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ABSTRACT

Capital rationing is an empirically well-documented phenomenon. This constraint requires managers to make investment decisions between mutually exclusive investment opportunities. In a multiperiod agency setting, this paper analyses accounting rules that provide managerial incentives for efficient project selection. In oder to motivate a short-sighted manager to expend unobservable effort and to make efficient investment decisions, the principal sets up an incentive scheme based on residual income (e.g. EVA^{TM}). The paper shows that income smoothing generates a trade-off between agency costs resulting from differences in discount rates and the costs associated with the "congruity" of residual earnings.

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Project Selection, Income Smoothing and Bayesian Learning

Capital rationing is an empirically well-documented phenomenon. This constraint requires managers to make investment decisions between mutually exclusive investment opportunities. In a multiperiod agency setting, this paper analyses accounting rules that provide managerial incentives for efficient project selection. In oder to motivate a short-sighted manager to expend unobservable effort and to make efficient investment decisions, the principal sets up an incentive scheme based on residual income (e.g. EVA™). The paper shows that income smoothing generates a trade-off between agency costs resulting from differences in discount rates and the costs associated with the "congruity" of residual earnings. (JEL: M 41, G 31, D 82)

1 Introduction

In practice, compensation schemes based on accounting information play an important role in bringing managers into line with shareholders´ objectives.[1] In particular, residual income (e.g. EVA™) has received a great deal of attention.[2] For calculating residual income many firms start with accounting income under generally accepted accounting rules and subsequently make adjustments for performance measurement purposes.[3] When rewarding the manager on the basis of residual income, accounting rules and their adjustments are an important device in providing managerial incentives. Despite the considerable popularity, incentive schemes based on EVA™ have not been analyzed in

[1] For a survey see ITTNER AND LARCKER [2001].

[2] This performance measure is closely related to the firm´s market value of equity if earnings are measured in accordance with the clean surplus principle. See, e.g., PREINREICH [1937], PEASNELL [1982], OHLSON [1995].

[3] Up to 165 adjustments to generally accepted accounting principles are postulated in STEWART [1994]. For a survey see YOUNG AND O´BYRNE [2001, pp. 205-268].

situations in which a manager has to make an investment decision between mutually exclusive investment projects.

This paper will study a setting in which residual income should be able to induce a correct project selection. I will examine a multiperiod principal-agent model in which a capital investment decision is delegated to a better informed agent. Before obtaining access to profitable investment opportunities the manager has to exert research effort at his own expense. The principal implements an incentive scheme based on accounting information in order to motivate effort and managerial investment decisions that maximize firm value.

If the available investment projects are mutually exclusive, the agent will maximize firm value if he adopts the project with the highest net present value (NPV). When compensating the agent based on accounting information, income smoothing generates residual earnings that correctly reflect the ranking of various investment opportunities.[4] Due to his research effort, the agent is better informed about the NPV of the investment projects than the principal. Yet, an accounting system provides the principal with information about individual cash flows of each investment project adopted by the agent. Observing noisy cash flow signals, the principal updates his prior beliefs about the NPV. Annuitizing the conditional mean of the NPV generates a smoothed stream of residual earnings.

The paper will show that the more signals the principal observes, the better the capability of residual earnings to reflect the ranking of investment projects. Thus, the information contained in the cash flow signals is beneficial to the principal and would lead

[4] EGGINTON [1995] shows that representing residual earnings as the annuity of the NPV at each date leads to a periodic consistency of earnings and NPV which induces a manager to maintain the ranking of mutually exclusive investment projects.

him to compensate the agent as late as possible. However, shifting compensation payments to the future is costly to the principal if the manager is short-sighted and has a discount factor that exceeds the firm´s cost of capital. If an impatient manager is paid for his personal effort costs at a late point in time, he will demand a premium for late compensation. I will show that income smoothing leads to a trade-off between agency costs resulting from differences in discount rates and the benefits associated with the information contained in noisy cash flow signals.

2 Contribution to existing literature

This analysis builds on prior literature examining the potential of residual income in providing managerial investment incentives in multiperiod settings. Part of this earlier work shows that residual income can provide optimal investment incentives when the manager´s time preference is unknown to the principal.[5] These studies analyze goal-congruent performance measures which induce an agent to accept only positive NPV projects, or to determine the optimal level of investment. Some of these papers find residual income to be an optimal measure of performance if additional information about the growth rate of future cash flows is available to the principal. This information is used to construct a depreciation schedule that represents residual earnings as a positive constant of the NPV at each and every date. This allocation scheme is called "relative benefit depreciation schedule" (RBD schedule).

The optimality of the RBD schedule is crucially driven by the availability of reliable information about future cash flows. LAMBERT [2001] considers the analysis of a multi-

[5] See ROGERSON [1997], REICHELSTEIN [1997], [2000]; DUTTA AND ZHANG [2002], BALDENIUS AND ZIV [2003], WAGENHOFER [2003].

period setting in which additional information is not available as an important research issue. Following the suggestions in LAMBERT [2001, p. 79], this paper will analyze the economic characteristics of accounting rules that do not require information about a deterministic growth parameter of future cash flows.

In REICHELSTEIN [1997], [2000] and DUTTA AND REICHELSTEIN [2002] a manager is induced to accept (reject) all projects with a positive (negative) NPV. However, a manager has to reject investment opportunities with a positive NPV whenever capital constraints prevent the manager from realizing all proftable investment opportunities.[6] In this case, the principal wants the agent to realize the project with the highest NPV. It can be shown that the RBD schedule does not induce a manager to make an optimal investment decision between mutually exclusive projects.[7] Whereas the RBD schedule induces a manager to correctly differentiate between profitable and unprofitable projects, this paper studies a setting in which a short-sighted manager has to make a ranking of profitable investment opportunities.

This paper is also related to the analysis in REICHELSTEIN [2000] in which the agency costs of a cash flow-based incentive scheme is compared to residual income-based compensation. Different accounting rules lead to a different intertemporal allocation of economic performance. In particular, performance measurement has wealth effects if principal and agent have diverging time preferences. If the agent´s discount rate exceeds

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[6] GRAHAM AND HARVEY [2001], POTERBA AND SUMMERS [1995] and SCAPENS AND SALE [1981] demonstrate capital rationing to be a realistic assumption. For theoretical explanations see ANTLE AND EPPEN [1985], HARRIS AND RAVIV [1996], ZHANG [1997].

