hat{\theta}_L}$. Using these values, (ICP$_H$) reduces to

$$\frac{(k-1)\hat{\theta}_L^2}{(k-2)^2 T}\left(2 - k - k^2 + \sqrt{2}\sqrt{(k-1)k}\right)$$

which is positive for $k \in (1, \sqrt{5} - 1)$. Similar substitution and algebraic manipulation reveals that the second candidate solution also satisfies both (IRP$_H$) and (IRP$_L$).

Proof of Proposition 2

The principal's maximization program is given below, where e_{ij} denotes the agent's processing

effort when he observes $\sigma = \sigma_i$ but selects the contract $(\alpha_j, \beta_j))$ and we denote e_{ii} by e_i:

$$\max_{\alpha_H, \alpha_L, \beta_H, \beta_L} \quad p\left(\alpha_H + \beta_H e_H \hat{\theta}_H\right) + (1-p)\left(\alpha_L + \beta_L e_L \hat{\theta}_L\right)$$

$$s.t. \quad e_{ij} \in \arg\max_e E[(1-\beta_j)\theta e - \alpha_j - T\frac{1}{2}e^2 | \sigma_i] \qquad i,j \in \{H,L\}^2 \qquad \text{(ICA}_{ij})$$

$$E[(1-\beta_i)e_i\theta - \alpha_i - T\frac{1}{2}e_i^2 | \sigma_H] \geq 0 \qquad i \in \{H,L\} \qquad \text{(IRA}_i)$$

$$E\left[\begin{array}{c|c} (1-\beta_H)e_H\theta \\ -\alpha_H - \frac{Te_H^2}{2} \end{array} \sigma_H\right] \geq E\left[\begin{array}{c|c} (1-\beta_L)e_{HL}\theta \\ -\alpha_L - \frac{Te_{HL}^2}{2} \end{array} \sigma_H\right] \qquad \text{(ICA}_H)$$

$$E\left[\begin{array}{c|c} (1-\beta_L)e_L\theta \\ -\alpha_L - \frac{Te_L^2}{2} \end{array} \sigma_L\right] \geq E\left[\begin{array}{c|c} (1-\beta_H)e_{LH}\theta \\ -\alpha_H - \frac{Te_{LH}^2}{2} \end{array} \sigma_L\right] \qquad \text{(ICA}_L)$$

$$E[\beta_i e_i \theta_i + \alpha_i | \sigma_i] \geq 0 \qquad i \in \{H,L\} \qquad \text{(IRP}_i)$$

$$0 \leq \beta_i \leq 1 \qquad i \in \{H,L\}.$$

Applying the first order approach to constraints (ICA$_{ij}$) yields:

$$e_H = \frac{(1-\beta_H)\hat{\theta}_H}{T} \qquad\qquad e_L = \frac{(1-\beta_L)\hat{\theta}_L}{T}$$

$$e_{LH} = \frac{(1-\beta_H)\hat{\theta}_L}{T} \qquad\qquad e_{LH} = \frac{(1-\beta_L)\hat{\theta}_H}{T}.$$

We again ignore (IRA$_H$), (ICA$_L$), (IRP$_H$) and (IRP$_L$) and later verify that the solution to the relaxed problem satisfies these constraints. The principal's program thus becomes:

$$\max_{\alpha_H, \alpha_L, \beta_H, \beta_L} \quad p\left(\frac{(1-\beta_H)\beta_H\hat{\theta}_H^2}{T} + \alpha_H\right) + (1-p)\left(\frac{(1-\beta_L)\beta_L\hat{\theta}_L^2}{T} + \alpha_L\right)$$

$$s.t. \quad \frac{(1-\beta_L)^2\hat{\theta}_L^2}{2T} \geq \alpha_L \qquad \text{(IRA}_L)$$

$$\frac{(1-\beta_H)^2\hat{\theta}_H^2}{2T} - \frac{(1-\beta_L)^2\hat{\theta}_H^2}{2T} + \alpha_L \geq \alpha_H \qquad \text{(ICA}_H)$$

$$0 \leq \beta_i \leq 1 \qquad i \in \{H,L\}.$$

Increasing α_H until (ICA$_H$) binds will raise profits without changing (IRA$_L$), thus we use (ICA$_H$) to obtain α_H; which yields the principal's new program:

$$\max_{\alpha_L,\beta_H,\beta_L} \frac{-p\hat{\theta}_H^2\left(\beta_H^2+(\beta_L-2)\beta_L\right)+2(p-1)(\beta_L-1)\beta_L\hat{\theta}_L^2+2T\alpha_L}{2T}$$

$$s.t. \quad \frac{(1-\beta_L)^2\hat{\theta}_L^2}{2T} \geq \alpha_L \qquad\qquad\qquad (\text{IRA}_L)$$

$$0 \leq \beta_i \leq 1 \qquad i \in \{H,L\}.$$

Profits are increasing in α_L, therefore the principal raises α_L as large as possible while satisfying (IRA$_L$), resulting in:

$$\max_{\beta_H,\beta_L} \frac{(\beta_L-1)\hat{\theta}_L^2\left((2p-1)\beta_L-1\right)-p\hat{\theta}_H^2\left(\beta_H^2+(\beta_L-2)\beta_L\right)}{2T} \qquad (\text{A.6})$$

$$0 \leq \beta_i \leq 1 \qquad i \in \{H,L\}.$$

The principal's objective function (A.6) is decreasing in β_H, thus the optimal revenue share is given by $\beta_H = 0$. Optimizing over β_L obtains the menu proposed in the proposition. Substituting the menu from the proposition into (IRA$_H$), (ICA$_L$), (IRP$_H$) and (IRP$_L$), demonstrates that the previously ignored constraints are satisfied with the candidate solution.

Proof of Proposition 3

When $k \in (1, \sqrt{5}-1)$, subtracting the expected total surplus under top-down budgeting from that obtained under bottom-up budgeting yields: $g(p,k) \times \frac{p\hat{\theta}_L^2}{2T(-2+k)^2(1-2p+k^2p)^2}$, where $g(p,k)$ is quadratic in p and the second function is non-negative. The discriminant of $g(p,k)$ is $-(k-2)^2(k-1)^4(k+1)^3\left(k\left(k(3k-1)-8\sqrt{2}\sqrt{(k-1)k}+8\right)-4\right)$. On the relevant range, it carries the same sign as: $4-k\left(k(3k-1)-8\sqrt{2}\sqrt{(k-1)k}+8\right)$ which has 3 roots: $k=1$, $k=2$ and $k=-2.97$, all of which fall outside of $(1,\sqrt{5}-1)$. Thus, the discriminant does not change in sign over the relevant range and inspection reveals it to be negative, implying that $g(p,k)$ does not admit any real roots and is thus deemed positive by evaluation. Therefore, bottom-up budgeting generates greater expected total surplus when $k \in (1,\sqrt{5}-1)$.

When $k \geq \sqrt{5} - 1$, the difference in expected total surplus under top-down and bottom-up budgeting is given by:

$$\frac{p\hat{\theta}_L^2}{8T\left((k^2 - 2)\,p + 1\right)^2}\left(k^2 + \left(k^6 - 4k^2 + 4\right)p^2 - 2\left(k^4 - 2k^2 + 2\right)p\right). \tag{A.7}$$

The first part of (A.7) is positive, while the second part is quadratic in p and has a discriminate $-16(-1 + k^2)^3 < 0$, implying that there are no real roots. Evaluation reveals that (A.7) is always positive, therefore bottom-up budgeting generates the greatest expected surplus.

Proof of Proposition 4

When $k \in (1, \sqrt{5} - 1)$, we can write $\Pi_P^{BU} - \Pi_P^{TD}$ as:

$$\begin{pmatrix} k^5 p - k^4 p + k^3\left(p - 2\sqrt{2}\sqrt{(k-1)k}p\right) - k^2(p-2) \\ +2\left(\sqrt{2}\sqrt{(k-1)k} - 1\right)k(2p-1) + 4(p-1) \end{pmatrix}$$

$$\times \frac{\theta_L^2(k-1)p((j-1)p+1)^2}{2(k-2)^2 T((k-1)p+1)^2\left((k^2-2)\,p+1\right)}.$$

The second term is positive, and therefore any sign variation must emanate from the first term, which is linear in p with a positive leading coefficient, admitting the following necessary and sufficient condition for the difference in profits to be positive:

$$p > \frac{2}{k(k+1)\left(k + \sqrt{2}\sqrt{(k-1)k} - 1\right) + 2}. \tag{A.8}$$

If (A.8) is satisfied, then the principal's profits are greatest under bottom-up budgeting. The (RHS) of (A.8) is monotonically decreasing in k (and hence in a or any mean-preserving spread), demonstrating that for a fixed level of p, the difference in profits between the two modes may equal zero at most once.

