Equity-Based Compensation and Intertemporal Incentives in Dynamic Oligopoly Games

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Abstract

This paper studies the equilibrium formation of intertemporal incentives in dynamic oligopolistic interactions. We analyze a delegation game in which principals entrust decision making to managers whose pay structure is designed to maximize lifetime profits. If firms compete in strategic substitutes, patience can serve as commitment tool that provides a competitive advantage. A similar effect can be achieved if decision-making is delegated to agents whose compensation contracts link contemporaneous remuneration to future performance through stock ownership. Dynamic pay formation will typically induce time inconsistencies. Thus, managerial decisions will incorporate internal as well as external strategic considerations. In equilibrium owners will choose compensation structures with management ownership above the incentive alignment level.

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1 Introduction

In recent years equity-based compensation plans have gained increasing popularity and management ownership has become an important component of CEO income. For example, Holderness, Kroszner and Sheehan (1999) find that the mean percentage of common stock held by a firm's officers and directors as a group rose to 21 percent in 1995 from 13 percent in 1935. Mehran (1995) reports that equity-based plans account for 12.7 percent of total managerial remuneration, while 6.9 percent is in the form of new stock option grants. Thus, the structure of managerial compensation can have major implications for corporate governance.

There exists an extensive body of literature which deals with the design of optimal contracts and tries to explain the recent trends in managerial compensation. Standard agency theory (e.g. Mirrlees, 1976; Harris and Raviv, 1979; Holmstrom, 1979) postulates that since owners cannot manage their companies directly, they have to delegate decision making to outside agents. However, information asymmetries and incomplete contracts may induce managers to deviate from the goal of maximizing shareholder value. Thus, it is argued that in an environment of uncertainty performance-based pay brings managerial motivation in accordance with shareholders' interest. In particular, management ownership helps internalize intertemporal spillovers and avoids the bias toward short-termism.

If companies take into account that they operate in a market alongside other competitors, they may divest ownership from decision making for strategic reasons: delegation can serve as a commitment tool in strategic interactions. For example, if firms compete in strategic substitutes, the owner of the firm (also referred to as the principal) will benefit from aggressive management. The desired managerial behavior can be invoked with an appropriate pay design. The strategic delegation literature considers a variety of contracts where compensation is tied to sales (Sklivas, 1987), to opponents' performance (Miller and Pazgal, 2001), etc.

The objective of the present paper is to demonstrate that rewarding managers with company stock can also be justified on strategic grounds. Market competition may provide additional rationale for this type of compensation schemes which goes beyond the simple incentive alignment argument.

In dynamic interactions principals could obtain an advantage over opponent firms by strategically affecting managerial intertemporal trade-offs. Including company stock in remuneration effectively creates a link between contemporaneous pay and future company performance: stock holdings raise the perceived value of future profits. This, in turn, provides managers with an incentive to choose more aggressive strategies. If firms compete in strategic substitutes, market opponents will respond by cutting production. Thus, delegation of management coupled with transfer of ownership can increase the principal's equilibrium lifetime profit.

We try to capture this logic in the framework of capital accumulation games as formulated by Hanig (1986) and Reynolds (1987), where making an investment today increases future profits but incurs immediate costs. In this environment the principals delegate decision making to agents and design contracts which link managerial compensation through stock ownership to current and future profits. The problem is further complicated by the internal dynamic inconsistencies that such contracts generate: in addition to their effect on market competition, the intertemporal incentives will also create intra-firm conflicts. This relates the analysis to the literature on hyperbolic discounting (Harris and Laibson, 2001), anticipation (Loewenstein, 1987) and dynamic fiscal policies (Klein, Krusell and Rios-Rull, 2002). Nevertheless, direct effects and external strategic concerns dominate internal considerations. Agents will invest more aggressively if rewarded with company stock. Thus, in dynamic interactions equilibrium oligopoly incentives may involve designing compensation contracts that bias management through stock ownership toward future company performance.

The rest of the paper is organized as follows: Section 2 describes the industry structure, payoffs, the timing of activities and the equilibrium concept.

The first part of Section 3 analyzes the capital accumulation subgame. We use the technique developed by Harris and Laibson (2001) to derive conditions for the Markov-perfect equilibrium managerial strategies. These conditions incorporate the direct effect, as well as the external and internal strategic effects of investment decisions. In the case of linear-quadratic payoffs there exists a tractable solution involving linear strategies.

Then we proceed to the strategic delegation stage. We compute numerically the principals' best response functions and show that in equilibrium all owners choose contracts with managerial stock holdings above the incentive alignment level. As a result investment is so high that in the delegation equilibrium all principals end up with lower payoffs. Equilibrium management ownership increases as investment becomes less costly and more able to affect future payoffs. Moreover, the model predicts a link between the intensity of competition and the optimal compensation structure.

Section 4 concludes with a brief summary of the main results and suggestions for future research.

2 Setup

2.1 Industry Structure, Profits and Capital Accumulation

The industry structure adopted here is a discrete-time analog of the differential capital accumulation game studied by Reynolds (1987).