[7] Consider, e.g., two projects A and B that are mutually exclusive. They are given by the cash flow-tuples A = (-100;+10;+20;+150) and B = (-100;+125;+20;+10). At the firm´s cost of capital of 10 % the principal prefers A. Matching the cash investment of –100 and the interest costs according to the RBD scheme generates residual earnings for A of (0;+2.77;+5.54;+41.55) and for B of (0;+34.83;+5.54;+2.77). If compensation payments are strictly increasing in the performance measure, the agent seeks to maximize the present value of future residual earnings. If the agent´s discount rate is 20 % (or higher), the manager will prefer project B.

that of the principal, then agency costs vary depending on when the manager is compensated. Shifting compensation payments to earlier periods reduces the agent´s time preference premium and diminishes agency costs. REICHELSTEIN [2000] shows that residual income-based compensation at all intermediate periods of the project´s useful life economizes on agency costs in comparison to compensation based on the compounded value of cash flows. This paper shows that the availability of disaggregate cash flow information can considerably reduce agency costs even further if residual earnings provide ideal investment incentives at each date. In this case, compensation based on a single residual earnings figure can motivate the manager to work and make a correct investment decision at lower costs than compensation based on all residual earnings available in the course of time.

Furthermore, this paper shows that including all residual earnings in the incentive scheme is beneficial to the principal, if residual earnings do not provide ideal investment incentives. Using all residual earnings for performance measurement is beneficial to the principal because earnings are affected by noisy cash flow signals observed by the principal at subsequent dates. These cash flow signals are informative about the agent´s investment decision because they contain information about the profitability of the adopted investment project. Whereas in REICHELSTEIN [2000] managerial compensation at a late point in time generates additional agency costs but no benefits, I will show that late cash compensation can enhance the effectiveness of providing managerial investment incentives. The paper discusses a trade-off between the agency costs resulting from differences in discount rates and the efficiency in providing managerial investment incentives.

The remainder of the paper is organized as follows. Section 3 describes the model. Section 4 characterizes possible accounting rules that provide perfect incentives in a first best-scenario. Section 5 studies the comparative statics of these accounting rules in a second best-scenario in which principal and agent have asymmetric information. Section 7 concludes the study.

3 The Basic Model

In $t = 0$ a principal offers a contract to a manager (agent). The contract is designed to hire the manager for T periods which exactly cover the agent´s planning horizon. In oder to obtain access to profitable investment opportunities the agent has to exert research effort at each date $t \in [0,...,T-n]$. Managerial effort can be interpreted as a personal investment in firm-specific human capital. Upon recognizing the currently available investment projects, the agent has to decide which project to accept, if any. The investment decision is delegated to the agent because he has superior knowledge about the profitability of the investment projects. Due to exogenous constraints such as capital, time or capacity restrictions the manager can only realize one project each period. This requires the agent to establish a ranking of mutually exclusive investment projects. The principal would like the manager to accept the project with the highest NPV.

In order to gain access to profitable investment opportunities, the agent has to exert unobservable effort in each period. If the manager does not exert the required level of effort, then he does not recognize profitable investment projects by certainty at that time. Since managerial effort cannot be observed, the principal cannot assess whether a profitable investment project has not been realized in t because the agent has faield to exert the required level of effort, or because unfavorable conditions prevented the agent from obtaining access to profitable investment projects. For simplicity, I will assume that the agent´s effort choice is binary with $e_t \in \{0,1\}$. If the effort variable is $e_t = 1$ ($e_t = 0$), then the agent has exerted (no) effort in period *t*. For $e_t = 1$ the agent incurs effort costs at $v \cdot e_t$.

By exerting effort, the agent independently draws a sample of investment opportunities from a time-invariant distribution. Out of this sample the agent should be able to realize the investment project with the highest NPV. This means that each period the agent selects one project out of the same distribution of investment projects. The current investment decision is assumed to have no impact on the set of future investment opportunities. The ex ante probability that the agent will detect profitable investment opportunities is denoted $p \equiv f(NPV(\tilde{P}_t) \geq 0)$. The expected value of the ex ante probability distribution is assumed to be $E[NPV(P_t) \mid NPV(P_t) \geq 0] < \infty$. With a probability of $(1-p)$ there are currently no profitable projects available even if the agent expends the required level of effort.

The useful life of an investment project P_t realized in *t* consists of *n* periods. The investment project can be represented by the (*n*+1)-tuple $P_t = (\tilde{c}_{t0}, \tilde{c}_{t1}, ..., \tilde{c}_{tn})$ with $\tilde{c}_{t0} < 0$ denoting the initial investment outlay. The elements $\tilde{c}_{t1}$ ($\tilde{c}_{tn}$) denote the first (last) noisy cash flow of the project realized at date *t*. Provided that the manager chooses $e_t = 1$ the expected value of cash flows associated with P_t are known to the manager but not to the principal. The last project is realized at date $T-n$, which generates cash flows from period $T-n$ to *T*. This means that all cash flows are realized at date $t \in [1,...,T]$. Since the last investment decision is made at date $T-n$, the principal may want the manager to take outside employment opportunities starting at date $T-n+1$, while the incentive scheme holds the agent responsible for his investment decisions by receiving deferred cash compensation for the last *n* dates. Thus, the planning horizons of principal and agent are identical and comprise a space of time from $t=0$ to $t=T$.

At the beginning of each period the principal provides the agent with capital to finance the accepted investment project. It is assumed that the principal provides the agent with a fixed capital budget. Capital rationing requires the agent to make an investment decision between mutually exclusive profitable investment projects, i.e., out of two investment projects with identical cash investments the manager will be motivated to select the project with the highest NPV. *Table I* illustrates the sequence of events between two representative points of time.