If we substitute $k = 1$ into (A.8), then the (RHS) is equal to 1 and top-down budgeting dominates. Allowing k to increase indefinitely, (A.8) will eventually hold, and bottom-up budgeting will dominate. However, k, is bounded by either j or leaving the region from which this ex-

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pression is derived ($k \leq \sqrt{5} - 1$). In the second contract region, with $k > \sqrt{5} - 1$, we have $\Pi_P^{BU} - \Pi_P^{TD} = \frac{(k(k(k+2)p-1)-2p)}{4(k^2-2)p+4} \frac{(k-1)p\hat{\theta}_L^2}{T}$. The second expression and the denominator of the first expression in $\Pi_P^{BU} - \Pi_P^{TD}$ are always positive, so the only possible sign variation will result from variation in $k(k(k+2)p - 1) - 2p$. Simplifying, the following condition holds if and only if $\Pi_P^{BU} - \Pi_P^{TD}$ is positive in the region where $k \geq \sqrt{5} - 1$:

$$p > \frac{k}{k^3 + 2k^2 - 2}. \tag{A.9}$$

If (A.9) holds, the principal prefers bottom-up budgeting and since the (RHS) of (A.9) is decreasing in k (and hence in a or any mean-preserving spread), profits can only cross once j and a vary.

To complete the proof, we must exclude any jump discontinuities in the profit difference as one transitions from one contract form to the other at $k = \sqrt{5} - 1$, though as $k \to \sqrt{5} - 1$, the thresholds on p in (A.8) and (A.9) converge, precluding any such discontinuity.

Proof of Proposition 5

To facilitate the exposition, Proposition 5 is proved in five steps. The first two steps concern the principal's profits under each budgeting mode when the level of information, a, is changing, while the final two steps examine the agent's profits under the two alternative regimes when the level of information, a, is changing. The final step of the proof is to show that the sign of the first and second derivative of the profit function with respect to a for each party carries the same sign as the derivative of the profit function with respect to linear-mean preserving spreads (see (A.23) below for a formal definition of differentiation with respect to mean preserving spreads).

Principal's profits under top-down budgeting

To show that the principal's profits are "U" shaped over a under top-down budgeting, we first show that profits are decreasing in a when $k < \sqrt{5} - 1$, whereas larger values of a, which induce $k \geq \sqrt{5} - 1$, cause the the principal's profits to initially decrease in a, albeit with a positive second

derivative. We begin by differentiating the principal's profits, Π_P^{TD} when $1 < k < \sqrt{5} - 1$, over a:

$$\frac{d\Pi_P^{TD}(\beta_H(a), a)}{da} = \frac{\partial \Pi_P^{TD}(\beta_H, a)}{\partial \beta_H}\bigg|_{\beta_H = \beta_H(a)} \cdot \frac{\partial \beta_H(a)}{\partial a} + \frac{\partial \Pi_P^{TD}(\beta_H, a)}{\partial a}\bigg|_{\beta_H = \beta_H(a)}. \quad (A.10)$$

We sign the three parts to (A.10) individually. Note that $\frac{\partial \Pi_P^{TD}(\beta_H, a)}{\partial \beta_H} < 0$ follows directly from expressing $\Pi_P^{TD}(\beta_H, a)$ as:

$$\theta_L^2 \frac{((a-1)(j-1)p-1)^2 - p\left(\begin{array}{c}(\beta_H^2 - 1)\,(a(j-1)(p-1) - jp + p - 1)^2 \\ +((a-1)(j-1)p-1)^2\end{array}\right)}{2T},$$

which is decreasing in β_H for $\beta_H \geq 0$. To sign the second term in (A.10) we compute:

$$\frac{\partial \beta_H(a)}{\partial a} = \frac{\partial \beta_H(a)}{\partial \hat{\theta}_H}\frac{\partial \hat{\theta}_H}{\partial a} + \frac{\partial \beta_H(a)}{\partial \hat{\theta}_L}\frac{\partial \hat{\theta}_L}{\partial a} \quad (A.11)$$

$$\frac{\partial \hat{\theta}_H}{\partial a} = (1-p)(\theta_H - \theta_L) > 0 \quad (A.12)$$

$$\frac{\partial \hat{\theta}_L}{\partial a} = -p(\theta_H - \theta_L) < 0. \quad (A.13)$$

$$\frac{\partial \beta_H(a)}{\partial \hat{\theta}_H} = \frac{-1}{k}\left(\frac{2\sqrt{(k-1)k}k + \sqrt{2}((3-2k)k-2)}{2(k-2)2\sqrt{(k-1)k}\hat{\theta}_L}\right) > 0 \quad (A.14)$$

$$\frac{\partial \beta_H(a)}{\partial \hat{\theta}_L} = \left(\frac{2\sqrt{(k-1)k}k + \sqrt{2}((3-2k)k-2)}{2(k-2)2\sqrt{(k-1)k}\hat{\theta}_L}\right) < 0. \quad (A.15)$$

From (A.11) - (A.15), we can sign the second part of (A.10), $\frac{\partial \beta_H}{\partial a} \geq 0$. To sign the final term in (A.10), we substitute $k = \hat{\theta}_H / \hat{\theta}_L$ and the optimal revenue share $\beta_H = \beta_H(a)$ to yield the following expression (an un-ambiguously positive pre-multiplier has been omitted):

$$\frac{\partial \Pi_P^{TD}(\beta_H, a)}{\partial a}\bigg|_{\beta_H = \beta_H(a)}$$

$$= -3k + 2\sqrt{2}\sqrt{k-1}\sqrt{k} + 2.$$

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On the interval $k \in (1, \sqrt{5} - 1)$, the above expression is negative, therefore:

$$\left.\frac{\partial \Pi_P^{TD}(\beta_H, a)}{\partial a}\right|_{\beta_H = \beta_H(a)} < 0$$

which combined with $\frac{\partial \beta_H}{\partial a} \geq 0$ and $\frac{\partial \Pi_P^{TD}(\beta_H, a)}{\partial \beta_H} < 0$, establish that Π_P^{TD} is decreasing in a when $1 < k < \sqrt{5} - 1$ under top-down budgeting.

When $k \geq \sqrt{5} - 1$, the principal's profit function takes the form: $\Pi_P^{TD} = \frac{p\hat{\theta}_H\left(\hat{\theta}_H - \hat{\theta}_L\right) + 2\hat{\theta}_L^2}{4T}$ implying:

$$\frac{\partial \Pi_P^{TD}}{\partial a} = \frac{1}{4T}\left(2ap(p+1)\left(\theta_H - \theta_L\right)^2 + p\left(\theta_H - \theta_L\right)\left(-3p\left(\theta_H - \theta_L\right) - 3\theta_L\right)\right). \qquad \text{(A.16)}$$

Since $\frac{\partial \Pi_P^{TD}}{\partial a}$ is linear in a with a positive leading coefficient, the principal's profits are convex on this region, and evaluation demonstrates that $\frac{\partial \Pi_P^{TD}}{\partial a} < 0$ for sufficiently small a. We have therefore shown that the principal's profits are decreasing when $k < \sqrt{5} - 1$ and initially decreasing and convex in a when $k \geq \sqrt{5} - 1$. Since j and a move concomitantly with k the claim is proven.

Principal's profits under bottom-up budgeting

We now show that the principals' profits are always convex with bottom-up budgeting. With bottom-up budgeting, the principal's profits are given by $\Pi_P^{BU} = \frac{p^2\hat{\theta}_H^4 + (1-2p)p\hat{\theta}_H^2\hat{\theta}_L^2 + (p-1)^2\hat{\theta}_L^4}{2T\left(p\left(\hat{\theta}_H^2 - 2\hat{\theta}_L^2\right) + \hat{\theta}_L^2\right)}$. The numerator of $\frac{\partial^2 \Pi_P^{BU}}{\partial a^2}$ carries the sign:

$$-\frac{a^2\left(\left(k^2 - 2\right)p + 1\right)}{((a-1)(k-1)p + a)^2} \leq 0, \qquad \text{(A.17)}$$

whereas the denominator of $\frac{\partial^2 \Pi_S^{BT}}{\partial a^2}$ is the product of two functions:

$$\frac{1}{(j-1)^2(p-1)^2 p^2 \theta_L^2} \times \tag{A.18}$$

$$\left(\begin{array}{c} a^6(j-1)^6(p-1)p^2\left(p^2+p-1\right)^2 - 6a^5(j-1)^5 p^3\left(p^3-2p+1\right)\left((j-1)p+1\right) \\ +3a^4(j-1)^4(p-1)p\left(5p^3-2p+1\right)\left((j-1)p+1\right)^2 \\ -4a^3(j-1)^3(p-1)p(5(p-1)p+1)((j-1)p+1)^3 \\ +3a^2(j-1)^2(p-2)(5(p-1)p+1)((j-1)p+1)^4 \\ -6a(j-1)((p-4)p+2)((j-1)p+1)^5 + (p-5)((j-1)p+1)^6 \end{array} \right). \tag{A.19}$$

The first expression, (A.18), is always positive while the second, (A.19), is a seventh order polynomial in p, which we label $sp(a, j, p)$. To search for possible roots to $sp(a, j, p)$ with $p \in (0, 1)$, we apply a Mobius transform and complete a Descartes root test[1] by studying the coefficients of

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[1] See Eigenwillig [18] for details.