Consider an industry in which two firms $j \in \{1, 2\}$ possess a technology that requires one unit of capital to produce one unit of output. Each unit of capital incurs an operating cost of c_j to firm j. The good is homogeneous and its inverse industry demand is given by

$$p^t = A - X^t \tag{1}$$

where p^t and X^t are respectively the price and industry output at time t. For simplicity assume that initial capital stocks are below their steady state values, so that firms will always fully utilize all available capacity: $x_j^t = k_j^t, \forall t$. Thus, firm j's period-t profit gross of investment cost is

$$G_j^t(k_1^t, k_2^t) = (A - k_j^t - k_{-j}^t - c_j)k_j^t. \tag{2}$$

In each period firms simultaneously choose investment levels. Capital evolves according the following law-of-motion:

$$k_j^{t+1} = i_j^t + (1-\theta)k_j^t, \; j \in \{1, 2\} \tag{3}$$

where i_j^t is the firm j's level of investment in period t and θ is the depreciation rate.

If firm $j \in \{1, 2\}$ decides to invest i_j^t, it also incurs an immediate cost of $\frac{\mu}{2}(i_j^t)^2 + \eta i_j^t$, where $\mu > 0, \eta > 0$. This implies that firm j's period-t profit net of investment cost is

$$\pi_j(i_1^t, i_2^t, k_1^t, k_2^t) = (A - k_j^t - k_{-j}^t - c_j)k_j^t - \frac{\mu_j}{2}(i_j^t)^2 - \eta_j i_j^t. \tag{4}$$

Note that the firm j's instantaneous profit is concave in its own capital. Moreover, capital stocks are strategic substitutes: $\frac{\partial^2 \pi_j^t}{\partial k_j^t \partial k_l^t} < 0$.

All participants have a common discount factor δ. Therefore, firm j's period-t lifetime profit is given by $\Pi_j^t = \sum_{\tau=t}^{\infty} \delta^{t-1} \pi_j(i_1^t, i_2^t, k_1^t, k_2^t)$.

2.2 Management

Investment decisions are entrusted to a sequence of one-period agents (also called managers) who are fully informed and correctly forecast the outcome of future interactions. Managerial compensation is related to contemporaneous company performance, as well to long-term profitability. In particular, once profits are realized and dividends have been distributed, managers receive remuneration that consists of a performance-based wage and company stock[2]:

$$W_j^t = (\pi_j^t + \beta_j \delta \Pi_j^{t+1})\psi \tag{5}$$

where β_j is the relative weight of the stock package in managerial remuneration. Since the present paper focuses on the strategic value of delegation in dynamic interactions and not on profit sharing inside the firm, we assume that ψ is close to 0, so that compensation is small relative to profits. Thus, delegation affects the principals' payoffs only through the agents' investment decisions.

Managerial remuneration as specified by (5) can be rewritten as

$$W_j^t = (\pi_j^t + \beta_j \delta \pi_j^{t+1} + \beta_j \delta^2 \pi_j^{t+2} + \beta_j \delta^3 \pi_j^{t+3} + ...)\psi \tag{6}$$

Note that if the principals' objective is only to eliminate managerial short-termism, they would set $\beta_j = 1$. However, when firms compete in strategic substitutes, lifetime profits can be increased (ceteris paribus) by patient managers committed to aggressive investment through assigning a higher priority to future profits. Selection of managers according to time preference rates is infeasible because of observability

[2]Following Sklivas (1987), I assume that capital stocks and investment are not contractible for two reasons: i) principals cannot directly observe investment decisions; and ii) when the agents invest in multiple projects, "aggregate investment" is difficult to quantify. On the other hand, market indicators for company profitability are widely available.

issues. Nevertheless, principals can promote aggressive investment by increasing the weight of company stock in managerial compensation. Thus, market competition will induce them to choose $\beta_j > 1$.

Strotz (1956) demonstrates that non-exponential discounting (with $\beta_j \neq 1$) will create internal dynamic inconsistencies. Even when there are no strategic interactions between firms, if a future manager recalculates her optimal investment path, she will find out that it differs from the investment levels her predecessors would have preferred in these periods.

In particular, if managerial contracts are as defined by (6), from the period-$(t+1)$ viewpoint period-$(t+2)$ profits are discounted by $\beta_j \delta$; however, from the period-t perspective the period-$(t+2)$ effective discount factor is only δ. Therefore, if in period $(t+1)$ the decision maker revises the investment program, she will decide to invest more in that period. This implies that a forward-looking agent will expect "overinvestment" in the next period. Thus, she will use capital stock as an intra-firm commitment tool in order to alleviate internal dynamic inconsistencies.

2.3 The Strategic Delegation Game

Suppose that a given industry is characterized by the duopolistic market structure described above and consider the following game:

- In stage 0 the two principals simultaneously determine the optimal makeup of managerial pay W_j^t (as specified by (5)). That is, they commit to relative stock weights (β_1, β_2). The owners' objective is maximization of current firm value: $\Pi_j^1 = \sum_{t=1}^{\infty} \delta^{t-1} \pi_j(i_1^t, i_2^t, k_1^t, k_2^t)$.[3] Management contracts have a duration of 1 period. For simplicity assume that compensation structures cannot be renegotiated in the future, and thus do not change over time.