Table I: Sequence of events

$t=0$	t				$t+1$
Contract signed	Effort	Private Information	Investment Decision	Investment Outlay $\tilde{c}_{t0}$	Cash Flow $\tilde{c}_{t1}$

In order to motivate the agent to expend research effort and to make good investment decisions, the principal implements an incentive system that consists of a sharing rule s and some performance measure P . Wage payments w_t are given by

$$w_t = \max\{\overline{w}_t,\ \bar{s}_t + s_t P_t\}, \text{ for } 0 \leq t \leq T . \qquad (1)$$

The performance measure in (1) can be based on various intertemporally overlapping investment projects so that $P_t = \sum_{i=0}^{t-1} P_{i,t-i} \cdot I(P_i)$, with $I(P_i)=1$ if the agent has accepted a project in period *i*, and $I(P_i)=0$ otherwise. In (1) $\overline{w}_t \geq 0$ denotes the agent´s wealth constraints. This implies that the agent´s aggregate wage is restricted to positive compensation payments. The fixed wage $\bar{s}_t$ is crucially determined by the agent´s participation constraint. In order to retain the agent against competitive employment opportunities, the principal has to consider the agent´s market alternatives by at least providing him with his reservation utility:

$$\bar{s}_t = \bar{u}_t = 0 \text{, for all } t = 0,...,T. \tag{PC}$$

The agent is risk neutral and seeks to maximize the present value of future compensation payments net of effort costs:

$$U = \sum_{t=0}^{T} E[w_t - v \cdot e_t] \cdot g_A^t. \tag{2}$$

The variable g_A^t represents the agent´s discount factor with $g_A^t \equiv (1+r^A)^{-t}$. The agent can be motivated to exert effort only if the present value of future cash payments associated with his effort choice is able to compensate his personal effort costs. At each date, the principal has to consider the agent´s incentive compatibility constraint which is given by

$$p \sum_{i=0}^{n} s_{ti} E[P_{ti} \mid NPV(P_t) \geq 0] g_A^i \geq v. \tag{IC}$$

The principal is assumed to be risk neutral, as well. In this case, maximizing individual utility corresponds with maximizing firm value. Thus, the agent acts in accordance with the principal´s objective if he realizes the investment project with the highest NPV. The principal´s utility function is given by:

$$V = \sum_{t=0}^{T} E[c_t - w_t] \cdot g_P^t, \tag{3}$$

where $g_P^t \equiv (1+r^P)^{-t}$ and r^P denoting the principal´s cost of capital. The agent´s time preference can differ from that of the principal. In particular, it shall be assumed that the agent is more impatient than the principal, which can be expressed as $r^A > r^P$ and

$g_P^t > g_A^t$ for all t. Although the principal is *not* informed about g_A^t, he knows ex ante that $g_A^t \in [\underline{g}_A^t; g_P^t]$. Differences in discount rates can be attributed to imperfections that cause the manager´s borrowing and lending opportunities to be inferior to those available to the principal. This is frequently considered to be a realistic assumption, since capital markets prefer lending to a firm with deeper pockets and more extensive financial reporting requirements.[8] Due to these imperfections there are no infinitely large private banking activities between principal and agent.

4 „First best-incentives“ under symmetric information

The RBD schedule does not induce a manager to accept the project with the highest NPV, because these accounting rules represent residual earnings as a time-variant constant of the NPV, depending on the growth rate of cash flows. In order to motivate a short-sighted manager to accept the most profitable project, residual income can be represented as a time-*in*variant constant (e.g. the annuity) of the NPV in each period. In this case, the agent receives the highest compensation payments in each period if he realizes the most profitable investment project. The special role of this particular periodic consistency of residual income and NPV has been studied in EGGINTON [1995]. Representing residual earnings as a time-invariant constant of the NPV enables residual earnings to reflect the NPV rankings of mutually exclusive projects.

Starting with the clean surplus principle that requires all changes in net assets to be recognized in net income, residual earnings RI_{ti} can be expressed as

$$RI_{ti} = c_{ti} - (1 + r^P) B_{ti-1} + B_{ti} ,$$

8 See SRINIDHI, RONEN AND MAINDIRATTA [2001, p. 284].

with B_{ti} representing the book value of P_t at date $t+i$. For simplicity, it is assumed that changes in book value are caused by a single depreciation charge d_{ti} with $d_{ti} \equiv B_{ti-1} - B_{ti}$. In order to maintain the NPV rankings, EGGINTON [1995, p. 213] suggests the following depreciation schedule:

$$d_{ti} = c_{ti} - v \cdot NPV(P_t) - r^P \left(B_{t0} - \sum_{j=1}^{i-1} d_{tj} \right), \text{with } v = \frac{r^P (1+r^P)^n}{(1+r^P)^n - 1}. \qquad (4)$$

It can easily be verified that the depreciation charge d_{ti} is „complete“ since the present value of the allocated investment costs equal the initial investment outlay B_{t0}. The depreciation schedule d_{ti} generates residual earnings that represent a time-invariant constant of the NPV. Therefore, residual income coincides with the annuity of the NPV:

$$RI_{ti} = c_{ti} - d_{ti} - r^P \left(B_{t0} - \sum_{i=1}^{i-1} d_{ti} \right) = v \cdot NPV(P_t). \qquad (5)$$

Under this accounting rule the project with the highest NPV generates the highest performance measure in each and every period. If compensation payments are strictly increasing in the performance measure, the agent will be motivated to accept the most profitable project at all dates independently of his time preference.[9] This depreciation schedule generates residual earnings which are identical at all dates for projects of equal profitability. Consequently, both principal and agent are indifferent between projects of equal profitability. Yet, this solution requires the principal to be as well informed about the profitability of the investment opportunity as the agent. In this respect, the analysis of this section can be regarded as a first best-case in which principal and agent have

9 Note, that the depreciation schedule d_{ti} generates efficient incentives for project selection without having to restrict the domain of available projects to the class of investment opportunities with only positive cash inflows in $i = 1,...,n$.

symmetric information about the project´s NPV.[10] This benchmark can never be attained by taking asymmetric information into consideration.

Nevertheless, assume that the agent is compensated based on the performance measure in (5) which provides perfect investment incentives in each period. For each adopted project the principal seeks to maximize the ex ante expected NPV net of compensation payments subject to the constraints of incentive compatibility and participation:

$$\max_{\bar{s}_t, s_{ti}} V(P_t) = pE[NPV(P_t) \mid NPV(P_t) > 0] - \sum_{i=1}^{n} s_{ti} g_P^i \, pE[P_{ti} \mid NPV(P_t) > 0] - \bar{s}_t \,, \tag{6}$$

subject to (IC) and (PC). In order to solve for the motivation problem, the principal can choose a bonus coefficient of:[11]

$$s_{ti} = s_t \cdot g_P^i / \underline{g}_A^i \,.$$

Solving the principal´s problem in (6) leads to the following results:[12]

Proposition 1: Assume that a performance measure P provides efficient investment incentives in each and every period $i = 1,...,n$ so that $P_{ti} = v \cdot NPV(P_t)$. If $g_P^i > g_A^i$, compensating the agent in all periods $i = 1,...,n$ based on P generates higher agency costs than a single compensation amount in $i = 1$.