$(p+1)^7 sp(a, j, \frac{1}{p+1})$ with respect to p, which are:

$$C_0 = -j^4\left(3a^2(j-1)^2 - 6aj(j-1) + 4j^2\right)$$

$$C_1 = \begin{pmatrix} -a^6(j-1)^6 + 6a^5j(j-1)^5 - 12a^4j^2(j-1)^4 + 4a^3j^3(j-1)^3 \\ +3a^2(j-4)j^3(j-1)^2 + 30aj^4(j-1) - j^5(5j+24) \end{pmatrix}$$

$$C_2 = \begin{pmatrix} 2a^6(j-1)^6 - 6a^5(j-1)^6 + 3a^4(j-8)j(j-1)^4 - 12a^3j^2(j-1)^4 \\ +3a^2j^2(j(5j+4)-6)(j-1)^2 - 12aj^3\left(j^2-5\right)(j-1) - 30j^4(j+2) \end{pmatrix}$$

$$C_3 = \begin{pmatrix} a^6(j-1)^6 - 6a^5(j+1)(j-1)^5 - 3a^4((j-2)j+4)(j-1)^4 \\ +4a^3j((j-9)j+3)(j-1)^3 - 6a^2j(j((j-10)j-3)+2)(j-1)^2 \\ -60aj^2(j+1)(j-1)^2 - 5j^3(15j+16) \end{pmatrix}$$

$$C_4 = \begin{pmatrix} -2a^6(j-1)^6 - 6a^5(j-1)^5 - 3a^4(j(j+2)-1)(j-1)^4 \\ +4a^3(3(j-3)j+1)(j-1)^3 - 3a^2(4j+1)(2(j-4)j+1)(j-1)^2 \\ 30aj(2j-1)(2j+1)(j-1) - 20j^2(5j+3) \end{pmatrix}$$

$$C_5 = \begin{pmatrix} -a^6(j-1)^6 - 3a^4(2j+1)(j-1)^4 + 12a^3(j-1)^4 - 3a^2(4j(3j-5)-1)(j-1)^2 \\ -6a\left(20j^2-1\right)(j-1) - 3j(25j+8) \end{pmatrix}$$

$$C_6 = -a(j-1)(a(j-1)(a(j-1)(3a(j-1)-4) + 3(8j-5)) + 60j) - 30j - 4$$

$$C_7 = -6a(j-1)(a(j-1)+2) - 5.$$

Simplification demonstrates that the coefficients above are always negative when $a \in [0,1]$ and $j > 1$, implying that $sp(a, j, p)$ (and therefore (A.19)) is constant in sign over the entire interval, $p \in (0, 1)$. Evaluation reveals that (A.19) is negative, therefore $\frac{\partial^2 \Pi_P^{BU}}{\partial a^2} \geq 0$, as both its numerator and denominator are negative.

Agent's rents under top-down budgeting

When $k \leq \sqrt{5} - 1$ both of the agent's individual rationality constraints bind, and he collects no rents. When $k > \sqrt{5} - 1$, the agent's rents are given by:

$$\Pi_A^{TD} = p \left(\frac{2\hat{\theta}_H \hat{\theta}_L + \hat{\theta}_H^2 - 4\hat{\theta}_L^2}{8T} \right).$$

The agent's rents are initially increasing in a, as

$$\left. \frac{\partial \Pi_A^{TD}}{\partial a} \right|_{a|k(a)=\sqrt{5}-1} = \frac{(j-1)p \left(\sqrt{5} + \left(5 - 2\sqrt{5} \right) p \right) \left((j-1)p + 1 \right) \theta_L^2}{4 \left(\left(\sqrt{5} - 2 \right) pT + T \right)} > 0.$$

However, $\frac{\partial^2 \Pi_A^{TD}}{\partial a^2} = (1 - p(p+4)) \frac{(\theta_H - \theta_L)^2}{4T}$, and does not vary in sign over the relevant range, though it can be either uniformly positive or negative over $0 \leq a \leq 1$; therefore $\frac{\partial \Pi_A^{TD}}{\partial a}$ admits at most a single root, which is attained from above.

Agent's rents under bottom-up budgeting

Under bottom-up budgeting, the agent collects rents given by $\Pi_A^{BU} = \frac{(1-p)^2 p(\hat{\theta}_H - \hat{\theta}_L)\hat{\theta}_L^4(\hat{\theta}_H + \hat{\theta}_L)}{2T(\hat{\theta}_L^2 + p(\hat{\theta}_H^2 - 2\hat{\theta}_L^2))}$. To prove that his profits are single peaked over a, we show that $\left. \frac{\partial \Pi_A^{BU}(a,j)}{\partial a} \right|_{a=0} > 0$ and the function, $\frac{\partial \Pi_A^{BU}(a,j)}{\partial a}$ have at most one root over the interval $a \in (0,1)$. To this end, we have $\left. \frac{\partial \Pi_A^{BU}(a,j)}{\partial a} \right|_{a=0} = \frac{p\theta_L^2(j-1)(1+(j-1)p)}{T} > 0$. To show that the function $\frac{\partial \Pi_A^{BU}(a,j)}{\partial a}$ has at most a single root over $a \in (0,1)$, we begin by noting that its denominator carries the same sign as $-1 - (-3 + a^2(1-j)^2 + 2j)p - (1-a)(j-1)(j-3+a(j-1))p^2 + (1-a)^2(j-1)^2 p^3$. The denominator thus has two roots in a, both of which fall out of the range $(0,1)$ when $0 < p < 1$ and $j > 1$; implying that the denominator has a constant (negative) sign throughout the relevant range. We can express the numerator as: $f(a,p,j) \left((-1+j)(-1+p)^2 p(1 + (-1+a+j-aj)p)^3 \theta_L^2 \right)$, where $f(a,p,j)$ is a fourth order polynomial in a and the rest of the expression is always positive. We search for possible roots in a over the $(0,1)$ interval by again applying the Descartes test to the Mobius transform on $f(a,p,j)$. In particular, we verify the number of roots of $H(a,j) = (a+1)^4 f(\frac{1}{1+a}, j, p)$, which itself is a

fourth degree polynomial over a. The coefficients of a in $H(a, j)$ are negative when $p = 0$, though each coefficient has a unique root over p when $0 < p \leq 1$, which we denote R_i, where the index, i, denotes the relevant order of a:

$$R_0 = \frac{-j^3 + \sqrt{j^6 + 8j^5 - 2j^4 - 14j^3 + j^2 + 6j + 1} - j + 1}{2\left(2j^4 - j^3 - 3j^2 + 2\right)}$$

$$R_1 = \frac{-j^3 - 3j^2 + \sqrt{j^6 + 6j^5 + 99j^4 - 68j^3 - 117j^2 + 54j + 41} - 3j + 3}{2\left(7j^3 - 9j^2 - 6j + 8\right)}$$

$$R_2 = \frac{-j^2 + \sqrt{j^4 + 12j^3 - 10j^2 - 12j + 13} - 2j + 1}{2\left(2j^2 - 5j + 3\right)}$$

$$R_3 = \frac{2j - \sqrt{3j^2 - 2j + 3}}{j - 1}$$

$$R_4 = 1$$

The roots above are ordered, in that for any $j > 1$: $R_0 \leq R_1 \leq R_2 \leq R_3 \leq R_4 = 1$. Thus, for $j > 1$ and $1 > p > 0$, there is at most one sign variation along the ordered coefficients. Since the denominator of $\frac{\partial \Pi_A^{BU}(a,j)}{\partial a}$ does not vary in sign and the numerator has at most a single sign change as a varies, $\frac{\partial \Pi_A^{BU}(a,j)}{\partial a}$ has at most a single root in a over the interval $(0, 1)$, as was to be shown.