[3] Since ψ is assumed to be very small, the cost of managerial compensation is ignored.

- From period 1 on, managers play the infinite-horizon capital accumulation subgame specified above:

  1. at the beginning of each period new managers are appointed; they choose contemporaneous investment levels; profits are then realized and dividends are distributed.
  2. at the end of each period, agents receive compensation as specified by (5) and retire.

Their objective is the maximization of managerial remuneration W_j^t given the contract structures (β_1, β_2).

2.4 Equilibrium Concept

The equilibrium concept employed here is that of subgame perfect equilibrium. In stage 0 owners take into account how their decisions will affect managerial behavior in future interactions. Thus, once we determine the outcome of the capital accumulation subgame, we can apply standard backward induction to calculate the structure of the equilibrium compensation contracts.

Definition 1 *A subgame-perfect equilibrium of the strategic delegation game described above consists of compensation structures β_1^*, β_2^* and an investment sequence $\{i_1^{*t}, i_2^{*t}\}_{t=1}^{\infty}$ such that:*

1. *neither principal wants to unilaterally deviate:* $\Pi_j^1(\beta_j^*, \beta_{-j}^*, i_j^{*1}, i_{-j}^{*1}, i_j^{*2}, i_{-j}^{*2}, ...) \geqq \Pi_j^1(\beta_j, \beta_{-j}^*, i_j^{*1}, i_{-j}^{*1}, i_j^{*2}, i_{-j}^{*2}, ...), \forall j, \beta_j;$
2. *given (β_1^*, β_2^*), the sequence $\{i_1^{*t}, i_2^{*t}\}_{t=1}^{\infty}$ is the subgame-perfect equilibrium investment profile of the capital accumulation subgame:* $W_j^t(\beta_j^*, \beta_{-j}^*, i_j^{*t}, i_{-j}^{*t}, i_j^{*t+1}, i_{-j}^{*t+1}, ...) \geqq W_j^t(\beta_j^*, \beta_{-j}^*, i_j^t, i_{-j}^{*t}, i_j^{*t+1}, i_{-j}^{*t+1}, ...), \forall j, t, i_j^t.$

We focus on a particular class of subgame perfect equilibria of the capital accumulation subgame, namely the stationary Markov-perfect equilibrium in differentiable strategies: we restrict the analysis to investment strategies $i = (i_1, i_2)$ which depend only on current capital stocks $k = (k_1, k_2)$ and the firm's identity j: $R(k) = (R_1(k), R_2(k))$.

In order to provide a recursive description of the problem we follow Harris and Laibson (2001). Let $\Pi_j(k_1, k_2)$ denote firm j's value (the infinite sum of discounted profits) as a function of current capital stocks. It solves the recursive equation

$$\Pi_j(k_1,k_2) = \pi_j(R_1(k), R_2(k), k_1, k_2) + \delta\Pi_j(R_1(k)+(1-\theta)k_1, R_2(k)+(1-\theta)k_2), j \in \{1,2\}. \tag{7}$$

Let $W_j(k_1, k_2)$ be the compensation of firm j's contemporaneous manager when capital stocks are (k_1, k_2), given that all other agents do not deviate. Managers choose investment optimally, therefore their strategies must satisfy the Bellman equation[4]:

$$W_j(k_1,k_2) = \max_{i_j} \left\{\pi_j(i_1,i_2,k_1,k_2) + \beta_j\delta\Pi_j(i_1+(1-\theta)k_1, i_2+(1-\theta)k_2)\right\}, j \in \{1,2\}. \tag{8}$$

Since $R_j(k_1, k_2)$ is the equilibrium strategy of firm j's manager, it must be true that

$$R_j(k_1,k_2) = \arg\max_{i_j} \left\{\pi_j(i_1,i_2,k_1,k_2) + \beta_j\delta\Pi_j(i_1+(1-\theta)k_1, i_2+(1-\theta)k_2)\right\}, j \in \{1,2\}. \tag{9}$$

Finally, managerial stock ownership creates a payoff link between firm j's successive agents:

$$\beta_j\Pi_j(k_1,k_2) = W_j(k_1,k_2) - (1-\beta_j)\pi_j(R_1(k_1,k_1), R_2(k_1,k_2), k_1, k_2), j \in \{1,2\}. \tag{10}$$

[4] Since ψ is time-invariant and does not affect the equilibrium investment paths, in the subsequent analysis it is normalized to 1.

Definition 2 *The Markov-perfect equilibrium of the capital accumulation subgame is characterized by a pair of strategy functions* $R_1(k_1, k_2), R_1(k_1, k_2)$ *which is a fixed point of the mapping defined by (9) and value functions* $\Pi_j(k_1, k_2), W_j(k_1, k_2)$ *that solve equations (7),(8),(10).*

3 Analysis

3.1 The Capital Accumulation Subgame

Throughout the capital accumulation subgame (β_1, β_2) are taken as given by all agents. Adopt the perspective of firm j's contemporaneous manager. Let $k' = (k_1', k_2')$ and $i' = (i_1', i_2')$ denote the next period's capital stocks and investment levels; let $k'' = (k_1'', k_2'')$ and $i'' = (i_1'', i_2'')$ refer to the capital stocks and investment levels two periods ahead. Furthermore, let $g^j(x)$ be the partial derivative of $g(x)$ with respect to the j-th argument.