In order to hold the impatient manager at his minimum utility level, cash compensation has to be the higher, the later the manager is compensated. For $g_A^i < g_P^i$ deferring cash compensation to the future has wealth effects, since the agent charges a premium

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10 In principle, the provision of investment incentives is immaterial under symmetric information. The analysis in section 5 below studies the implementation and the comparative statics of income smoothing when the principal is less informed about the profitability of the available investment opportunities.

11 An agent whose actual discount factor exceeds the lower bound $\underline{g}_A^i$ will earn rents, which result from deferring cash compensations to the future at a higher interest rate. However, due to the performance measure in (5) the incentive scheme induces an optimal project selection.

12 All proofs appear in the appendix.

for late compensation. Proposition 1 shows that the accumulated agency costs continuously increase in the course of time. If residual earnings generate efficient investment incentives in every period *i*, agency costs can be considerably reduced by focusing all compensation payments on the first period. Since the performance measure provides efficient investment incentives at all dates, the agent can be effectively rewarded for hard work and good decisions already by a single compensation amount at date $i=1$. When disaggregate cash flow information is available, compensation in $i>1$ generates additional agency costs resulting from differences in discount rates, but no benefits. The following section shows that including subsequent residual earnings in the incentive scheme brings about some benefits if the principal is less informed about the NPV of the realized project.

5. The income smoothing-solution in a second best-scenario

In this section, I will analyse the properties of smoothed residual earnings to provide investment incentives in a setting in which principal and agent have asymmetric information. I will first provide a description of the information asymmetry between principal and agent. Afterwards, I will analyze the comparative statics of the income smoothing-solution.

5.1 Representation of asymmetric information and Bayesian updating

The investment project P generates a stream of uncertain cash flows $\tilde{c}_{ti}$, $i=0,...,n$. The variable $\ln\tilde{c}_{ti} = \ln c_{ti} + \ln\tilde{e}_{ti}$ is normally distributed with mean $E[\ln\tilde{c}_{ti}] = \ln c_{ti}$. The noise term $\tilde{e}_{ti}$ is a lognormally distributed random variable. Choosing $e_t = 1$, the agent can ascertain the parameter c_{ti} whereas this information is not available to the principal. It is assumed that communication between principal and agent about private information of the latter is blocked.[13] Since the agent is better informed about the profitability of the investment project, the principal delegates the investment decision to the agent.[14] The agent acts in the best interests of the principal if he realizes the project with the highest NPV. Assuming, without loss of generality, that the principal´s cost of capital is zero, the NPV can be reprensented as the sum of the uncertain cash flow stream $\ln N\tilde{P}V_t = \sum_{i=0}^{n} \ln \tilde{c}_{ti} = \sum_{i=0}^{n} \ln c_{ti} + \ln \tilde{e}_{ti}$.

In contrast to prior literature, this analysis takes into consideration that the principal can have prior beliefs about the NPV. Since all cash flows are lognormally distributed, the principal´s a priori beliefs are:

$$E^P[N\tilde{P}V_t] = \exp\left\{ E^P\left[\sum_{i=0}^{n} \ln \tilde{c}_{ti}\right] + Var\left[\sum_{i=0}^{n} \ln \tilde{c}_{ti}\right] \Big/ 2 \right\}. \tag{7}$$

I assume that the principal has implemented an accounting system that provides him with information about realized cash flows.[15] In each period, a noisy signal $\tilde{S}_{ti}$ informs the principal about individual cash flows with

$$\ln \tilde{S}_{ti} \equiv \ln \tilde{c}_{ti} + \ln \tilde{q}_{ti} = \ln c_{ti} + \ln \tilde{e}_{ti} + \ln \tilde{q}_{ti}. \tag{8}$$

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13 MELUMAD, MOOKHERJEE AND REICHELSTEIN [1992] show that delegating decisions to responsibility centers is superior to centralized decision making when communication is limited.

14 Whereas in standard agency literature the agent is exogenously endowed with private information, in this analysis the agent must work to acquire superior information about the profitability of the investment projects. Similarly LAMBERT [1986] and DEMSKI AND SAPPINGTON [1984].

15 To some extent, this assumption is realistic since recent accounting standards in particular tend to require the availability of disaggregate cash flow information. Besides IAS 7.50 (d) and FRS 1.8 which recommend the provision of disaggregate cash flow information at segment level, SFAS 141 also requires the availability of such data when testing goodwill and intangible assets for impairment at reporting unit level which might be even one level below segment.

The additional noise term q embodies a possible measurement error that may stem from attributing an aggregate cash flow of various overlapping investment projects to individual projects. The random variables $\ln\tilde{e}_{ti}$ and $\ln\tilde{q}_{ti}$ are normally distributed with mean $E[\ln\tilde{e}_{ti}]=E[\ln\tilde{q}_{ti}]=0$. For simplicity, I assume that all elements of the vector $\left(\ln\tilde{e}_{t0},...,\ln\tilde{e}_{tn},\ln\tilde{q}_{t0},...,\ln\tilde{q}_{tn}\right)$ are pairwise independent. The $(n+2)$-dimensional random variable $\left(N\tilde{P}V_t,\tilde{\boldsymbol{S}}_{\boldsymbol{t}}\right)$ has a joint lognormal distribution with $\tilde{\boldsymbol{S}}_{\boldsymbol{t}}=\left(\tilde{S}_{t0},...,\tilde{S}_{tn}\right)^T$ representing a $(n+1)$-dimensional random variable.

In this setting, the principal does not know the actual mean of the NPV. However, for generating an ex ante smooth stream of residual earnings the principal can annuitize the conditional mean of the NPV at each date $t+i$ based on the information available at that date. Under asymmetric information, smoothed residual earnings can be written as $RI_{ti}^*\equiv v\cdot E^P[N\tilde{P}V_t\,|\,\tilde{S}_{t0},...,\tilde{S}_{ti}]$. This representation is characterized by the following proposition.

