Dynamic Moral Hazard with History-Dependent Participation Constraints. The Case of CEO Pay

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INTRODUCTION

- Executive pay dynamics and composition
- CEO wealth
- Pay performance sensitivity
- Curbing executive pay
  - AIG Bonuses
  - Russia
MOTIVATION

- CEO pay
  - What is the optimal compensation scheme?
  - Current vs future pay?
  - Is working hard always optimal?
  - Evolution of manager’s wealth?
  - Non-degenerate long-term distribution?

- Limited commitment?
  - Participation constraints may influence the shape of the optimal contract
  - Reservation utilities are treated as fixed, while in reality they may vary with the history of observables
RELATION TO LITERATURE

- **Characterization:**

- **Repeated moral hazard with hidden information:**
  Thomas and Worrall (1990), Phelan (1995)

- **Repeated moral hazard with hidden action:**

- **Participation:**

- **Calibration:**
  Aseff and Santos (2005)
Framework

- Repeated moral hazard
- Hidden action
- Limited commitment
- History dependent reservation utilities
Results

- **Theoretical (general):**
  - Existence
  - Recursive representation

- **Theoretical (short-term dependence):**
  - State space derived under constant reservation utilities
  - Sufficient condition for insurance against fluctuations in the value of agent’s outside options

- **Computational algorithm dealing with non-convexities**
Numerical:

- Exerting effort predominant, shirking still optimal for rich-enough managers

- Optimal wage scheme and CEO’s future utility tend to grow in both his/her current utility and in future profit

- Manager’s utility tends to increase weakly in the long run and appears to have a non-degenerate long-term distribution depending on the initial utility promise, but not on the initial history (at least for a short-term dependence).
MODEL

Assumptions:

- Discrete time, \( t \)
- Initial period of contracting 0
- \( \theta \) periods observed before time 0
- Stationary set of \( n \) distinct outcomes (gross profits), \( Y \)
- Stationary, compact set of actions (managerial effort), \( A \)
- Stationary, compact set of transfers (wages), \( W \)
- Current outcome depends on current action only
  \[ \pi : Y \times A \rightarrow (0, 1) \text{ s.t. } \sum_{y} \pi(y, .) = 1 \text{ and } \pi(y, .) \text{ cont. on } A \]
• Principal
  ○ $u : W \times Y \to \mathbb{R}$, cont., decr. in transfer, incr. in outcome;
  ○ discounts the future by a factor $\beta_P \in (0, 1)$.

• Agent
  ○ $v : W \times A \to \mathbb{R}$, cont., incr. in transfer, decr. in action;
  ○ discounts the future by a factor $\beta_A \in (0, 1)$.

• Reservation utilities exogenously depend only on the previous $\theta$ outcomes:
  
  Let $l : Y^\theta \to L := \{1, \ldots, n^\theta\}$.

  Then, at node $y^{t-1} \in Y^t \times l$,
  
  $\mathcal{U}_l$ principal’s reservation utility
  $\mathcal{V}_l$ agent’s reservation utility
\[
\begin{align*}
Y_t &= \{ (a_t(y_{t-1}), w_t(y_{t-1}, y)) : y \in Y \} \\
a'_t(y_{t-1}) &= \text{exercised by agent, unobserved by principal} \\
y_{t-1}, y_t &= \text{observed by both} \\
c_{t+1}(y_{t-1}, y_t) &= \text{signed}
\end{align*}
\]
Notation:

\( c_l := (a_l, w_l) \) a super-contract signed at node \( l \) at the beginning of period 0

\( U_\tau(c, y^{\tau-1}) \) principal’s expected discounted utility at node \( y^{\tau-1} \)

\( V_\tau(c, y^{\tau-1}) \) agent’s expected discounted utility at node \( y^{\tau-1} \)
[Principal's Problem]

\[
\sup_c U_0(c,l) \quad \text{s.t.:}
\]

\[
a_t(.) \in A
\]

\[
w_t(.) \in W
\]

\[
V_t(a,.) \geq V_t(a',.), \forall \text{ admissible } a'
\]

\[
V_t(.,\bar{l}) \geq V_{\bar{l}}
\]

\[
U_t(.,\bar{l}) \geq U_{\bar{l}}
\]
**Assumption:** Set of constraints is non-empty.