Proposition 3 *The Markov-perfect equilibrium investment strategies* $i_1 = R_1(k_1, k_2), i_2 = R_2(k_1, k_2)$ *satisfy the system of generalized Euler equations*

$$\begin{aligned}
&\{\pi_1^1(i,k) + \beta_1\delta\pi_1^3(i',k') - \delta\left((1-\beta_1)R_1^1(k') + 1 - \theta\right)\pi_1^1(i',k')\} + \\
&\left\{M_1\left[\beta_1\delta\pi_1^2(i',k') + \beta_1\delta^2\pi_1^4(i'',k'') - \beta_1\delta^2(1-\theta)\pi_1^2(i'',k'') - \delta^2(1-\beta_1)R_1^2(k'')\pi_1^1(i'',k'')\right]\right\} - \\
&\left\{N_1[\delta\pi_1^1(i',k') + \beta_1\delta^2\pi_1^3(i'',k'') - \delta^2\left((1-\beta_1)R_1^1(k'') + 1 - \theta\right)\pi_1^1(i'',k'')]\right\} = 0
\end{aligned} \tag{11}$$

and

$$\begin{aligned}
&\{\pi_2^2(i,k) + \beta_2\delta\pi_2^4(i',k') - \delta_2\left((1-\beta_2)R_2^2(k') + 1 - \theta\right)\pi_2^2(i',k')\} + \\
&\left\{M_2\left[\beta_2\delta\pi_2^1(i',k') + \beta_2\delta^2\pi_2^3(i'',k'') - \beta_2\delta^2(1-\theta)\pi_2^1(i'',k'') - \delta^2(1-\beta_2)R_2^1(k'')\pi_2^2(i'',k'')\right]\right\} - \\
&\left\{N_2[\delta\pi_2^2(i',k') + \beta_2\delta^2\pi_2^4(i'',k'') - \delta^2\left((1-\beta_2)R_2^2(k'') + 1 - \theta\right)\pi_2^2(i'',k'')]\right\} = 0
\end{aligned} \tag{12}$$

where $M_1 = R_2^1(k')$, $N_1 = \dfrac{[R_2^2(k'') + 1 - \theta]R_2^1(k')}{R_2^1(k'')}$, $M_2 = R_1^2(k')$, $N_2 = \dfrac{[R_1^1(k'') + 1 - \theta]R_1^2(k')}{R_1^2(k'')}$.

Proof. See Appendix ■

These equilibrium conditions incorporate three effects of a marginal increase in current investment.

- Direct effect: the future benefits of higher capital stocks are weighed against increased investment costs.

- External (inter-firm) strategic effect: contemporaneous managers take into account the subsequent reaction of the opponent firm. The strategic substitutability of capital stocks will induce an increase in current investment in order to discourage future market competitors.

- Internal (intra-firm) strategic effect: contemporaneous managers take into account the behavior of their own successors within the firm. Since internal dynamic inconsistencies will drive next period's agents to overinvest, contemporaneous managers try to reduce capital stock two periods ahead by cutting current investment.

In the case when $\beta_1 = \beta_2 = 1$ internal strategic effects disappear and equations (11), (12) are reduced to the equilibrium conditions of a standard capital accumulation game as played by agents with exponential discounting.

If instantaneous profits are as specified by (4), we conjecture that current agents' strategies are linear in capital stocks: $R_1(k_1^t, k_2^t) = r_1 - a_1 k_1^t - b_1 k_2^t$, $R_2(k_1^t, k_2^t) = r_2 - a_2 k_1^t - b_2 k_2^t$. Substitution in (11), (12) yields

$$-\mu i_1 - \eta - \delta((1-\beta_1)a_1 + 1 - \theta)(-\mu i_1' - \eta) + \beta_1\delta(A - c - 2k_1' - k_2')$$
$$-\delta^2 a_2(\beta_1 k_1'' + (1-\beta_1)b_1(-\mu i_1'' - \eta))$$
$$-\delta(b_2 + 1 - \theta)(-\mu i_1' - \eta - \delta((1-\beta_1)a_1 + 1 - \theta)(-\mu i_1'' - \eta) + \beta_1\delta(A - c - 2k_1'' - k_2'') = 0$$

and

$$-\mu i_2 - \eta - \delta((1-\beta_2)a_2 + 1 - \theta)(-\mu i_2' - \eta) + \beta_2\delta(A - c - 2k_2' - k_1')$$
$$-\delta^2 a_1(\beta_2 k_2'' + (1-\beta_2)b_2(-\mu i_2'' - \eta))$$
$$-\delta(b_1 + 1 - \theta)(-\mu i_2' - \eta - \delta((1-\beta_2)a_2 + 1 - \theta)(-\mu i_2'' - \eta) + \beta_2\delta(A - c - 2k_2'' - k_1'') = 0.$$

Applying the conjectures to the above conditions gives us equations for the optimal strategy parameters. These equations are non-linear polynomials and have a multiplicity of solutions. However, only one root is consistent with dynamic stability. Along the equilibrium path capital stocks accumulate according to the following law-of-motion:

$$\begin{aligned} k_1^{t+1} &= r_1 + (1-\theta-a_1)k_1^t - b_1 k_2^t \\ k_2^{t+1} &= r_2 - a_2 k_1^t + (1-\theta-b_2)k_2^t. \end{aligned}$$

Thus, the steady state is stable if the eigenvalues of the matrix

$$\begin{bmatrix} 1-\theta-a_1 & -b_1 \\ -a_2 & 1-\theta-b_2 \end{bmatrix}$$

are inside the unit-circle. Only one root of (11), (12) fulfills this requirement.