Profits with respect to linear mean preserving spreads

Under either top-down, bottom-up budgeting, the principals profits (or agent's rents) can be expressed in terms of $\hat{\theta}_H, \hat{\theta}_L, p$ and T, implying that:

$$\frac{d\Pi(\hat{\theta}_H(\theta_H, \theta_L, a, p), \hat{\theta}_L(\theta_H, \theta_L, a, p), T, p)}{da} = \frac{\partial \Pi}{\partial \hat{\theta}_H} \frac{\partial \hat{\theta}_H}{\partial a} + \frac{\partial \Pi}{\partial \hat{\theta}_L} \frac{\partial \hat{\theta}_L}{\partial a} \tag{A.20}$$

$$\frac{d^2\Pi(\hat{\theta}_H(\theta_H, \theta_L, a, p), \hat{\theta}_L(\theta_H, \theta_L, a, p), T, p)}{da^2} =$$
$$\frac{\partial \hat{\theta}_H}{\partial a}\left(\frac{\partial^2 \Pi}{\partial \hat{\theta}_H^2} \frac{\partial \hat{\theta}_H}{\partial a} + \frac{\partial^2 \Pi}{\partial \hat{\theta}_H \hat{\theta}_L} \frac{\partial \hat{\theta}_L}{\partial a}\right) + \frac{\partial \hat{\theta}_L}{\partial a}\left(\frac{\partial^2 \Pi}{\partial \hat{\theta}_L^2} \frac{\partial \hat{\theta}_L}{\partial a} + \frac{\partial^2 \Pi}{\partial \hat{\theta}_L \hat{\theta}_H} \frac{\partial \hat{\theta}_H}{\partial a}\right), \tag{A.21}$$

since $\frac{\partial^2 \hat{\theta}_i}{\partial a^2} = 0$. We parameterize a linear mean preserving spread as:

$$\theta_H(\lambda) = \theta_H + \lambda(\theta_H - (p\theta_H + (1-p)\theta_L)) \tag{A.22}$$

$$\theta_L(\lambda) = \theta_L - \lambda((p\theta_H + (1-p)\theta_L) - \theta_L) \tag{A.23}$$

where $\lambda > 0$. Using this definition we have that:

$$\frac{\partial \hat{\theta}_H(\theta_H(\lambda), \theta_L(\lambda), a, p)}{\partial \lambda} = a(1-p)(\theta_H - \theta_L) = a\frac{\partial \hat{\theta}_H}{\partial a}$$

$$\frac{\partial^2 \hat{\theta}_H(\theta_H(\lambda), \theta_L(\lambda), a, p)}{\partial \lambda^2} = 0 = \frac{\partial^2 \hat{\theta}_H}{\partial a^2}$$

$$\frac{\partial \hat{\theta}_L(\theta_H(\lambda), \theta_L(\lambda), a, p)}{\partial \lambda} = -ap(\theta_H - \theta_L) = a\frac{\partial \hat{\theta}_L}{\partial a}$$

$$\frac{\partial \hat{\theta}_L(\theta_H(\lambda), \theta_L(\lambda), a, p)}{\partial \lambda} = 0 = \frac{\partial^2 \hat{\theta}_L}{\partial a^2}$$

which implies that:

$$\frac{d\Pi(\hat{\theta}_H(\theta_L, \theta_H, \lambda, a, p), \hat{\theta}_L(\theta_L, \theta_H, \lambda, a, p), T}{d\lambda} = \frac{\partial \Pi}{\partial \hat{\theta}_H}\frac{\partial \hat{\theta}_H}{\partial \lambda} + \frac{\partial \Pi}{\partial \hat{\theta}_L}\frac{\partial \hat{\theta}_L}{\partial \lambda}$$

$$= a\left(\frac{\partial \Pi}{\partial \hat{\theta}_H}\frac{\partial \hat{\theta}_H}{\partial a} + \frac{\partial \Pi}{\partial \hat{\theta}_L}\frac{\partial \hat{\theta}_L}{\partial a}\right) \tag{A.24}$$

$$\frac{d^2\Pi(\hat{\theta}_H(\theta_L, \theta_H, \lambda, a, p), \hat{\theta}_L(\theta_L, \theta_H, \lambda, a, p), T}{d\lambda^2} =$$

$$\frac{\partial \hat{\theta}_H}{\partial \lambda}\left(\frac{\partial^2 \Pi}{\partial \hat{\theta}_H^2}\frac{\partial \hat{\theta}_H}{\partial \lambda} + \frac{\partial^2 \Pi}{\partial \hat{\theta}_H \hat{\theta}_L}\frac{\partial \hat{\theta}_L}{\partial \lambda}\right) + \frac{\partial \hat{\theta}_L}{\partial \lambda}\left(\frac{\partial^2 \Pi}{\partial \hat{\theta}_L^2}\frac{\partial \hat{\theta}_L}{\partial \lambda} + \frac{\partial^2 \Pi}{\partial \hat{\theta}_L \hat{\theta}_H}\frac{\partial \hat{\theta}_H}{\partial \lambda}\right)$$

$$= a\frac{\partial \hat{\theta}_H}{\partial a}\left(\frac{\partial^2 \Pi}{\partial \hat{\theta}_H^2}a\frac{\partial \hat{\theta}_H}{\partial a} + \frac{\partial^2 \Pi}{\partial \hat{\theta}_H \hat{\theta}_L}a\frac{\partial \hat{\theta}_L}{\partial a}\right) + a\frac{\partial \hat{\theta}_L}{\partial a}\left(\frac{\partial^2 \Pi}{\partial \hat{\theta}_L^2}a\frac{\partial \hat{\theta}_L}{\partial a} + \frac{\partial^2 \Pi}{\partial \hat{\theta}_L \hat{\theta}_H}a\frac{\partial \hat{\theta}_H}{\partial a}\right)$$

$$= a^2\left\{\frac{\partial \hat{\theta}_H}{\partial a}\left(\frac{\partial^2 \Pi}{\partial \hat{\theta}_H^2}\frac{\partial \hat{\theta}_H}{\partial a} + \frac{\partial^2 \Pi}{\partial \hat{\theta}_H \hat{\theta}_L}\frac{\partial \hat{\theta}_L}{\partial a}\right) + \frac{\partial \hat{\theta}_L}{\partial a}\left(\frac{\partial^2 \Pi}{\partial \hat{\theta}_L^2}\frac{\partial \hat{\theta}_L}{\partial a} + \frac{\partial^2 \Pi}{\partial \hat{\theta}_L \hat{\theta}_H}\frac{\partial \hat{\theta}_H}{\partial a}\right)\right\} \tag{A.25}$$

Comparing (A.20) to (A.24) and (A.21) to (A.25) and noting that $a > 0$, the sign of the both the first and second derivatives of the profit function for the principal with respect to any linear-mean preserving spread is the same as the sign of that same derivative with respect to a. Therefore any statement with respect to first- and second-order behaviors with respect to a is equally valid with

respect to linear-mean preserving spreads.

Proof of Proposition 6

Total expected surplus under top-down budgeting when $k < \sqrt{5} - 1$ is simply given by the principal's profits since the agent collects no rents. As shown in Proposition 5, the principal's profits are decreasing with a in this region and therefore total expected surplus is decreasing. When $k \geq \sqrt{5} - 1$, the derivative of the total expected surplus with respect to a is equal to:

$$\frac{a(k-1)(1-p)p\theta_L^2}{4T((a-1)(k-1)p+a)^2}(3k-4). \tag{A.26}$$

The first part of (A.26) is always positive while the second is positive when $k \geq 4/3$. In other words, under top-down budgeting, total surplus is increasing with a only when $k \geq 4/3$ and decreasing otherwise. Under bottom-up budgeting, differentiating total expected surplus with respect to a yields an unambiguously positive expression times:

$$1 - 7p + 17p^2 - 17p^3 + 6p^4 + k(-2p + 5p^2 - 3p^3) + k^2(p - 10p^2 + 18p^3 - 9p^4)$$

$$+ k^5(p^3 - p^4) + k^3(-p^2 + p^4) + k^4(3p^2 - 8p^3 + 5p^4) + k^6(p^3 - p^4). \tag{A.27}$$

For sufficiently large k, the positive k^6 term will dominate and the expression will be positive.

Proof of Proposition 7

When we define budget emphasis as:

$$E[(1 - \beta_i)\theta_i e_i] = p(1 - \beta_H)e_H\hat{\theta}_H + (1-p)(1-\beta_L)e_L\hat{\theta}_L, \tag{A.28}$$

then, under top-down budgeting when $k < \sqrt{5} - 1$, the expression becomes:

$$\frac{\hat{\theta}_L^2\left(2\left(k^2 + k - 2\right)p - 2\sqrt{2}k\sqrt{(k-1)k}p + (k-2)^2\right)}{(k-2)^2T}.$$

Taking the derivative and then examining the limit as a and j go to their minimum values reveals

two negative expression, thus, under top-down budgeting, budget emphasis is initially decreasing. Similar analysis, when $k \geq \sqrt{5} - 1$ yields the following conditions for when budget emphasis is increasing:

$$a > \frac{3p}{3p+1} \qquad j > \frac{3ap + a - 3p + 3}{3ap + a - 3p}.$$

In other words, if both a and j are sufficiently large, then budget emphasis is increasing under top-down budgeting. Under bottom-up budgeting (A.28) becomes:

$$\frac{1}{T} \frac{p\hat{\theta}_H^2 - ((-1+p)^3 \hat{\theta}_L^6}{\hat{\theta}_L^2 + p(\hat{\theta}_H^2 - 2\hat{\theta}_L^2)^2}, \tag{A.29}$$

the derivative of which, with respect to a yields:

$$-1 - k + (4 + 3(-1+k)k^2)p + (-5 + 3k(2 + k(2 - 4k + k^3)))p^2$$
$$+ (2 + k(-6 + k(-3 + 12k - 6k^3 + k^5)))p^3, \tag{A.30}$$

where a positive pre-multiplier has been removed. Once again we use a Mobius transform and complete a Descrates root test to note that there is, at most a single positive root of this expression on the interval $p \in \{0, 1\}$. Evaluation of (A.30) at $a = 0$ yields a negative expression. Therefore, under bottom-up budgeting, the budget emphasis is initially decreasing and then, possibly, increasing with respect to a. Note that since (A.29) can be expressed solely in terms of $\hat{\theta}_L$ and $\hat{\theta}_H$, any shape with respect to a is shared with respect to j. See the discussion at the end of Proposition 4 for details.