**Theoretical results:**

- IC is equivalent to Green (1987)’s temporary IC (TIC) at all successive nodes.
- The sets of possible expected discounted utilities are compact and depend on the outcome history in previous $\theta$ periods only.
- An optimal contract exists.
RECURSIVE CHARACTERIZATION

\( \text{AP} \rightarrow \) admissible, incentive-compatible supercontract that only guarantees the participation of the agent

\( \text{2P} \rightarrow \) admissible, incentive-compatible supercontract that guarantees the participation of both the agent and the principal

Recursive stationary form?

State space:

- expected discounted utility of the agent (endogenous!)
- truncated outcome histories (dependence through reservation utilities)
More Notation:

\( V^{AP}(l) \) - the set of expected discounted utilities for the manager signing an AP contract at \( l \)

\( V^{AP} := \{V^l(l)\} \) - the Cartesian product of such sets indexed by \( L \)

\( V^{2P} \) - the correspondingly indexed product of sets of expected discounted utilities for the manager signing a 2P contract
For any $V = \{V_l\} \in V^{AP}$, $U^{AP^*}(V)$ is a vector with a general element $U^{AP^*}(V_l, l)$ that stays for the maximum utility the principal can get by signing an AP contract offering $V_l$ to the manager.

For any $V \in V^{2P}$, $U^*(V)$ is a vector with a general element $U^*(V_l, l)$ that denotes the maximum utility the principal can get by signing a 2P contract offering $V_l$ to the manager.

$\hat{U}^*$ - the extension of $U^*$ on $V^{AP}$ s.t. for any $V \in V^{AP}$, $\hat{U}^*(V)$ has a general element

$\hat{U}^*(V_l, l) := \begin{cases} U^*(V_l, l) & \text{if } V_l \in V^{2P}(l) \\ -\infty & \text{otherwise} \end{cases}$

Let $l_+ : L \times Y \to L$ maps today’s initial histories and current outcomes to tomorrow’s initial histories.
DEFINING THREE IMPORTANT OPERATORS

$\tilde{B}$, $T$, and $T$
Imagine $\theta = 0$:

- $\tilde{B}$ maps a set $X$ of agent's expected discounted utilities to a subset that can be supported by admissible, TIC, single-period contracts consistently promising continuations in $X$.

- $T$ maps a function $U : V^{AP} \to \mathbb{R}$ to the value function of a single-period principal’s problem where principal’s continuation utility is given by $U$ and the maximum is taken over all admissible, TIC contracts consistently promising agent’s continuation utilities in $V^{AP}$.

- $T$ is as $T$, but punishes the principal severely for any violation of his/her participation constraint at the current node and/or its immediate successors.
For any \( X \in \mathbb{R}^{n^0}, \tilde{\mathcal{B}}(X) = \{\tilde{B}_l(X)\} \) with

\[
\tilde{B}_l(X) := \{V \in X_l : \exists c_R = \{a-, w_+(y), V_+(y) : y \in Y\} \text{ s.t.:}
\]

\[
a_- \in A
\]

\[
w_+(y) \in W, \forall y \in Y
\]

\[
\sum_{y \in Y} [v(w_+(y), a_-) + \beta_A V_+(y)]\pi(y, a_-) = V
\]

\[
\sum_{y \in Y} [v(w_+(y), a'_-) + \beta_A V_+(y)]\pi(y, a'_-) \leq V, \forall a'_- \in A
\]

\[V_+(y) \in X_{l+}(i,y)\]
For any $U = \{U_l\}$ s.t. $U_l : V^{AP}(l) \to \mathbb{R}$ upper semi-continuous (usc) and bounded with respect to the sup metric, and any $V \in V^{AP}$, $T(U)(V) = \left\{ T_l(U)(V_l) \right\}$ with