3.2 The Strategic Delegation Stage

3.2.1 Equilibrium Properties

In stage 0 principals anticipate the outcome of managerial interactions and design compensation contracts which maximize period-1 firm value. Strategic substitutability of capital stocks in future profits implies that principals can increase their payoffs (ceteris paribus) by choosing pay structures that commit managers to aggressive investment.

Choosing a higher β_j will have several implications for future investment decisions.

- Since the next period's benefit of current investment is discounted by a higher effective factor, the direct effect will motivate contemporaneous managers to increase investment.

- As future profits gain importance in managerial compensation, contemporaneous agents will pursue a bigger strategic advantage over subsequent market competitors. Thus, the external strategic effect will induce an increase in investment.

- The dynamic inconsistency problem within firms will become more severe, thus the internal strategic effects will drive contemporaneous agents to cut investment.

Consider an otherwise symmetric duopoly game in which the principal of firm 1 who does not resort to strategic delegation ($\beta_1 = 1$) competes against the principal of firm 2 who delegates investment decisions to a sequence of managers with compensation structures $\beta_2 = 1.2$. Figure 1 illustrates the equilibrium capital paths and shows that accounting for all direct, external and internal strategic effects of investment decisions, managers will invest more aggressively relative to principals if their contemporaneous pay is designed with a higher weight on future profits. This suggests that in stage 0 principals will choose compensation contracts with $\beta_j > 1$.

Figure 2 illustrates the interdependence between the period-1 value of firm 2 and managerial compensation structure β_2 in an industry where firm 2's competitor does not delegate investment decisions ($\beta_1 = 1$). For small managerial stock holdings there exists a positive relationship between management ownership and financial performance. If, however, β_2 exceeds a threshold level, managerial objectives become too misaligned with the principal's goal. Thus, principal 2's payoff is concave in managerial stock holdings β_2 and attains its maximum at $\beta_2 = 1.12$.

Of course, the opponent principal will react by resorting to delegation and providing her managers with similar incentives. In order to find the equilibrium of the strategic delegation game we need to calculate the principals' best response functions. Figure 3a shows the owner 2's best response $\Gamma_2(\beta_1)$ in (β_1, β_2) space. Figure 3b is a combined graph of the best responses $(\Gamma_1(\beta_2), \Gamma_2(\beta_1))$ of both principals.

The point of intersection determines the subgame-perfect compensation structures. Numerical computations yield a unique and stable equilibrium. The owners' reaction functions are upward-sloping: if one of the principals decides to reward her managers with more stock, the opponent managers are so discouraged from investing that their principal will find it optimal to offer additional incentives in the form of a bigger stock portfolio β_j. Thus, from the principals' perspective managerial stock holdings are strategic complements.

3.2.2 Comparative Statics

Table 1 provides numerical examples of the equilibrium compensation structures β_j^*, as well as the steady-state capital stocks and instantaneous profits. A comparative statics analysis will reflect the effect of parameter shifts on the relative value of commitment to owners versus managers.

For example, suppose that investment becomes more capable of affecting future payoffs (low θ, high δ). Keeping compensation structures fixed, external strategic considerations will drive agents to invest more aggressively, since a future competitive advantage will have a higher value. However, principals will try to promote even more aggressive management by designing compensation contracts with higher stock weights β_j^*. Similarly, if investment becomes cheaper (low μ, η), in equilibrium the principals will choose pay structures with higher stock portfolios.

An increase in market size A or a reduction in operating costs c will have the opposite effect on the makeup of managerial pay. Agents become so aggressive that in equilibrium the principals will reduce β_j^* in order to lower investment (however, the relative stock weights will remain above 1).

Furthermore, there is a link between competition intensity and managerial compensation structure, since the delegation of investment decisions to aggressive agents provides an advantage over a bigger number of firms. At the other extreme, if the market is served by a monopoly, the optimal contract involves $\beta = 1$.

The equilibrium compensation contracts also depend on the initial capital stocks (k_1^1, k_2^1), since period-1 firm values will be affected by the transition paths.

Table 2 illustrates the principals' equilibrium payoffs with and without strategic delegation. Competition in strategic substitutes usually implies that in a delegation equilibrium principals will experience a reduction in payoffs. While it is individually rational to separate ownership from management decision making, if both principals engage in delegation the intense competition will reduce profits and firm values.