Incentive strength, $(1-p)(1-\beta_L) + p(1-\beta_H)$, is weakly decreasing in j and a under top-down budgeting since, Proposition 5 found β_H to be decreasing in k when $k < \sqrt{5} - 1$ and constant thereafter. Under bottom-up budgeting, incentive strength simplifies to:

$$\frac{p\left((k^2 - 1)p - 1\right) + 1}{(k^2 - 2)p + 1},$$

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which is decreasing in k.

Proof of Proposition 8

We define the performance-pay ratio as:

$$\frac{E[(1 - \beta_i)e\theta_i]}{E[(1 - \beta_i)e_i - \alpha_i - \frac{e^2}{2T}\theta_i]},$$

which is equal to:

$$\frac{2\left(p\left(\left(\left(k^2 - 2\right)kp + k + p\right)\left(\left(k^3 - 2k - 1\right)p + k\right) + 3(p - 1)\right) + 1\right)}{\left(k^2 - 1\right)(p - 1)^2 p} \tag{A.31}$$

under bottom-up budgeting. Taking the derivative of (A.31) with respect to k yields:

$$\left(k^2 - 1\right)^2\left(2k^2 - 3\right)p^3 + \left(2k^4 - 4k^2 + 1\right)p^2 + 2p - 1, \tag{A.32}$$

where a positive pre-multiplier has been removed. For a fixed p, the expression above is increasing and unbounded in k, implying that for sufficiently large k, the derivative is increasing. Under top-down budgeting rents are equal to zero when $k < \sqrt{5} - 1$, the measure is therefore undefined therein. When $k \geq \sqrt{5} - 1$ the derivative of the performance-pay ratio with respect to k is given by:

$$-16(1 + k) + 4(4 + k^2)p,$$

where a positive pre-multiplier has been removed. This expression is positive as long as $k > \frac{2 + 2\sqrt{1 + p - p^2}}{p}$.

Proof of Lemma 2 When there is no private information, the principal will only choose to target high-effort when the benefits associated with it outweigh the direct cost of c_H. Under the non-

intervention case, this implies that:

$$c_H \leq (\alpha_H - \alpha_L)(p_H - p_L)(G - B), \tag{A.33}$$

while, when the principal intervenes, she will only target high-effort when:

$$c_H \leq (\alpha_H - \alpha_L)(c_P + (G - B)(p_H - p_P)). \tag{A.34}$$

Since $p_G > p_P$, the principal will never intervene when the good signal is realized. However, since the principal must engage in personally costly effort when she intervenes, she will only do so when:

$$c_P \leq (p_P - p_L)(G - B). \tag{A.35}$$

Proof of Proposition 9 In this section we assume that the signal is contractible, but the agent's effort is not. To determine the optimal contract we compare the principal's profit under four different regimes, dependent on the agent's incentivized effort choice and if the principal chooses to intervene or not. We first consider the case when the principal chooses not to intervene while incentivizing high-effort from the agent. The principal's program becomes:

$$\max_{w_G, w_B} \quad G(p_H \alpha_H + p_L(1 - \alpha_H)) + B((1 - p_H)\alpha_H + (1 - p_L)(1 - \alpha_H))$$

$$- \alpha_H w_G - (1 - \alpha_H)w_B$$

$$s.t. \quad \alpha_H w_G + (1 - \alpha_H)w_B - c_H \geq \alpha_L w_G + (1 - \alpha_L)w_B \tag{IC}$$

$$\alpha_H w_G + (1 - \alpha_H)w_B - c_H \geq 0 \tag{IR}$$

$$w_i \geq 0 \quad i \in \{G, B\}. \tag{LL}$$

We can we-rewrite the (IC) and (IR) constraint as:

$$w_G \geq \frac{c_H}{\alpha_H - \alpha_L} + w_B \tag{IC}$$

$$w_G \geq \frac{\alpha_H - 1}{\alpha_H} w_B + \frac{c_H}{\alpha_H} \tag{IR}$$

Since the (LL) constraint guarantees that $w_B \geq 0$, from the (IC) constraint we have that that $w_G > 0$ and therefore the (LL) constraint associated with w_G will never bind. Since the principal's profits are decreasing in w_G, we see that to maximize proifts, she will decrease w_G until either (IC) or (IR) binds. However, subtraction of the (RHS) of (IR) and (IC) constraints yields:

$$\frac{\alpha_H - 1}{\alpha_H} w_B + \frac{c_H}{\alpha_H} - \left(\frac{c_H}{\alpha_H - \alpha_L} + w_B \right)$$
$$= \frac{\alpha_L c_H + w_B(\alpha_H - \alpha_l)}{-\alpha_L(\alpha_H - \alpha_L)} < 0,$$

implying that when the principal reduces w_G to increase profits, the (IC) constraint will bind before the (IR) constraint and w_G will therefore equal $\frac{c_H}{\alpha_H - \alpha_L} + w_B$. Re-writing the principal's program and using standard methods implies that the w_B will be set to zero and the optimal contract becomes:

$$w_G = \frac{c_H}{\alpha_H - \alpha_L}$$
$$w_B = 0,$$

and the principal's expected profits are equal to:

$$\Pi_{HN}^{FB} = G(p_H \alpha_H + p_L(1 - \alpha_H)) + B((1 - p_H)\alpha_H + (1 - p_L)(1 - \alpha_H))$$
$$- \alpha_H \left(\frac{c_H}{\alpha_H - \alpha_L} \right). \tag{A.36}$$

If the principal neither intervenes nor targets high-effort, the optimal contract is simply $w_G =$

$w_B = 0$ and her profits are equal to:

$$\Pi_{LN}^{FB} = G(p_H \alpha_L + p_L(1 - \alpha_L)) + B((1 - p_H)\alpha_L + (1 - p_L)(1 - \alpha_L)). \tag{A.37}$$

Comparing equations (A.37) and (A.36) yields the following condition on when the principal will choose between high- and low-effort when she does not intervene:

$$\frac{(\alpha_H - \alpha_L)^2}{\alpha_H}(G - B)(p_H - p_L) \geq c_H.$$

Comparing the above with (A.33), we note that the principal chooses a lower boundary for c_H when she is unable to contract on the effort level.

If the principal instead chooses to intervene and target high-effort, she needs to choose two wage levels: w_{NI} and w_I for the cases when a high-signal is seen and she does not intervene and the case when the low-signal is seen and she chooses to intervene. The program becomes:

$$\max_{w_G, w_B, w_I} \quad G(p_H \alpha_H + p_P(1 - \alpha_H)) + B((1 - p_H)\alpha_H + (1 - p_P)(1 - \alpha_H))$$

$$- \alpha_H w_G - (1 - \alpha_H)w_I - (1 - \alpha_H)c_P$$

$$s.t. \quad \alpha_H w_G + (1 - \alpha_H)w_I - c_H \geq \alpha_L w_G + (1 - \alpha_L)w_I \tag{IC}$$

$$\alpha_H w_G + (1 - \alpha_H)w_I - c_H \geq 0 \tag{IR}$$

$$w_i \geq 0 \quad i \in \{G, B\} \tag{LL}$$

Note that this program can be solved using the same method as the no-intervention, high-effort benchmark case, which yields the following solution:

$$w_I = 0$$

$$w_{NI} = \frac{c_H}{\alpha_H - \alpha_L}.$$

The principal's expected profits are equal to:

$$\Pi_{HI}^{FB} = G(p_H \alpha_H + p_P(1 - \alpha_H)) + B((1 - p_H)\alpha_H + (1 - p_P)(1 - \alpha_H))$$
$$- \alpha_H \frac{c_H}{\alpha_H - \alpha_L} - (1 - \alpha_H)c_P.$$

When the principal chooses to intervene and targets low-effort the solution is to set $w_{NI} = w_I = 0$, which generates expected profits for the principal equal to:

$$\Pi_{LI}^{FB} = G(p_H \alpha_H + p_P(1 - \alpha_H)) + B((1 - p_H)\alpha_H + (1 - p_P)(1 - \alpha_H)) - (1 - \alpha_H)c_P.$$

Comparing the two profit expressions implies that the principal prefers to target high-effort when:

$$\Pi_{HI}^{FB} - \Pi_{LI}^{FB} \geq 0$$
$$c_H \leq \frac{(\alpha_H - \alpha_L)^2}{\alpha_H}(c_P + (G - B)(p_H - p_P))$$
$$c_P \geq c_H \frac{\alpha_H}{(\alpha_H - \alpha_L)^2} - (G - B)(p_H - p_P)$$

Comparing (A.34) to the above expression and noting that $\frac{\alpha_H - \alpha_L}{\alpha_H} < 1$ implies that the parameter spaces under which the principal targets high-effort is smaller in this first best case than in the economically efficient regime. We also note that:

$$\Pi_{HI}^{FB} - \Pi_{HN}^{FB} = (1 - \alpha_H)((G - B)(p_P - p_L) - c_P)$$
$$\Pi_{LI}^{FB} - \Pi_{LN}^{FB} = (1 - \alpha_H)((G - B)(p_P - p_L) - c_P),$$

implying that the cut-off between intervening and non-intervening is equal to the efficient level.