Proposition 2: For any multivariate lognormal distributed random vector $(N\tilde{P}V_t,\tilde{S}_{t1},...,\tilde{S}_{tn})$ smoothed residual earnings RI_{ti}^* associated with project P_t can be expressed as

$$RI_{ti}^*=v\cdot E^P[N\tilde{P}V_t\,|\,\tilde{S}_{t0},...,\tilde{S}_{ti}]= \tag{9}$$

$$v\cdot\exp\left\{\underbrace{\sum_{j=0}^{i}\left(1-b_{tj}\right)}_{\to 0\text{ for }b\to 1}\left(E^P[\ln\tilde{c}_{tj}]+\frac{Var[\ln\tilde{c}_{tj}]}{2}\right)+\underbrace{\sum_{j=0}^{i}b_{tj}\ln\tilde{S}_{tj}}_{\text{increasing in }i}+\underbrace{\sum_{j=i+1}^{n}\left(E^P[\ln\tilde{c}_{tj}]+\frac{Var[\ln\tilde{c}_{tj}]}{2}\right)}_{\to 0\text{ for }i\to n}\right\}$$

$$\text{with } b_{tj}=\frac{Cov[N\tilde{P}V_t,\ln\tilde{S}_{tj}]}{Var[\ln\tilde{S}_{tj}]}=\frac{Var[\ln\tilde{c}_{tj}]}{Var[\ln\tilde{c}_{tj}]+Var[\ln\tilde{q}_{tj}]}\le 1.$$

The performance measure in (9) consists of three terms within the brace. The first and the second component represent a weighted average of the principal´s a priori beliefs and the cash flow signals. The impact of prior beliefs and signals on the posterior mean depends on a priori noise and the noise of the signal which is reflected by b: the noisier the signal, the lower its impact on the posterior mean. If a signal contains perfect information ($Var[\ln \tilde{q}_i] = 0$), all a priori beliefs are discarded. The regression coefficient b_{tj} shows the credibility of the signal $\tilde{S}_{tj}$ in relation to the credibility of a priori information. The third component represents the principal´s a priori beliefs about future cash flows subsequent to date $t+i$ for which no cash flow signals have been observed so far.

5.2 Income smoothing and providing investment incentives

Since the principal is not properly informed about the NPV, smoothed residual earnings can only be expressed as the annuitized conditional mean of the NPV. Provided that all fixed wages are zero, the agent receives compensation payments based on RI^*_{ti}:

$$w_t = \max\{0\,; s_t \cdot P_t\} \text{ with } P_t = \sum_{i=0}^{t-1} RI^*_{i,t-i} \cdot I(P_i)\,.$$

Since the principal a priori expects the agent to realize an investment project with a non-negative NPV, the expected performance measure RI^*_{ti} is non-negative. As all random variables are lognormally distributed and thus continuous in the interval $(0,\infty)$, the agent´s limited liability constraint is met at all dates. Thus, the constraints of incentive compatibility (IC) and of participation (PC) remain unaffected.

However, the agent´s investment decision crucially depends on the performance measure RI^*_{ti}. When making an investment decision at date t, the agent expects his cash compensation at date $t+i$ to be based on the principal´s a priori information and on the observed cash flow signals. The impact of the principal´s prior information on the performance measure entails some inefficiencies in motivating value maximizing investment decisions. If a priori beliefs have a strong impact on the performance measure, the agent is more likely to select that project which the principal *believes* to be the most profitable one. The performance measure entails some non-congruity. In accordance with DATAR/KULP/LAMBERT [2001, p. 80], I will denote N to be an aggregate measure of non-congruity associated with the performance measure P_{ti}:

$$N = \sum_{i=1}^{n} \left(N\tilde{P}V(P_t) - \tilde{P}_{ti}(P_t) \right)^2 .$$

For $N = 0$ the performance measure is said to be perfectly congruent. The non-congruity of each individual $R\tilde{I}_{ti}^*$ is measured by:

$$N(ß,i) = N\tilde{P}V(P_t) - \frac{1}{v} R\tilde{I}_{ti}^*(P_t), \text{ with } ß = (b_1, ..., b_i). \tag{10}$$

Proposition 2 shows that the weight of prior information in the performance measure gradually decreases in the course of time, i.e., the congruity of the performance measure depends on

- the informativeness of the signals: $\partial N(ß,i)/\partial ß < 0$,
- the number of signals observed by the principal: $\partial N(ß,i)/\partial i < 0$.

It can easily be verified that $N(ß,i) = 0$ for $ß = (1,...,1)$ and $i = n$. The lack of congruity generates additional costs in terms of inducing sub-optimal managerial investment decisions. These costs are denoted $f(N(ß,i))$ with

$$f(N(ß,i)) \equiv N\tilde{P}V\left(P_t\left(N(ß,i) = 0\right)\right) - N\tilde{P}V\left(P_t\left(N(ß,i) > 0\right)\right).$$

This definition implies that $f(0)=0$, $f(N(\beta,i)>0)>0$ and $\partial f(.)/\partial N(\beta,i)>0$. The lack of congruity induces the agent to deviate from the optimal investment strategy. By normalizing the agent´s reservation utility to zero the principal´s problem is:

$$\max_{s_{ti},\bar{s}_t} \left\{ pE\left[N\tilde{P}V(P_t) \mid N(\beta,i)\right] - p\cdot s_{ti}\cdot E\left[R\tilde{I}^*_{ti}(P_t) \mid N(\beta,i)\right]\cdot g^i_P - \bar{s}_t \right\}$$

s.t.: $p\cdot s_{ti}\cdot E\left[R\tilde{I}^*_{ti}(P_t) \mid N(\beta,i)\right]\cdot g^i_A \geq v$ and $\bar{s}_t = 0$.

The comparative statics of compensation at date $t+i$ based on $R\tilde{I}^*_{ti}$ can be examined by comparing a benchmark case ($N(\beta,i)=0$ and $g^t_P = g^t_A$) with the second best-scenario in which $N(\beta,i)>0$ and $g^t_P > g^t_A$. The following proposition shows the results.

Proposition 3: Assume that for $e_t = 1$ the manager is rewarded by cash compensation at date $t+i$. Rewarding the agent at date $t+i$ on the basis of RI^*_{ti} causes agency costs of

$$AC\left(f(.),v,\underline{g^i_A}\right) = p\cdot f\left(N(\beta,i)\right) + v\left(\frac{g^i_P}{\underline{g^i_A}} - 1\right). \tag{11}$$

In line with previous findings, proposition 3 shows that agency costs increase in the course of time due to the differences in discount rates. The second term in (11) shows that compensating the agent at date $t+i$ for his effort costs incurred in t is more expensive than rewarding him in period $t+i-1$. In order to hold the agent at his minimum utility level, cash compensations have to increase in the course of time. This component would induce the principal to reward the agent as early as possible. If the principal is less informed about the NPV of the realized project, the increase in agency costs resulting from the agent´s impatience can be traded against the benefits resulting from the first term in (11). Proposition 3 shows that a compensation in late periods also brings about some benefits. Revising prior beliefs based on the signals observed at date $t+i$ reduces the costs associated with the lack of congruity.