4 Conclusion

This paper studies dynamic strategic delegation in oligopoly games with capital accumulation. Tying managerial compensation through company stock to future profits can serve as a commitment tool in strategic interactions: it provides managers with an incentive to implement aggressive investment programs. If firms compete in strategic substitutes, this type of wage formation discourages opponent's investment and has the potential to increase shareholder value. The weight of company stock in managerial pay is determined by intertemporal trade-off considerations and the market structure. In the delegation equilibrium all managers engage in more aggressive investment, and eventually the principals end up with lower payoffs.

The paper can be extended in several directions. In order to simplify the analysis, we assumed that in stage 0 owners can commit to a compensation scheme with time invariant stock weights β_j. However, if compensation schemes are to be renegotiated in the future, players might decide to deviate. Furthermore, we restricted the wage contracts to a specific functional form. Expanding the set of possible contracts offers additional opportunities for future research.

Appendix A. MPE of the Capital Accumulation Subgame

In this appendix we derive the optimality conditions for the Markov-perfect equilibrium of the capital accumulation subgame.

Suppose that equilibrium strategies are continuous and differentiable functions. Optimality suggests that the firm 1's contemporaneous agent will choose an investment level which satisfies the first-order condition

$$\pi_1^1(i,k) + \beta_1 \delta \Pi_1^1(k') = 0. \tag{13}$$

This gives us the derivative of the agent's continuation value function with respect to her own next-period's stock of capital:

$$\Pi_1^1(k') = -\frac{\pi_1^1(i,k)}{\beta_1 \delta}. \tag{14}$$

Instead of explicitly finding the derivatives $W_1^1(k)$ and $W_1^2(k)$ of the current value function from the envelope condition, we can avoid additional calculations by directly using the recursive equation (7). Differentiating (7) with respect to k_1 yields after shifting one period ahead

$$\Pi_1^1(k') = R_1^1(k')\pi_1^1(i',k') + R_2^1(k')\pi_1^2(i',k') + \pi_1^3(i',k') + \delta\{[R_1^1(k') + 1 - \theta]\Pi_1^1(k'') + R_2^1(k')\Pi_1^2(k'')\}. \tag{15}$$

Also, differentiation of (7) with respect to the opponent's capital stock k_2 and shifting one period gives us

$$\Pi_1^2(k') = R_1^2(k')\pi_1^1(i',k')+R_2^2(k')\pi_1^2(i',k')+\pi_1^4(i',k')+\delta\{R_1^2(k')\Pi_1^1(k'')+[R_2^2(k')+1-\theta]\Pi_1^2(k'')\}. \tag{16}$$

After substituting the own-capital derivatives of the lifetime profit function from (14) in (15) we obtain an equation for $\Pi_1^2(k'')$:

$$-\frac{\pi_1^1(i,k)}{\beta_1\delta} =$$
$$R_1^1(k')\pi_1^1(i',k') + R_2^1(k')\pi_1^2(i',k') + \pi_1^3(i',k') - \frac{[R_1^1(k')+1-\theta]\pi_1^1(i',k')}{\beta_1} + \delta_1 R_2^1(k')\Pi_1^2(k'').$$

Solving for $\Pi_1^2(k'')$ yields

$$\Pi_1^2(k'') =$$
$$\frac{1}{R_2^1(k')}\{-\frac{\pi_1^1(i,k)}{\beta_1\delta^2} + \frac{\pi_1^1(i',k')\,[1-\theta+(1-\beta_1)R_1^1(k')]}{\beta_1\delta} - \frac{R_2^1(k')\pi_1^2(i',k')}{\delta} - \frac{\pi_1^3(i',k')}{\delta}\}. \tag{17}$$

By shifting (17) one period ahead we find the derivative of the next agent's lifetime profit function with respect to opponent's capital:

$$\Pi_1^2(k''') =$$
$$\frac{1}{R_2^1(k'')}\{-\frac{\pi_1^1(i',k')}{\beta_1\delta^2} + \frac{\pi_1^1(i'',k'')\,[1-\theta+(1-\beta_1)R_1^1(k'')]}{\beta_1\delta} - \frac{R_2^1(k'')\pi_1^2(i'',k'')}{\delta} - \frac{\pi_1^3(i'',k'')}{\delta}\}. \tag{18}$$

Substituting the derivatives of the lifetime profit function from (14), (17) and (18) in (16) shifted one period ahead yields (11). Similar computations give us (12).