Proof of Proposition 10 As in the previous proofs we find the principal's profit maximizing contract by solving for the contract under four regimes and comparing the profits under each to determine the conditions under which each contract is preferred. We first consider the case where the principal refrains from intervening and targets high-effort; the principal's program therefore

becomes:

$$\max_{w_G, w_B} \quad (G - w_G)(\alpha_H p_H + (1 - \alpha_H)p_L) + (B - w_B)(\alpha_H(1 - p_H) + (1 - \alpha_H)(1 - p_L))$$

$$\text{s.t.} \quad w_G(\alpha_H p_H + (1 - \alpha_H)p_L) + w_B(\alpha_H(1 - p_H) + (1 - \alpha_H)(1 - p_L)) - c_H$$

$$\geq w_G(\alpha_L p_H + (1 - \alpha_L)p_L) + w_B(\alpha_L(1 - p_H) + (1 - \alpha_L)(1 - p_L)) \qquad \text{(IC)}$$

$$w_G(\alpha_H p_H + (1 - \alpha_H)p_L) + w_B(\alpha_H(1 - p_H) + (1 - \alpha_H)(1 - p_L))$$

$$\geq c_H \qquad \text{(IR)}$$

$$w_i \geq 0. \quad i \in \{G, B\} \qquad \text{(LL)}$$

Simplifying the (IC) constraint yields:

$$(w_G - w_B)(p_H - p_L)(\alpha_H - \alpha_L) \geq c_H,$$

implying that $w_G > w_B$. From this and the (LL) constraint associated with w_B we know that $w_G > 0$ and the (LL) constraint associated with the wage conditional on a high-outcome does not bind. We can also express the (IC) constraint as:

$$w_G \geq w_B + \frac{c_H}{(p_H - p_L)(\alpha_H - \alpha_L)}, \qquad \text{(A.38)}$$

while the (IR) constraint becomes:

$$w_G \geq \frac{c_H + w_B \left(\alpha_H \left(p_H - p_L\right) + p_L - 1\right)}{\alpha_H \left(p_H - p_L\right) + p_L}. \qquad \text{(A.39)}$$

Subtracting the (RHS) of (A.38) from the (RHS) of (A.39) yields:

$$-\frac{w_B \left(p_H - p_L\right) \left(\alpha_H - \alpha_L\right) + c_H \left(\alpha_L \left(p_H - p_L\right) + p_L\right)}{\left(p_H - p_L\right) \left(\alpha_H - \alpha_L\right) \left(\alpha_H \left(p_H - p_L\right) + p_L\right)} < 0,$$

implying that, since the objective function is decreasing in w_G, profit maximization implies lower-

ing w_G until (IC) binds; the (IR) will never bind. The program can therefore be re-written as:

$$\max \quad (G - (w_B + \frac{c_H}{(p_H - p_L)(\alpha_H - \alpha_L)}))(\alpha_H p_H + (1 - \alpha_H)p_L)$$
$$+ (B - w_B)(\alpha_H(1 - p_H) + (1 - \alpha_H)(1 - p_L))$$
$$s.t. \quad w_B \geq 0. \tag{LL}$$

Taking the derivative of the objective function with respect to w_B yields a negative expression, implying that the ifnal solution to this program is:

$$w_G = \frac{c_H}{(p_H - p_L)(\alpha_H - \alpha_L)}$$
$$w_B = 0.$$

The principal's expected profits are equal to:

$$\Pi_{HN}^{SB} = (G - \frac{c_H}{(p_H - p_L)(\alpha_H - \alpha_L)})(\alpha_H p_H + (1 - \alpha_H)p_L)$$
$$+ B(\alpha_H(1 - p_H) + (1 - \alpha_H)(1 - p_L)). \tag{A.40}$$

If the principal targets low-effort without intervention, the optimal solution is $w_G = w_B = 0$ and yielding expected profits equal to:

$$\Pi_{LN}^{SB} = G(\alpha_L p_H + (1 - \alpha_L)p_L) + B(\alpha_L(1 - p_H) + (1 - \alpha_L)(1 - p_L)). \tag{A.41}$$

Simplification of the difference between (A.40) and (A.41) implies that the principal prefers high-effort when:

$$c_H \leq \frac{(p_H - p_L)(G - B)(\alpha_H - \alpha_L)^2}{\alpha_H p_H + (1 - \alpha_H)p_L}.$$

When the principal targets high-effort and intervenes, her maximization program becomes:

$$\max_{w_G, w_B, w_I} \alpha_H(p_H(G - w_G) + (1 - p_H)(B - w_B)) + (1 - \alpha_H)(p_P G + (1 - p_P)B - c_P - w_I)$$

$$\text{s.t.} \quad \alpha_H p_H w_G + \alpha_H(1 - p_H)w_B + (1 - \alpha_H)w_I - c_H$$

$$\geq \alpha_L p_H w_G + \alpha_L(1 - p_H)w_B + (1 - \alpha_L)w_I \tag{ICP}$$

$$p_H w_G + (1 - p_H)w_B \geq w_I \tag{ICR$_H$}$$

$$p_L w_G + (1 - p_L)w_B \leq w_I \tag{ICR$_L$}$$

$$\alpha_H p_H w_G + \alpha_H(1 - p_H)w_B + (1 - \alpha_H)w_I \geq c_H \tag{IR}$$

$$w_i \geq 0. \quad i \in \{G, I, B\} \tag{LL}$$

(ICP) simplifies to:

$$p_H w_G + (1 - p_H)w_B - w_I \geq \frac{c_H}{\alpha_H - \alpha_L}, \tag{A.42}$$

which implies that $w_G \leq w_I \leq w_B$ or $w_G \geq w_I \geq w_B$ since the (RHS) of (A.42) is greater than zero. However, we also have, from (ICR$_H$) and (ICR$_L$) that:

$$p_H w_G + (1 - p_H)w_B \geq w_I$$

$$p_L w_G + (1 - p_L)w_B \leq w_I,$$

which implies that:

$$p_H w_G + (1 - p_H)w_G \geq p_L w_G + (1 - p_L)w_B$$

$$(w_G - w_B)(p_H - p_L) \geq 0,$$

therefore, $w_G \geq w_I \geq w_B$. We can rewrite the (IR) constraint as:

$$p_H w_G + (1 - p_H)w_B \geq \frac{c_H}{\alpha_H} - \frac{(1 - \alpha_H)}{\alpha_H}w_I,$$

which, when the (RHS) of this expression is compared with the (RHS) of (A.42) implies that the (IR) constraint does not bind. The (RHS) of (A.42) also implies that (ICR_H) does not bind since:

$$p_H w_G + (1 - p_H)w_B - w_I \geq \frac{c_H}{\alpha_H - \alpha_L} \geq 0.$$

The principal's program becomes:

$$\max_{w_G, w_B} \quad \alpha_H(p_H(G - w_G) + (1 - p_H)(B - w_B)) + (1 - \alpha_H)(p_P G + (1 - p_P)B - c_P - w_I)$$

$$\text{s.t.} \quad p_H w_G + (1 - p_H)w_B \geq \frac{c_H}{\alpha_H - \alpha_L} + w_I \quad\quad\quad\quad\quad \text{(ICP)}$$

$$p_L w_G + (1 - p_L)w_B \leq w_I \quad\quad\quad\quad\quad\quad\quad\quad\quad \text{(ICR}_L\text{)}$$

$$w_B \geq 0. \quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \text{(LL)}$$