Corollary: Assume that the agent is compensated based on RI_{ti}^{*} for his effort e_t. In each period $i=1,...,n$ such a compensation generates a trade-off between the agency costs associated with the agent´s time preference premium and the costs due to the lack of congruity. This trade-off can be expressed as

$$\frac{dAC\left(f(.),v,\underline{g}_{A}^{i}\right)}{di}=p\cdot\underbrace{\underbrace{\frac{\partial f(N(\boldsymbol{\beta},i))}{\partial N(\boldsymbol{\beta},i)}}_{>0}\underbrace{\frac{dN(\boldsymbol{\beta},i)}{di}}_{<0}}_{<0}+v\underbrace{\left(\frac{?_{P}^{i}}{\underline{?}_{A}^{i}}\cdot\ln\frac{g_{P}^{i}}{\underline{g}_{A}^{i}}\right)}_{>0}. \tag{12}$$

The trade-off between agency costs resulting from differences in discount rates and the costs depending on the congruity of the performance measure can be described by the variation of agency costs with respect to time. Whereas a compensation at date $i=1$ is rather cheap with respect to the agent´s time preference premium, the congruity of the performance measure is rather low at that date ($N(\boldsymbol{\beta},i=1)$ is relatively high). However, at date $i=n$ the weight of the cash flow signals in the performance measure is relatively high, so that the provision of efficient investment incentives is rather probable ($N(\boldsymbol{\beta},i=n)$ is relatively low). Yet, at date $i=n$ the agency costs resulting from the agent´s impatience are relatively high. The enhancing congruity of the performance measure can be regarded as a counterpart to the increase in agency costs resulting from differences in discount rates. However, due to the benefits resulting from an enhanced incentive provisioning my results show that a compensation based on RI_{ti}^{*} in $i>1$ can be endogenously justified in the presence of diverging discount rates, even if disaggregated information about realized cash flows are available to the principal.

6 Conclusion

Empirical and anecdotical evidence emphasizes that managers have to consider capital restrictions when making investment decisions. If a manager cannot adopt all profitable projects available, he has to make an investment decision between mutually exclusive projects. This paper examines a multiperiod agency model in which a short-sighted manager has to exert unobservable effort and make an investment decision between mutually exclusive projects. The manager is rewarded on the basis of residual income since both tasks are not contractible.

This paper shows that income smoothing induces an impatient manager to realize the investment project with the highest NPV. Under symmetric information, perfect income smoothing can be achieved ex ante by an appropriate depreciation schedule. Under asymmetric information, the effectiveness in providing investment incentives improves in the course of time. A key assumption of the analysis is that the principal has established an information system that in each period provides him with a noisy signal about individual operative cash flows. These signals are informative about the profitability of the investment project. Based on these signals the principal revises his prior beliefs so that his expectations about the NPV of the realized project become more and more precise in the course of time. Representing smoothed residual earnings as the annuity of the expected NPV causes a trade-off between agency costs resulting from the differences in discount rates and benefits associated with the information content of the cash flow signals. This analysis justifies a continuous residual income-based compensation in a setting in which the manager has a higher time preference than the principal and disaggregate cash flow information is available.

Appendix

Proof of Proposition 1: In order to compare agency costs, I will define a scenario in which principal and agent have identical discount rates as the benchmark case. Normalizing the agent´s reservation utility to zero and setting $s_{ti} = s_t$ and $g_P^i = g_A^i$ and solving the principal´s problem in (6) leads to

$$V^{BM}(P_t) = pE[NPV(P_t) \,|\, NPV(P_t) > 0] - v\,.$$

STEP 1: *Compensation at all dates* $i = 1,...,n$. In the second best-scenario it is $g_P^i > g_A^i$. In this case, the principal can choose a bonus coefficient of

$$s_{ti} = s_t \cdot g_P^i / \underline{g_A^i}\,, \tag{13}$$

in order to solve the motivation problem. An agent with a time preference of g_A^i can realize rents. Substituting (13), (IC) and (PC) into (6) yields

$$V^{SB}(P_t) = pE[NPV(P_t) \,|\, NPV(P_t) > 0] - \frac{v}{p\sum_{i=1}^{n} E[P_{ti} \,|\, NPV(P_t) > 0] g_P^i} p\sum_{i=1}^{n} E[P_{ti} \,|\, NPV(P_t) > 0] \frac{(g_P^i)^2}{g_A^i}$$

Recollecting terms and setting $E[P_{ti} \,|\, NPV(P_t) > 0] = v \cdot E[NPV(P_t) \,|\, NPV(P_t) > 0]$ gives

$$V^{SB}(P_t) = pE[NPV(P_t) \,|\, NPV(P_t) > 0] - v\sum_{i=1}^{n} v\,\frac{(g_P^i)^2}{g_A^i}$$

This leads to agency costs of

$$AC^*(P_t) = v\left(\sum_{i=1}^{n} v\,\frac{(g_P^i)^2}{g_A^i} - 1\right).$$

STEP 2: *Single compensation at date* $i = 1$. Compensating the agent only in $i = 1$ yields a principal´s residual of

$$V^{SB}(P_t) = pE[NPV(P_t) \mid NPV(P_t) > 0] - s_{t1} p v E[NPV(P_t) \mid NPV(P_t) > 0] g_P^1$$

s.t. $s_{t1} \geq \dfrac{v}{v pE[NPV(P_t) \mid NPV(P_t) > 0] g_A^1}$.

This leads to

$$V^{SB}(P_t) = pE[NPV(P_t) \mid NPV(P_t) > 0] - v\left(\frac{g_P^1}{g_A^1}\right).$$

The agency costs are

$$AC^{**}(P_t) = v\left(\frac{g_P^1}{g_A^1} - 1\right).$$

Both AC^* and AC^{**} become zero for $g_P^i = g_A^i$.