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	$\delta = 0.65$ $k_i = 55$	$\delta = 0.75$ $k_i = 55$	$\delta = 0.85$ $k_i = 55$	$\delta = 0.65$ $k_i = 40$	$\delta = 0.75$ $k_i = 40$
$\theta = 0.1$ $\mu, \eta = 10$ $A - c = 200$	$\beta_j^* = 1.14$ $\widehat{k} = 56.3$ $\widehat{\pi} = 3925$	$\beta_j^* = 1.21$ $\widehat{k} = 61.4$ $\widehat{\pi} = 3417$	$\beta_j^* = 1.43$ $\widehat{k} = 67.0$ $\widehat{\pi} = 2703$	$\beta_j^* = 1.09$ $\widehat{k} = 55.6$ $\widehat{\pi} = 3986$	$\beta_j^* = 1.14$ $\widehat{k} = 60.6$ $\widehat{\pi} = 3517$
$\theta = 0.2$ $\mu, \eta = 10$ $A - c = 200$	$\beta_j^* = 1.08$ $\widehat{k} = 45.1$ $\widehat{\pi} = 3838$	$\beta_j^* = 1.12$ $\widehat{k} = 51.0$ $\widehat{\pi} = 3464$	$\beta_j^* = 1.18$ $\widehat{k} = 56.9$ $\widehat{\pi} = 2872$	$\beta_j^* = 1.06$ $\widehat{k} = 44.7$ $\widehat{\pi} = 3855$	$\beta_j^* = 1.09$ $\widehat{k} = 50.5$ $\widehat{\pi} = 3510$
$\theta = 0.1$ $\mu, \eta = 8$ $A - c = 200$	$\beta_j^* = 1.17$ $\widehat{k} = 58.9$ $\widehat{\pi} = 3854$	$\beta_j^* = 1.28$ $\widehat{k} = 63.6$ $\widehat{\pi} = 3359$	$\beta_j^* = 1.71$ $\widehat{k} = 69.4$ $\widehat{\pi} = 2705$	$\beta_j^* = 1.12$ $\widehat{k} = 58.4$ $\widehat{\pi} = 3913$	$\beta_j^* = 1.18$ $\widehat{k} = 62.7$ $\widehat{\pi} = 3475$
$\theta = 0.1$ $\mu, \eta = 10$ $A - c = 300$	$\beta_j^* = 1.08$ $\widehat{k} = 84.1$ $\widehat{\pi} = 9025$	$\beta_j^* = 1.13$ $\widehat{k} = 91.3$ $\widehat{\pi} = 7989$	$\beta_j^* = 1.24$ $\widehat{k} = 98.5$ $\widehat{\pi} = 6677$	$\beta_j^* = 1.07$ $\widehat{k} = 83.9$ $\widehat{\pi} = 9052$	$\beta_j^* = 1.11$ $\widehat{k} = 91.0$ $\widehat{\pi} = 8053$
$\theta = 0.2$ $\mu, \eta = 10$ $A - c = 300$	$\beta_j^* = 1.06$ $\widehat{k} = 67.9$ $\widehat{\pi} = 8478$	$\beta_j^* = 1.09$ $\widehat{k} = 76.4$ $\widehat{\pi} = 7967$	$\beta_j^* = 1.15$ $\widehat{k} = 85.1$ $\widehat{\pi} = 6679$	$\beta_j^* = 1.05$ $\widehat{k} = 67.6$ $\widehat{\pi} = 8768$	$\beta_j^* = 1.08$ $\widehat{k} = 76.1$ $\widehat{\pi} = 8001$
$\theta = 0.1$ $\mu, \eta = 8$ $A - c = 300$	$\beta_j^* = 1.11$ $\widehat{k} = 88.0$ $\widehat{\pi} = 8853$	$\beta_j^* = 1.17$ $\widehat{k} = 94.4$ $\widehat{\pi} = 7888$	$\beta_j^* = 1.32$ $\widehat{k} = 100.8$ $\widehat{\pi} = 6755$	$\beta_j^* = 1.08$ $\widehat{k} = 87.5$ $\widehat{\pi} = 8932$	$\beta_j^* = 1.13$ $\widehat{k} = 93.8$ $\widehat{\pi} = 7997$
$\theta = 0.1$ $\mu, \eta = 10$ $A - c = 400$	$\beta_j^* = 1.07$ $\widehat{k} = 112.4$ $\widehat{\pi} = 16117$	$\beta_j^* = 1.11$ $\widehat{k} = 121.7$ $\widehat{\pi} = 14353$	$\beta_j^* = 1.19$ $\widehat{k} = 130.7$ $\widehat{\pi} = 12200$	$\beta_j^* = 1.06$ $\widehat{k} = 112.2$ $\widehat{\pi} = 16166$	$\beta_j^* = 1.09$ $\widehat{k} = 121.2$ $\widehat{\pi} = 14467$
$\theta = 0.2$ $\mu, \eta = 10$ $A - c = 400$	$\beta_j^* = 1.05$ $\widehat{k} = 90.7$ $\widehat{\pi} = 15652$	$\beta_j^* = 1.08$ $\widehat{k} = 101.9$ $\widehat{\pi} = 14284$	$\beta_j^* = 1.13$ $\widehat{k} = 113.2$ $\widehat{\pi} = 12106$	$\beta_j^* = 1.04$ $\widehat{k} = 90.4$ $\widehat{\pi} = 15687$	$\beta_j^* = 1.07$ $\widehat{k} = 101.6$ $\widehat{\pi} = 14344$

Table 1: **The Strategic Delegation Game**. The table shows the equilibrium relative stock weights β_j and the steady-state values of firm capital stock $\widehat{k}$ and firm profits $\widehat{\pi}$.