$$T_l(U)(V_l) := \max \sum_{y \in Y} \left[ c_{R} u(w_+(y), y) + \beta_{P} U_{l_+(l,y)}(V_+(y)) \right] \pi(y, a_-)$$

s.t. RAA, RAW, TIC, PK hold, and

$$V_+(y) \in V^{AP}(l_+(l,y)), \forall y \in Y$$
∀l ∈ L, ∀V ∈ V^{AP}(l), ∀U : V^{AP} → (\mathbb{R} \cup \{-∞\})^n,\
Γ_R(V, U, l) := \{ c_R : \text{RAA, RAW, TIC, PK, CP hold at } (V, l) \text{ and } \}
U_{l^+(l,y)}(V_+(y)) \geq U_{l^+(l,y)}, \forall y \in Y\}.

Λ_R(V, U, l) := \begin{cases} 
Γ_R(V, U, l) \text{ if } U_l(V) \geq U_l \\
\emptyset \text{ otherwise} 
\end{cases}

\text{For any } U = \{U_l\} \text{ s.t. } U_l : V^{AP}(l) → \mathbb{R} \cup \{-∞\} \text{ usc and bounded from above, and any } V ∈ V^{AP}, \mathbf{T}(U)_{(V)} = \left\{ T_l(U)_{(V_l)} \right\} \text{ with}

T_l(U)_{(V_l)} := \begin{cases} 
-∞ \text{ if } Λ_R(V_l, U, l) = \emptyset \\
\max_{CR \in Λ_R(V_l, U, l)} \left\{ \sum_{y \in Y} \left[ u(w_+(y), y) + β_P U_{l^+(l,y)}(V_+(y)) \right] \pi(y, a_-) \right\} \text{ o/w}
\end{cases}
ALGORITHM

**Step 1.** Compute the state space supporting AP

**Step 2.** Compute the optimal AP (defined over the solution of step 1)

**Step 3.** Use the value function obtained at step 2 as an initial guess for computing the optimal 2P and recover its state space
More on the Algorithm:

**Step 1.** Start with the set $\widetilde{X}_0 := \left\{ \left[ V_l, \hat{V} \right] \right\}$ where $\hat{V} = \frac{v(\max W, \min A)}{1-\beta_A}$ and iterate on the set operator $\widetilde{B}$ until convergence. The limit is $V^{AP}$.

**Step 2.** Take a function $U = \{ U_l \}$ such that $U_l : V^{AP}(l) \to \mathbb{R}$ usc and bounded with respect to the sup metric, $\forall l \in L$. Iterate on $T(\cdot)$ until convergence. The limit is $U^{AP*}(\cdot)$.

**Step 3.** Take $U^{AP*}(\cdot)$ as an initial guess and iterate on $T(\cdot)$ until convergence. The limit is $\hat{U}^*(\cdot)$. Moreover, $V^{2P}(l) = \{ V \in V^{AP}(l) : \hat{U}^*(V,l) \geq U_l \}$. Then, for any $V \in V^{2P}(l)$, we have $U^*(V,l) = \hat{U}^*(V,l)$. 
MORE STRUCTURE (EXECUTIVE PAY)

- Relax \( w_t \in W \) to \( w_t \geq \underline{w} \)
- \( u(w_t, y_t) = y_t - w_t \)
- \( v(w_t, a_t) = v(w_t) - a_t \), where \( v \) cont., strictly increasing and concave

\[ w_t(\cdot) \leq \bar{w}, \text{ where } \bar{w} := w + \frac{1}{\pi} \left( \frac{\max Y - w}{1 - \beta_p} - \underline{U} \right) \text{ with} \]
\[ \pi := \min_{(y,a) \in Y \times A} \pi(y, a), \underline{U} := \min_{l \in L} U_l. \]

Then, take \( W = [\underline{w}, \bar{w}] \).
STATE SPACE - PROPERTIES:

• \( \theta = 0 \)

  - \( w(.,y) \leq \bar{w}, \forall y \in Y: \)
    \[
    V^{AP} = \left[ \max \left\{ V, \frac{v(w) - \min A}{1 - \beta_A} \right\}, \frac{v(\bar{w}) - \min A}{1 - \beta_A} \right]
    \]

  - \( w(.,y) \leq y, \forall y \in Y: \)
    \[
    \min V^{AP} = \max \left\{ V, \frac{v(w) - \min A}{1 - \beta_A} \right\}
    \]
    \[
    \max V^{AP} = \frac{\max_{a \in A} \{ E_a v(\min \{y, \bar{w}\}) - a) \}}{1 - \beta_A}
    \]
    if \( \min A \in \operatorname{arg\,max}_{a \in A} \{ E_a v(\min \{y, \bar{w}\}) - a) \}, \)
    then \( V^{AP} \) convex
\[ \theta = 1 \text{ and } V_{\hat{y}} = \min_{y \in Y} \{ V_y \} \]

- \[ \max V^{AP}(y) = \frac{\nu(w) - \min A}{1 - \beta_A}, \ \forall y \in Y \]

- \[ \min V^{AP}(y)? \]

\[ \min V^{AP}(\hat{y}) > V_{\hat{y}} \text{ if } \max_{a \in A} \{ \beta a E_a a V - a \} > V_{\hat{y}} - \nu(w) \]
\[ \min V^{AP}(y) = V_y, \ \forall y \in Y, \text{ otherwise.} \]

if \[ V_{\hat{y}} \leq \frac{\nu(w) - \min A}{1 - \beta_A} \text{ and } \exists y \in Y : V_y > V_{\hat{y}}, \]

then \[ \min V^{AP}(\hat{y}) > \frac{\nu(w) - \min A}{1 - \beta_A} \]
Remark 1: Step 1 requires iteration on possibly non-convex sets!

Method: Define a grid over the initial guess. After each iteration exclude a small neighborhood around each unfeasible point and update the grid over the resulting set. Stop when convergence in a properly defined metric is achieved.

Remark 2: In the numerical optimization, use $v_+ := v(w_+)$ instead of $w_+$; the constraints are linear in $a_-, v_+, \text{ and } V_+; \text{ then, recover the optimal compensation by inverting the optimal } v_+$. 
PARAMETERIZATION


\[ Y = \{y(1), y(2), y(3)\} = \{0.55, 1.12, 1.7\}; \]
\[ A = \{a, \bar{a}\} = \{0.1253, 0.1469\}; \]
\[ \pi(y(1)|a) = 0.1508, \pi(y(2)|a) = 0.8121, \pi(y(3)|a) = 0.0371, \]
\[ \pi(y(1)|\bar{a}) = 0.1268, \pi(y(2)|\bar{a}) = 0.8082, \pi(y(3)|\bar{a}) = 0.065; \]
\[ w = 0; \]
\[ \beta_A = \beta_P = 0.96; \]
\[ \nu(\cdot) = \sqrt(\cdot); \]
\begin{itemize}
  \item $\theta = 1$, which encompasses $\theta = 0$ as a subcase;
  \item $U = 0$;
  \item $V(.) \in \{L = \frac{v(w)-\bar{a}}{1-\beta_A} = -3.6725, M = 0, H = -L\}$;
  \item nonnegative correlation between initial histories and agent’s reservation utilities $\Rightarrow$ 10 possible combinations of reservation utility values across initial histories:
\end{itemize}

For example, LMH, which stays for $V(y_{(1)}) = L$, $V(y_{(2)}) = M$, $V(y_{(3)}) = H$, is allowed while LHM is not
Three different cases:

**Case 1** $w(\cdot) \leq \bar{w}$. Take $\hat{V} = \frac{v(\bar{w})-a}{1-\beta_A}$.

**Case 2** $w(\cdot) \leq \min(\bar{w}, \bar{y})$. The principal may borrow up to $\bar{y} - y$ units of consumption every period given a current stock price realization $y$. Take $\hat{V} = \frac{v(\min(\bar{w}, \bar{y})) - a}{1-\beta_A}$.