STEP 3: Now, I will show that $AC^*(P_t) > AC^{**}(P_t)$ iff $g_P^i > g_A^i$. Starting with the claim gives

$$v\left(\sum_{i=1}^{n} v \frac{(g_P^i)^2}{g_A^i} - 1\right) > v\left(\frac{g_P^1}{g_A^1} - 1\right)$$

$$\sum_{i=1}^{n} v \frac{(g_P^i)^2}{g_A^i} > \frac{g_P^1}{g_A^1} \sum_{i=1}^{n} v g_P^i \tag{14}$$

The claim in Proposition 1 is true iff the expression in (14) holds by strict inequality in at least one period $t+i$ and by equality in all other periods $i = 1, \ldots, n$:

$$v \frac{(g_P^i)^2}{g_A^i} \geq v \frac{g_P^{i+1}}{g_A^1} \text{ so that } g_P^{i-1} \geq g_A^{i-1} \tag{15}$$

(15) holds for $i = 1$ by equality and per definition for all $i > 1$ by inequality. This completes the proof of proposition 1. □

Proof of Proposition 2: The vector $(N\tilde{P}V_t, \tilde{\boldsymbol{S}}_t)$ with $\tilde{\boldsymbol{S}}_t = (\tilde{S}_{t0},...,\tilde{S}_{tn})$ is a $(n+2)$ dimensional random variable. The random variable is $(N\tilde{P}V_t, \tilde{\boldsymbol{S}}_t) \sim \log N(\boldsymbol{\mu}, \boldsymbol{S})$ distributed, with a finite mean $\boldsymbol{\mu} \in \Re^{n+2}$ and variance-covariance-matrix $\boldsymbol{S} \in \Re^{n+2 \times n+2}$. The variable $N\tilde{P}V_t$ is a one-dimensional random variable and the vector $\tilde{\boldsymbol{S}}_t$ a $(n+1)$-dimensional random variable. The mean-vector and the variance-covariance-matrix can be expressed as

$$\boldsymbol{\mu} = \begin{bmatrix} m_{NPV} \\ \boldsymbol{\mu}_S \end{bmatrix}_{n+2\times 1} \text{ and } \boldsymbol{S} = \begin{bmatrix} S_{NPV,NPV} & \boldsymbol{S}_{NPV,S} \\ \boldsymbol{S}_{S,NPV} & \boldsymbol{S}_{S,S} \end{bmatrix}_{n+2\times n+2}. \tag{16}$$

By standard multivariate normal statistics the conditional mean can be expressed as a weighted average of a priori beliefs and signals:[16]

$$E^P[\ln N\tilde{P}V_t \,|\, \ln \tilde{\boldsymbol{S}}_t] = E^P[\ln N\tilde{P}V_t] + S_{\ln NPV \ln S} S^{-1}_{\ln S \ln S}(\ln \tilde{\boldsymbol{S}}_t - E^P[\ln \tilde{\boldsymbol{S}}_t]) \tag{17}$$

$$Var[\ln N\tilde{P}V_t \,|\, \ln \tilde{\boldsymbol{S}}_t] = Var[\ln N\tilde{P}V_t] - S_{\ln NPV \ln S} S^{-1}_{\ln S \ln S} S_{\ln S \ln NPV} \tag{18}$$

For $\ln \tilde{\boldsymbol{S}}_t = \left(\ln \tilde{S}_{t0}, \ln \tilde{S}_{t1}\right)$ it is

$$S_{\ln NPV \ln S} = \left(Cov[\ln N\tilde{P}V_t, \ln \tilde{S}_{t0}] \;\; Cov[\ln N\tilde{P}V_t, \ln \tilde{S}_{t1}]\right) \text{ and} \tag{19}$$

$$S_{\ln S \ln S} = \begin{pmatrix} Cov[\ln \tilde{S}_{t0}, \ln \tilde{S}_{t0}] & Cov[\ln \tilde{S}_{t0}, \ln \tilde{S}_{t1}] \\ Cov[\ln \tilde{S}_{t1}, \ln \tilde{S}_{t0}] & Cov[\ln \tilde{S}_{t1}, \ln \tilde{S}_{t1}] \end{pmatrix} = \begin{pmatrix} Var[\ln \tilde{S}_{t0}] & 0 \\ 0 & Var[\ln \tilde{S}_{t1}] \end{pmatrix} \tag{20}$$

Substituting (19) and (20) into (17) gives

$$E^P[\ln N\tilde{P}V_t \,|\, \ln \tilde{S}_{t0}, \ln \tilde{S}_{t1}] = E^P[\ln N\tilde{P}V_t] +$$

$$\left(Cov[\ln N\tilde{P}V_t, \ln \tilde{S}_{t0}] \;\; Cov[\ln N\tilde{P}V_t, \ln \tilde{S}_{t1}]\right) \begin{pmatrix} \dfrac{1}{Var[\ln \tilde{S}_{t0}]} & 0 \\ 0 & \dfrac{1}{Var[\ln \tilde{S}_{t1}]} \end{pmatrix} \left(\ln \tilde{\boldsymbol{S}}_t - E^P[\ln \tilde{\boldsymbol{S}}_t]\right)$$

[16] See DEGROOT [1970, Theorem 1, p. 167]. For an application to lognormal multivariate statistics see KROUSE [1986, p. 327-329]

$$E^P[\ln N\tilde{P}V_t \,|\, \ln\tilde{S}_{t0}, \ln\tilde{S}_{t1}] = E^P[\ln N\tilde{P}V_t] + \sum_{i=0}^{1} \frac{Cov[\ln N\tilde{P}V_t, \ln\tilde{S}_{ti}]}{Var[\ln\tilde{S}_{ti}]} (\ln\tilde{S}_{ti} - E^P[\ln\tilde{S}_{ti}]) .$$

With $Cov[\ln N\tilde{P}V_t, \ln\tilde{S}_{ti}] = Var[\ln\tilde{c}_{ti}]$ the conditional mean for $i+1$ observations is given by

$$E^P[\ln N\tilde{P}V_t \,|\, \ln\tilde{S}_{t0}, ..., \ln\tilde{S}_{ti}] = E^P[\ln N\tilde{P}V_t] + \sum_{j=0}^{i} b_{tj} (\ln\tilde{S}_{tj} - E^P[\ln\tilde{S}_{tj}]) \text{, with} \tag{21}$$

$$b_{tj} = \frac{Cov[N\tilde{P}V_t, \ln\tilde{S}_{tj}]}{Var[\ln\tilde{S}_{tj}]} = \frac{Var[\ln\tilde{c}_{tj}]}{Var[\ln\tilde{c}_{tj}] + Var[\ln\tilde{q}_{tj}]} \le 1 .$$