Decreasing w_I until (ICR_L) binds increases profits without changing the (ICP) constraint. Hence, $w_I = p_L w_G + (1 - p_L)w_B$. Substitution of this definition into the objective function yields an expression which is decreasing with respect to w_B; w_B is set to zero. The objective function is also decreasing in w_G, so ICR_L will bind and the final solution is:

$$w_B = 0$$

$$w_I = \frac{p_L c_H}{(\alpha_H - \alpha_L)(p_H - p_L)}$$

$$w_G = \frac{c_H}{(\alpha_H - \alpha_L)(p_H - p_L)}.$$

Computing the expected profits yields:

$$\Pi_{HI}^{SB} = B\left((\alpha_H - 1)\, p_P - p_H \alpha_H + 1\right) + G\left((1 - \alpha_H)\, p_P + p_H \alpha_H\right)$$
$$+ \frac{c_H\left((\alpha_H - 1)\, p_L - p_H \alpha_H\right)}{(p_H - p_L)\,(\alpha_H - \alpha_L)} + c_P\,(\alpha_H - 1). \tag{A.43}$$

If the principal targets low-effort, the optimal contract is to simply pay the agent $w_I = w_G = w_B = 0$ and her profits are equal to:

$$\Pi_{LI}^{SB} = (1 - \alpha_L)\left(B\,(1 - p_P) - c_P + G p_P\right) + \alpha_L\left(B\,(1 - p_H) + G p_H\right). \tag{A.44}$$

Comparing her profits between targeting high-effort (A.43) and low-effort (A.44) implies that she will prefer high-effort when:

$$c_H \leq \frac{(p_H - p_L)\,(\alpha_H - \alpha_L)^2\,(c_P - (B - G)\,(p_H - p_P))}{\alpha_H\,(p_H - p_L) + p_L}.$$

Proof of Proposition 11 When the principal has the agent target low-effort, the program doesn't change from the case without path dependence since paying the agent their reservation wage in all states yields a truthful reporting. Similarly, when the principal targets high-effort, but chooses not to intervene, the optimization program is the same as the case without any linkage, implying that the only contract that needs to be solved for is the case of the principal targeting high-effort and choosing to intervene.

The (IC) constraints become more complicated since the principal must prevent the agent from engaging in multiple possible strategies. If we define Π to be the rents earned by the agent, then the (IC) constraint becomes:

$$E[\Pi|\text{TT}, e_H] \geq \max\{E[\Pi|\text{TT}, e_L], E[\Pi|\text{LT,Low Effort}],$$
$$E[\Pi|\text{TL,Low Effort}], E[\Pi|\text{LL,Low Effort}]\},$$

where (XX), $X \in T, L$ represents the agents strategy choice on whether to reveal the truth or lie for the good or bad signal, respectively. We ignore the possibility that the agent will lie in the high state because the principal can costlessly prevent it. In particular, some of the contracts, since adding any additional constraint is weakly costly to the principal, we assume that the principal, given two contracts will always choose the contract which does not violate these additional constraints. With a small amount of manipulation it can be shown that as long as $w_G^I \geq w_B^I$ and $w_G \geq w_B$ then the principal need not worry about the possibility that the agent will misrepresent the high signal. Since we (basically) ignore this possibility, for the duration of this analysis, any discussion with respect to the agent telling the truth or misrepresenting is about a low-signal, unless otherwise noted.

In the first region, $\frac{i_H}{i_L} \leq \frac{p_H}{p_L}$ and, as is standard, we ignore some constraints and show that the final solution satisfies those constraints. In particular, we ignore the (ICR$_L$), (IR), some (LL) constraints and the constraint associated with the agent shirks and then tells the truth in the low state; the program becomes:

$$
\max_{w_G, w_B, w_G^I, w_B^I} \quad \alpha_H p_H (G - w_G) + \alpha_H (1 - p_H)(B - w_B)
$$

$$
+ (1 - \alpha_H)(i_H (G - w_G^I) + (1 - e_i)(B - w_B^I) - c_P)
$$

$$
s.t. \quad p_H w_G + (1 - p_H) w_B \geq i_H w_G^I + (1 - i_H) w_B^I \tag{ICR$_H$}
$$

$$
\alpha_H (p_H w_G + (1 - p_H) w_B) + (1 - \alpha_H)(i_H w_G^I + (1 - i_H) w_B^I) - c_H
$$

$$
\geq \alpha_L (p_H w_G + (1 - p_H) w_B) + (1 - \alpha_L)(p_L w_G + (1 - p_L) w_B) \tag{ICP$_L$}
$$

$$
w_B \geq 0
$$

$$
w_B^I \geq 0
$$

In our above program the variables w_G^I and w_B^I always appear with the same parameterization, implying that the principal does not need to maximize each individually and can instead combine

the two (we will refer to this combined variable as w^I) . The resulting program:

$$\max_{w_G, w_B, w^I} \alpha_H p_H (G - w_G) + \alpha_H (1 - p_H)(B - w_B)$$

$$+ (1 - \alpha_H)(i_H G + (1 - i_H)B - w^I - c_P)$$

$$s.t. \quad p_H w_G + (1 - p_H)w_B \geq w^I \qquad \text{(ICR}_H)$$

$$\alpha_H (p_H w_G + (1 - p_H)w_B) + (1 - \alpha_H)w^I - c_H$$

$$\geq \alpha_L (p_H w_G + (1 - p_H)w_B) + (1 - \alpha_L)(p_L w_G + (1 - p_L)w_B) \qquad \text{(ICP}_L)$$

$$w_B \geq 0$$

Taking the derivative of the objective function, (ICR$_H$) and (ICP$_L$) with respect to w^I yields, respectively, expressions which are negative, negative and positive. Therefore, (ICP$_L$) will bind since, if it did not, decreasing w^I would yield increased profits and slack in the remaining constraints. Solving (ICP$_L$) for w_I and substituting the resulting expression into our program yields an objective function which is decreasing in w_G and a constraint, (ICR$_H$) which is increasing in w_G implying that the principal will bind (ICR$_H$) to maximize profits. Solving (ICR$_H$) for w_G and substituting the resulting expression into the objective function yields an expression which is decreasing in w_B. This parameter is thus set to zero and the final contract becomes:

$$w_B = 0$$

$$w_G = \frac{c_H}{(1 - \alpha_L)(p_H - p_L)}$$

$$w^I = \frac{c_H p_H}{(1 - \alpha_L)(p_H - p_L)}.$$

We note that there are a number of solutions since only the weighted average of w_G^I and w_B^I, w^I, is specified and not each value. We also see that both parties receive the same expected profit under any contract which specifies the correct sum, though the principal, wishing to avoid having the agent misrepresent the high signal will choose a contract which has $w_G^I \geq w_B^I$. If we simply choose to specify the contract which admits the largest parameter space, then we set $w_B^I = 0$, which

yields the contract presented in the text. Substitution of this solution into the ignored constraints implies that (ICR$_L$) is always positive, but (ICP$_{TT}$) will only bind when

$$c_H \frac{i_H p_L - i_L p_H}{i_H(p_H - p_L)}, \tag{A.45}$$

which is positive when $\frac{i_H}{i_L} \geq \frac{p_H}{p_L}$.

In the second case, $\frac{i_H}{i_L} \geq \frac{p_H}{p_L}$ and $\frac{i_H}{i_L} \geq \frac{\frac{\alpha_H}{(1-\alpha_H)}}{\frac{\alpha_L}{1-\alpha_L}}$, which occurs when the principal solves the following program:

$$\max_{w_G, w_B, w_G^I, w_B^I} \quad \alpha_H p_H(G - w_G) + \alpha_H(1 - p_H)(B - w_B)$$

$$+ (1 - \alpha_H)(i_H(G - w_G^I) + (1 - i_H)(B - w_B^I) - c_P)$$

$$s.t. \quad p_H w_G + (1 - p_H)w_B \geq i_H w_G^I + (1 - i_H)w_B^I \tag{ICR$_H$}$$

$$\alpha_H(p_H w_G + (1 - p_H)w_B) + (1 - \alpha_H)(i_H w_G^I + (1 - i_H)w_B^I) - c_H$$

$$\geq \alpha_L(p_H w_G + (1 - p_H)w_B) + (1 - \alpha_L)(i_L w_G^I + (1 - i_L)w_B^I) \tag{ICP$_{TT}$}$$

$$w_B \geq 0$$

$$w_B^I \geq 0.$$

In this case, the principal can eliminate a variable by substituting $p_H w_G + (1 - p_H)w_B = w^{NI}$, where NI stands for "no-intervention." Taking the derivative with respect to w^{NI}, the objective function, (ICR$_H$) and (ICP$_{TT}$) are decreasing, increasing and increasing respectively; the principal will therefore decreasing w^{NI} until one of these constraints binds. If we first assume that (ICR$_H$) binds, the $w^{NI} = w_B^I(1 - i_H) + w_G i_H$. Substituting this expression into the objective function and taking the derivative with respect to w_B^I yields a negative expression, implying that w_B^I will be set to zero. After substituting zero for w_B^I, and taking the derivative with respect to w_G^I generates a negative value and positive value for the objective and remaining constraint, respectively. This implies that the remaining constraint, (ICP$_{TT}$) will also bind. If, on the other hand, (ICP$_{TT}$) binds first then a similar analysis shows that (ICR$_H$) will bind with $w_B^I = 0$ on the parameter set that we

are concerned with.