**Case 3** $w(\cdot, y) \leq \min(\bar{w}, y), \forall y \in Y$. The principal is prevented from borrowing. Take $\hat{V} = \frac{v(\min(\bar{w}, \bar{y})) - a}{1-\beta_A}$. 
RESULTS

- Insurance across (initial-history) states

- Exerting effort appears to be the predominant strategy for the principal, but shirking may still be optimal when the manager is rich enough.

- The optimal wage scheme and the future utility of the manager tend to grow in both his/her current utility and in the future realization of the stock price.
CEO’s utility weakly increases in the long run. In particular, managers who start rich tend to keep their utility level while those who start poor get richer in time.

Manager’s utility has a non-degenerate long-term distribution depending on the initial utility promise, but not on the initial stock price realization (i.e. the manager appears to be fully insured against fluctuations in his/her outside option value).
EXECUTIVE COMPENSATION IN TIME

LMH  LLL  MMM  HHH
THANK YOU!
COMPLIMENTARY SLIDES
Theory behind Step 1

Choose some $\hat{V} \in \mathbb{R} : \hat{V} \geq \max_{l \in L} \{ \max V^{AP}(l) \}$.

For any $X \subset \mathbb{R}^{n^0}$, let $B(X) = \{ B_l(X) \}$ with $B_l(X) := \{ V \in [L_l, \hat{V}] : \exists c_R : \text{RAA, RAW, TIC, PK, and RCPAP hold at } (V, l) \}$, where RCPAP is defined as:

$$V_+(y) \in X_{l_+(l,y)} \cap [L_{l_+(l,y)}, +\infty), \forall y \in Y$$

- $B(V^{AP}) = V^{AP}$
- if $\exists X \subset \mathbb{R}^{n^0} : B(X) = X$, then $X \subset V^{AP}$
Let $X_0$ compact: $V^{AP} \subset X_0 \subset \mathbb{R}^{n_0}$ and $B(X_0) \subset X_0$. Define $X_{i+1} := B(X_i), \forall i \in \mathbb{Z}_+$. Then, $X_{i+1} \subset X_i, \forall i \in \mathbb{Z}_+$ and $X_\infty := \lim_{i \to \infty} X_i = V^{AP}$.

Take $\tilde{X}_0 = \left\{ \left[ \begin{array}{c} L \ni, \tilde{V} \end{array} \right] \right\}$ and let $\tilde{X}_{i+1} := \tilde{B}(\tilde{X}_i), \forall i \in \mathbb{Z}_+$. Then, $\tilde{X}_{i+1} \subset \tilde{X}_i, \forall i \in \mathbb{Z}_+$ and $\tilde{X}_\infty := \lim_{i \to \infty} \tilde{X}_i = V^{AP}$.

$\tilde{B}(V^{AP}) = V^{AP}$.

If $\exists X: \emptyset \neq X \subset \tilde{X}_0$ and $\tilde{B}(X) = X$, then $X \subset V^{AP}$.
Theory behind Step 2

- \( T(U^{AP^*}) = U^{AP^*} \)
- \( T \) maps \((\{USCB_1\}, \mu)\) into itself
- \( T \) is a contraction mapping with modulus \( \beta_P \) in terms of the metric \( \mu \)
- Let \( \tilde{U} \in (\{\beta_i\}, \mu) : T(\tilde{U}) = \tilde{U} \). Then, \( \tilde{U} = U^{AP^*} \)
- \( \forall U \in (\{USCB_1\}, \mu), \mu(T^i(U), U^{AP^*}) \xrightarrow[i \to \infty]{} 0 \), where \( T^i(U) := T(T^{i-1}(U)) \) for any \( i \in \mathbb{Z}_{++} \) with \( T^0(U) := U \)
Theory behind Step 3