Substituting (19) and (20) into (18) yields a conditional variance of

$$Var[\ln N\tilde{P}V_t \,|\, \ln\tilde{S}_{t0}, ..., \ln\tilde{S}_{ti}] = Var[\ln N\tilde{P}V_t] - \sum_{j=0}^{i} \frac{Cov[\ln N\tilde{P}V_t, \ln\tilde{S}_{tj}]^2}{Var[\ln\tilde{S}_{tj}]} . \tag{22}$$

Following equation (7) the conditional mean of the lognormal variables can be written as

$$E^P[N\tilde{P}V_t \,|\, \tilde{S}_{t0}, ..., \tilde{S}_{ti}] = \tag{23}$$

$$\exp\left\{ E^P[\ln N\tilde{P}V_t \,|\, \ln\tilde{S}_{t0}, ..., \ln\tilde{S}_{ti}] + \frac{Var[\ln N\tilde{P}V_t \,|\, \ln\tilde{S}_{t0}, ..., \ln\tilde{S}_{ti}]}{2} \right\}$$

Substituting (21) and (22) into (23) gives

$$E^P[N\tilde{P}V_t \,|\, \tilde{S}_{t0}, ..., \tilde{S}_{ti}] =$$

$$\exp\left\{ E^P[\ln N\tilde{P}V_t] + \sum_{j=0}^{i} b_{tj} (\ln\tilde{S}_{tj} - E^P[\ln\tilde{S}_{tj}]) + \left(Var[\ln N\tilde{P}V_t] - \sum_{j=0}^{i} \frac{Cov[\ln N\tilde{P}V_t, \ln\tilde{S}_{tj}]^2}{Var[\ln\tilde{S}_{tj}]} \right) \Big/ 2 \right\}$$

Since $\sum_{j=0}^{i} \frac{Cov[\ln N\tilde{P}V_t, \ln\tilde{S}_{tj}]^2}{Var[\ln\tilde{S}_{tj}]} = \sum_{j=0}^{i} b_{tj} Var[\ln\tilde{c}_{tj}]$ it is

$$E^P[N\tilde{P}V_t \mid \tilde{S}_{t0},...,\tilde{S}_{ti}] =$$
$$\exp\left\{E^P[\ln N\tilde{P}V_t] + \frac{Var[\ln N\tilde{P}V_t]}{2} + \sum_{j=0}^{i} b_{tj}\left(\ln \tilde{S}_{tj} - E^P[\ln \tilde{S}_{tj}] - \frac{Var[\ln \tilde{c}_{tj}]}{2}\right)\right\}$$

Since the principal´s prior beliefs are $E^P[\ln N\tilde{P}V_t] = E^P\left[\sum_{j=0}^{i}\ln \tilde{c}_{tj} + \sum_{j=i+1}^{n}\ln \tilde{c}_{tj}\right]$, the conditional mean can be represented as a weighted average of prior information and signals:

$$E^P[N\tilde{P}V_t \mid \tilde{S}_{t0},...,\tilde{S}_{ti}] =$$
$$\exp\left\{\sum_{j=0}^{i}(1-b_{tj})\left(E^P[\ln \tilde{c}_{tj}] + \frac{Var[\ln \tilde{c}_{tj}]}{2}\right) + \sum_{j=i+1}^{n}\left(E^P[\ln \tilde{c}_{tj}] + \frac{Var[\ln \tilde{c}_{tj}]}{2}\right) + \sum_{j=0}^{i} b_{tj}\ln \tilde{S}_{tj}\right\}$$

Expressing smoothed residual earnings as the annuity of the conditional mean of the NPV with $RI_{ti}^* = v \cdot E^P[N\tilde{P}V_t \mid \tilde{S}_{t0},...,\tilde{S}_{ti}]$ completes the proof. □

Proof of Proposition 3: In order to determine agency costs, I will define a scenario as the benchmark solution in which principal and agent have identical discount rates and the performance measure is perfectly congruent at each date $i = 1,...,n$. For this scenario the principal´s residual can be written as

$$V^{FB}(P_t) = \max_{s_{ti},\bar{s}_t}\left\{pE\left[N\tilde{P}V(P_t) \mid N(\boldsymbol{ß},i) = 0\right] - p \cdot s_{ti} \cdot E\left[R\tilde{I}_{ti}^*(P_t) \mid N(\boldsymbol{ß},i) = 0\right] \cdot g_P^i - \bar{s}_t\right\}$$

s.t.: $p \cdot s_{ti} \cdot E\left[R\tilde{I}_{ti}^*(P_t) \mid N(\boldsymbol{ß},i) = 0\right] \cdot g_A^i \geq v$ and $\bar{s}_t = 0$.

For $g_A^i = g_P^i$ it is

$$V^{FB}(P_t) = pE[N\tilde{P}V(P_t) \mid N(\boldsymbol{ß},i) = 0] - v\,.$$

In the second best scenario the principal´s problem becomes:

$$V^{SB}(P_t) = \max_{s_{ti},\bar{s}_t}\left\{pE\left[N\tilde{P}V(P_t) \mid N(\boldsymbol{ß},i) > 0\right] - p \cdot s_{ti} \cdot E\left[R\tilde{I}_{ti}^*(P_t) \mid N(\boldsymbol{ß},i) > 0\right] \cdot g_P^i - \bar{s}_t\right\}$$

s.t.: $p \cdot s_{ti} \cdot E\left[\tilde{RI}_{ti}^{*}(P_t) \mid N(\boldsymbol{ß},i) > 0\right] \cdot g_A^i \geq v$ and $\bar{s}_t = 0$, with $\underline{g}_A^i < g_P^i$.

This yields:

$$V^{SB}(P_t) = pE[N\tilde{P}V(P_t) \mid N(\boldsymbol{ß},i) > 0] - v\frac{g_P^i}{\underline{g}_A^i}.$$

Thus, agency costs crucially depend on i:

$$V^{FB}(P_t) - V^{SB}(P_t) = AC\left(f(.), v, \underline{g}_A^i\right) = p \cdot f(N(\boldsymbol{ß},i)) + v\left(\frac{g_P^i}{\underline{g}_A^i} - 1\right),$$

with $f(N(\boldsymbol{ß},i)) \equiv N\tilde{P}V\left(P_t\left(N(\boldsymbol{ß},i)=0\right)\right) - N\tilde{P}V\left(P_t\left(N(\boldsymbol{ß},i)>0\right)\right)$. $\square$

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