In our restricted case we thus have (ICP$_{TT}$) and (ICR$_H$) both binding and w_B^I will be set to zero. Solving these two expression yields:

$$w^{NI} = \frac{c_H i_H}{(1 - \alpha_L)(i_H - i_L)}$$

$$w_G^I = \frac{c_H}{(1 - \alpha_L)(i_H - i_L)}$$

$$w_B^I = 0.$$

The remaining constraints are both decreasing with respect to w_B and since the principal is ambivalent between the multiple contracts, we consider the case where $w_B = 0$ since it admits the largest range of parameters. Such a substitution yields the complement of equation (A.45) and are therefore satisfied by our assumptions. Checking this solution against the ignored constraints shows that they are positive on the relevant region.

In the final region, $\frac{i_H}{i_L} \geq \frac{p_H}{p_L}$ and $\frac{i_H}{i_L} \leq \frac{\frac{\alpha_H}{(1-\alpha_H)}}{\frac{\alpha_L}{1-\alpha_L}}$ and the principal contends with the following reduced program:

$$\max_{w_B^I, w_G^I, w_G, w_B} \quad \alpha_H p_H (G - w_G) + \alpha_H (1 - p_H)(B - w_B)$$

$$+ (1 - \alpha_H)(i_H (G - w_G^I) + (1 - i_H)(B - w_B^I) - c_P)$$

$$s.t. \quad \alpha_H(p_H w_G + (1 - p_H)w_B) + (1 - \alpha_H)(i_H w_G^I + (1 - i_H)w_B^I) - c_H$$

$$\geq \alpha_L(p_H w_G + (1 - p_H)w_B) + (1 - \alpha_L)(p_L w_G + (1 - p_L)w_B) \quad \text{(ICP}_L\text{)}$$

$$\alpha_H(p_H w_G + (1 - p_H)w_B) + (1 - \alpha_H)(i_H w_G^I + (1 - i_H)w_B^I) - c_H$$

$$\geq \alpha_L(p_H w_G + (1 - p_H)w_B) + (1 - \alpha_L)(i_L w_G^I + (1 - i_L)w_B^I) \quad \text{(ICP}_{TT}\text{)}$$

$$w_B \geq 0$$

$$w_B^I \geq 0$$

The derivatives of the objective function, (ICP$_L$) and (ICP$_{TT}$) with respect to w_B are, respectively,

negative, negative and positive. We can therefore increase profits by decreasing w_B until either w_B is equal to zero or (ICP$_{TT}$) binds. If (ICP$_{TT}$) binds before w_B is equal to zero then we can solve it for w_G and substitute this expression into the objective function and the remaining constraint. Manipulation of this expression implies that $\frac{\partial \text{Obj}}{\partial w_G^I} * \frac{\partial \text{ICP}_L}{\partial w_G^I} \leq 0$. Since this is negative, maximizing profits changing w_G^I until (ICP$_L$) binds. Solving (ICP$_L$) for w_G^I and substituting this expression into the objective function implies that both $\frac{\partial \text{Obj}}{\partial w_B}$ and $\frac{\partial \text{Obj}}{\partial w_B^I}$ are negative. Therefore $w_B = w_B^I = 0$. If, on the other hand, $w_B = 0$ before (ICP$_{TT}$) binds then the derivative with respect to w_G of the objective function and ICP$_{TT}$ are negative and positive respectively. If

$$p_H(\alpha_H - \alpha_L) - (1 - \alpha_L)p_L < 0, \tag{A.46}$$

the derivative of (ICP$_L$) is negative, implying that the principal will decrease w_G until (ICP$_{TT}$) binds. Solving the binding constraint for w_G and substituting that expression into the objective function implies that the ratio between the objective function and (ICP$_L$) of the derivatives with respect to w_G^I is negative; therefore (ICP$_L$) will bind optimally. If (A.46) does not hold, then the derivative with respect to w_G of the two constraints is the same sign (and opposite of that of the objective function). The principal will therefore decrease w_G until one of the constraints binds. If (ICP$_{TT}$) binds first, then the analysis in the previous section applies, while when (ICP$_L$) binds first the previous analysis can be applied by swapping the constraints (solve (ICP$_L$) for w_G and then compare the ratio of the derivatives with respect to w_G^I of the objective function and (ICP$_{TT}$)). In either case, both constraints bind and we can solve them jointly for w_G and w_G^I, substitute into the objective function and see that the derivative of the result, with respect to w_B and w_B^I are both negative, implying that the final contract is equal to:

$$w_B = w_B^I = 0$$

$$w_G = \frac{c_H i_L}{p_L \left(i_H(1 - \alpha_H) + i_L (\alpha_L - 1)\right) + i_L p_H (\alpha_H - \alpha_L)}$$

$$w_G^I = \frac{c_H p_L}{p_L \left(i_H (1 - \alpha_H) + i_L (\alpha_L - 1)\right) + i_L p_H (\alpha_H - \alpha_L)}$$

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The solution above satisfies the remaining constraints on the relevant range.

Proof of Proposition 12 We begin with an analysis of the economically efficient level of intervention. Similar to Lemma 2, in the sense that since there are no informational inefficiencies, the principal can simply pay the agent any combination of wages which satisfies the (IR) constraint by giving the agent an expected payment of c_H. When comparing regimes, therefore, the principal will engage in high-effort when there is no intervention, only when:

$$c_H \leq (\alpha_H - \alpha_L)(p_H - p_L)(G - B),$$

which is the same condition as in Lemma 2. Comparing the marginal costs and benefits associated with intervening when the principal has targeted low-effort yields the following condition as to when the principal will intervene:

$$(i_L - p_L)(G - B) \geq c_P.$$

The above equation also implies that when $i_L < p_L$ the principal will intervene. Similar analysis implies that the principal will engage in intervention, conditional on high-effort, when:

$$(i_H - p_L)(G - B) \geq c_P, \tag{A.47}$$

which is always true for some values of c_P. Unlike the case without linked intervention, the boundary between high-effort and intervention and low-effort is non-null. Comparing the profits under each regime implies that the principal will choose intervention when the following expression holds true:

$$c_P \leq -\frac{c_H}{1 - \alpha_H} + \frac{(G - B)((1 - \alpha_H)i_H + \alpha_H p_H - \alpha_L p_H - p_L + \alpha_L p_L)}{(1 - \alpha_H)},$$

which is decreasing in c_H. The final boundary, between the region where the principal intervenes

and selects high-effort and where she chooses low-effort has the following boundary:

$$c_P \leq \frac{c_H}{\alpha_H - \alpha_L} + \frac{(G - B)(-i_H(1 - \alpha_H) + i_L - \alpha_L i_L - \alpha_H p_H + \alpha_L p_H)}{\alpha_H - \alpha_L}.$$

The second part of this proof compares the economically efficient levels of intervention discussed above and the second-best levels derived from comparing the profits under the second-best contract. We first consider the boundary between when the principal targets high-effort and intervenes and targets high-effort and does not intervene. The contract contains three cases. When going between the high-effort intervention and high-effort no intervention regions, the boundary line is equal to the economically efficient line (A.47) with one of the following terms added on:

$$\frac{c_H(\alpha_L(p_H + p_L))}{(\alpha_H - \alpha_L)(1 - \alpha_L)(p_H - p_L)}$$

$$\frac{c_H \left(\frac{i_H(\alpha_H - \alpha_L)}{(\alpha_L - 1)(i_H - i_L)} + \frac{p_L}{p_H - p_L} + \alpha_H \right)}{(\alpha_H - 1)(\alpha_L - \alpha_H)}$$

$$\frac{c_H p_L (i_H - i_L)(\alpha_L(p_H - p_L) + p_L)}{(p_H - p_L)(\alpha_H - \alpha_L)(p_L(i_H(-\alpha_H) + i_H + i_L(\alpha_L - 1)) + i_L p_H(\alpha_H - \alpha_L))}.$$

All of these terms are positive and increasing in c_H. When moving from the case when the principal does not intervene and incentivizes high-effort and the case where the principal does not intervene and targets low-effort yields the same cut-off levels as the unlinked case since neither of these contracts change with this model extension. Unlike the unlinked case, there is a boundary between the case intervention, high-effort case and the no-intervention, low-effort case. Comparing the boundary line in (c_H, c_p) space we find that line between the economically efficient boundary and the second-best boundary share the same c_p intercept, but the line for second-best boundary has a more negative slope, implying that the boundary line has moved inward and decreased the amount of intervention. The last boundary, between the case when the principal targets high-effort and intervention and the case where the principal targets low-effort and intervention only exists when $i_L > p_L$, since if this inequality is reversed the principal will never wish to intervene. Using analysis similar to the previous cases we find that the boundary line has moved inward, implying

that the principal increases the region where low-effort is targeted, though the intervention region remains unchanged. The final boundary, between where the principal targets low-effort intervention and low-effort without intervention does not change since when compared to the second-best unlinked case since the contract is unchanged.

Appendix B

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