	$\delta = 0.65$ $k_i = 55$	$\delta = 0.75$ $k_i = 55$	$\delta = 0.85$ $k_i = 55$	$\delta = 0.65$ $k_i = 40$	$\delta = 0.75$ $k_i = 40$	$\delta = 0.85$ $k_i = 40$
V_d^1	13459	18069	26840	12921	17522	26635
V_{nd}^2	13590	18464	28456	13022	17836	27788

Table 2: **The Principals' Payoffs**. The table shows the equilibrium period-1 firm value with delegation V_d^1 and the period-1 firm value without delegation V_{nd}^1. The calculations are based on parameters $A - c = 200, \mu = 10, \eta = 10, \theta = 0.1$

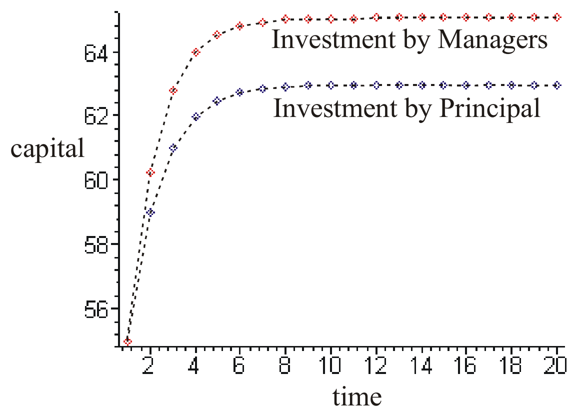

Figure 1: **Capital Paths Under Delegated and Direct Management**. The first capital path is calculated for $\beta_2 = 1.2$ and the second capital path is calculated for $\beta_2 = 1$. The opponent's compensation structure is $\beta_1 = 1$. The figure is based on simulations in which $A = 1000, c_1 = c2 = 800, \theta = 0.1, \delta = 0.6, \mu_1 = \mu_2 = 3, \eta_1 = \eta_2 = 3$ and initial capital stocks $k_1^1 = k_2^1 = 10$

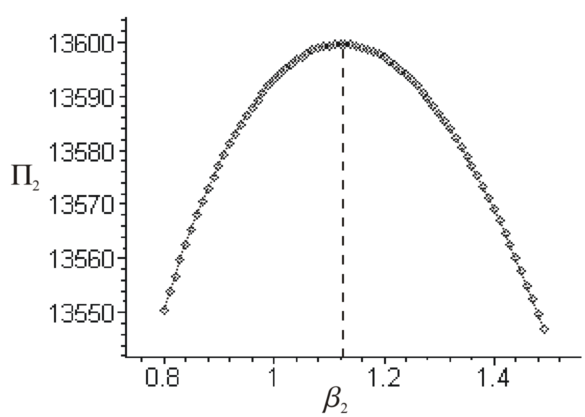

Figure 2: **Owner's Payoff as a Function of Managerial Stock Ownership**. The figure illustrates the relationship between the principal 2's payoff Π_2^1 and managerial stock ownership β_2 when when firm 2 competes against an opponent with $\beta_1 = 1$. It is calculated for the parameters $A = 1000, c_1 = c2 = 800, \theta = 0.1, \delta = 0.65, \mu_1 = \mu_2 = 10, \eta_1 = \eta_2 = 10$ and initial capital stocks $k_1^1 = k_2^1 = 55$

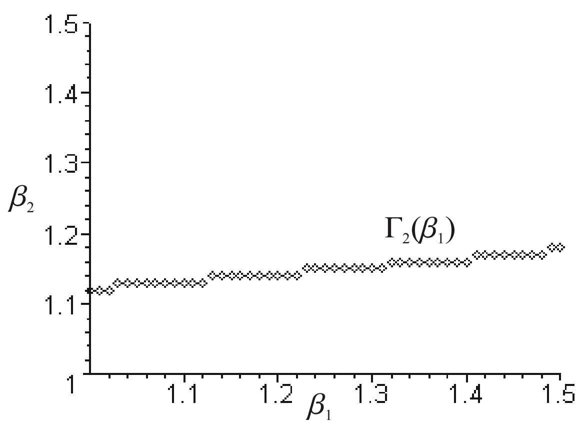

Figure 3a

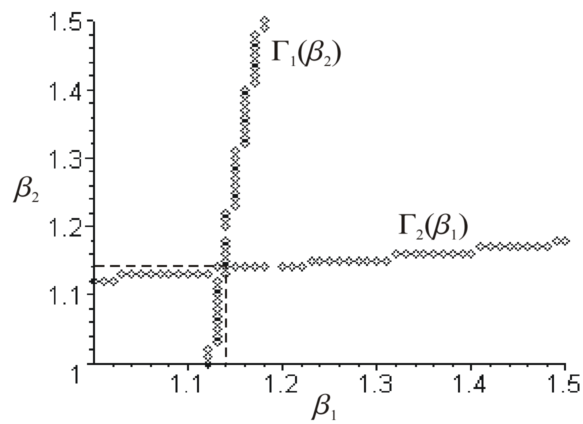

Figure 3b

Figure 3: **Owners' Reaction Functions**. Figure 3a illustrates the principal 2's optimal choice of β_2 given the opponent's compensation structure β_1. Figure 3b is a combined graph of the reaction functions of both players. is calculated for the parameters. The calculations are based on parameters $A = 1000, c_1 = c2 = 800, \theta = 0.1, \delta = 0.65, \mu_1 = \mu_2 = 10, \eta_1 = \eta_2 = 55$ and initial capital stocks $k_1^1 = k_2^1 = 10$.