- $T$ maps $\{USCBA_l\}$ into itself
- For any $V \in V^{AP}$, let $D_0(V) := U^{AP^*}(V)$ and $D_{i+1}(V) := T(D_i), \forall i \in \mathbb{Z}_+$. $\{D_i\}_{i=1}^\infty$ is a weakly decreasing sequence and $\exists D_\infty \in \{USCBA_l\}$ : $D_i(V_l, l) \rightarrow D_\infty(V_l, l), \forall V_l \in V^{AP}(l), \forall l \in L$
- $T(D_\infty) = D_\infty$
- if $\exists D' \in \{USCBA_l\} : T(D') = D'$, then $D' \leq D_\infty$
- $T(\hat{U}^*) = \hat{U}^*$
- For any $V \in V^{AP}$, $\hat{U}^*(V) = D_\infty(V)$
Figure 1: Value functions for the AP and 2P contracts ordered by initial history: $U^{AP}^*(.,l), U^*(.,l), l \in \{1, 2, 3\}$ (LMH, case 2)
Figure 2: Value functions for the AP and 2P contracts ordered by initial history: $U^{AP^*}(\cdot, l), U^*(\cdot, l), l \in \{1, 2, 3\}$ (LMH, case 3)
Figure 3: Optimal effort as a function of initial utility promise: $a^*_{(.,l)}$, $l \in \{1, 2, 3\}$ (LMH, case 3)
Figure 4: Optimal future utility promise as a function of future profit:

\[ V_+^*(V, l, \cdot) : V \in V^{2P}(l), l \in \{1, 2, 3\} \text{ (LMH, case 3)} \]
Figure 5: Optimal future utility promise as a function of initial utility promise:

\[ V^*_t(l, y_{(k)}), \ t, k \in \{1, 2, 3\} \ (\text{LMH, case 3}) \]
Figure 6: Optimal wage as a function of future profit: $w^*_l(V,v,\cdot): V \in V^{2P}(l)$, $l \in \{1, 2, 3\}$ (LMH, case 2)
Figure 7: Optimal wage as a function of future profit: $w^*_+ (V, l, \cdot): V \in V^{2P} (l)$,

$l \in \{1, 2, 3\}$ (LMH, case 3)
Figure 8: Optimal wage as a function of initial utility promise: $w^*_+ (., l, y_{(k)})$,
$l, k \in \{1, 2, 3\}$ (LMH, case 2)
Figure 9: Optimal wage as a function of initial utility promise: $w^*_{+}(l, y_{(k)})$, $l, k \in \{1, 2, 3\}$ (LMH, case 3)
Figure 10: Optimal effort in time: $a_t(V_0, l): V_0 \in V^2P(l), l \in \{1, 2, 3\}, \text{LMH, case 3}$
Figure 11: Optimal wage in time: $w_t (V_0, l): V_0 \in V^{2P}(l), l \in \{1, 2, 3\},$ LMH, case 3
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Figure 15: Empirical distribution of manager’s utility after 50 periods, $V_{50}$, conditional on initial history $y_0 = y^{(1)}$ and initial utility promise $V_0 \in V^{2LP}(y_0)$, LMH, case 3.
Figure 16: Empirical distribution of manager’s utility after 50 periods, $V_{50}$, conditional on initial history $y_0 = y_{(2)}$ and initial utility promise $V_0 \in V^{2P}(y_0)$, LMH, case 3
Figure 17: Empirical distribution of manager’s utility after 50 periods, $V_{50}$, conditional on initial history $y_0 = y_0(3)$ and initial utility promise $V_0 \in V^{21F}(y_0)$, LMH, case 3
EXECUTIVE UTILITY IN TIME

LMH  LLL  MMM  HHH
PAY-PERFORMANCE SENSITIVITIES
## State Space of the Optimal AP Contract

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Effects of Changing the Minimum Reservation Utility of the Principal
(LLL, case 1)

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