

Modelling a Firm as a Complex Adaptive System

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Introduction

Complex adaptive systems (CAS) are difficult to control and manage by nature. A company can be seen as an example of a CAS dependent on the management control to reach corporate goals like maximising profits, output, employee cooperation or satisfaction. It can be used as a laboratory for systems with higher complexity (Guiso, Sapienza, and Zingales 2015) and neglecting its intertwined nature might lead to ineffective management. The instruments available to organisational management can have unintended or unexpected dynamics that are not easily foreseeable and might derive from (i) the interaction between different management instruments, and (ii) agents' heterogeneous response to the implemented corporate strategies, leading to emergent behavioural patterns. Our paper offers an analysis of such dynamics with respect to two management instruments, financial rewards and monitoring strategies.

This abstract proposes extensions to an earlier agent-based model (Roos, Reale, and Banning 2021) and builds on top of its framework within which agents have heterogeneous value hierarchies (Schwartz et al. 2012) mediating the impact of management instruments on corporate performance. Moreover, co-evolutionary dynamics evolve from a feedback mechanism going from agents' behaviour to descriptive social norms¹ (Deutsch and Gerard 1955). The three extensions we propose involve (A) employees' adaptive behaviour driven by their satisfaction levels, (B) endogenous management instruments, and (C) hiring and firing mechanisms. Our core research questions are:

- Under which conditions can the firm get stuck in a bad steady state? Are multiple steady states possible?
- How do higher frequency and intensity of strategy changes affect corporate outcome?
- Is there a self-selection process over the long-run leading to increased shares of specific value-types?

This extended abstract can be conceived as a first step towards modelling an organisation as a CAS and

¹Descriptive social norms refer to what is *seen as normal* within an organisation, formalised here as the average behaviour of all employees.

does not represent a final list of extensions of interest.

Model

Every employee $i \in [1, N]$ has a daily time budget which has to be allocated among three activities: cooperation (t_{ic}), shirking (t_{is}) and, residually, individual tasks (t_{ip}). Agents' decisions about time allocation are modelled in terms of stochastic deviations, dependent on individual values, from the cooperative (t_c^*) and shirking (t_s^*) global norms.

(A) Adaptive behaviour. Each employee has a satisfaction level $S_i \in [0, 1]$ which affects performance through short-run² productivity effects. Dissatisfaction (low S_i) leads to a reduction in productivity π_i ³ because it impacts the intensity with which working time is used: $\pi_i(t_{ip} + t_{ic})$.

The firm's management employs a certain degree of monitoring Σ which can range between a fully trusting ($\Sigma = 0$) and a fully controlling ($\Sigma = 1$) management style. In a controlling environment, *Conservative* (C-type) employees are happiest and shirk much less than the social norm, and the opposite occurs to *Open-to-change* (O-type) employees⁴.

It is common knowledge that a certain degree of shirking is inevitable and might even be beneficial. To capture this, we introduce a parametrised threshold (t_s^{max}) below which shirking is tolerated. During each period, a random subset ($\Sigma * N$) of workers is observed. If workers get caught three times shirking more than t_s^{max} , the management will issue a written warning (w) signalling that repeating such behaviour might result in some form of punishment, i.e. getting fired (see below). The warnings have two effects: (i) the worker might shirk less in the future for fear of worst consequences, hence *individual* deviations from the shirking norm are modelled along with the type-specific ones; (ii) workers get *dissatisfied* with their

²In the long-run, employees' satisfaction levels are also likely to affect their willingness to work at the firm, possibly with the consequence of leaving, see section C.

³We use the variable $\pi_i = S_i$ on a forward-looking basis so that other productivity factors can be easily integrated at a later stage.

⁴Vice versa under a trusting management attitude.

work. This implies the existence of an optimum degree of monitoring for which the positive deviation from the shirking norm is minimised while keeping a high employee satisfaction (and thus productivity).

- (i) Receiving a w will reduce workers' positive deviations from the shirking norm. Formally we model this with an individual-specific scaling factor β_i , with $\beta_i = 1$ as its default state, which alters the upper bound of the triangular distribution used for individual decision making⁵, see Figure 1.

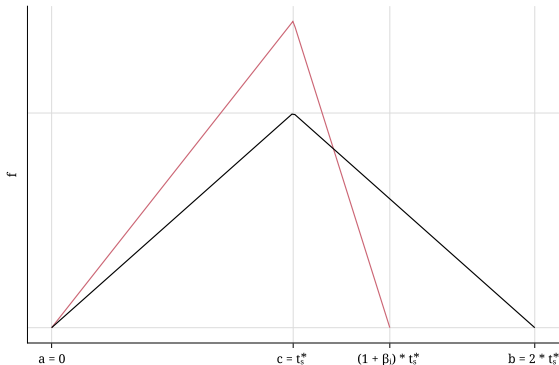


Fig. 1: Density function of a triangular distribution for shirking behaviour with $\beta_i = 0.4$.

- (ii) How a w impacts S_i depends on agents' value types: O-type workers become more dissatisfied after getting caught, lowering their productivity. Opposite reactions are assumed for C-type workers who endorse active monitoring, leading to higher satisfaction and productivity. *Self-Enhanced* (SE) and *Self-Transcendent* (ST) workers are more ambiguous regarding the management's monitoring efforts, resulting in no change to their personal satisfaction/productivity after receiving a w .

(B) Endogenous management. Both monitoring and incentives are dynamic and endogenous. The management observes key company benchmarks, namely average company output (\bar{O}_t) and shirking times ($\bar{t}_{s,t}$) over the past x periods, and judges recent developments based on the preset goals of desired output (O^d)⁶ and maximum acceptable shirking time (t_s^{max})⁷. It then decides on the degree of corporate monitoring ($\Sigma \in [0, 1]$)

$$\begin{aligned} \Sigma \uparrow & \quad \text{if} \quad \frac{1}{x} \sum_{t-x}^{t-1} \bar{t}_{s,t} > t_s^{max} \\ \Sigma \rightarrow & \quad \text{if} \quad \frac{1}{x} \sum_{t-x}^{t-1} \bar{t}_{s,t} \leq t_s^{max} \end{aligned} \quad (\text{a})$$

⁵Changes to β_i can be either permanent, i.e. getting caught once influences employees' behaviour forever, or temporary, such that employees will fall back to their old behaviour after a certain amount of time.

⁶The relevant threshold O^d is the maximum of the Cobb-Douglas type production function under the constraint $t_s = t_s^{max}$.

⁷Note that the reference point is shifted from an individual (as in section A) to a top-down aggregate view.

and on the amount of financial rewards ($\mu \in [0, 1]$)⁸. While monetary incentives are assumed to have positive steering effects on employee motivation, the management should keep μ as low as feasible as it contributes to the overall costs of the firm.

$$\begin{aligned} \mu \uparrow & < O^d \\ \mu \rightarrow & \text{if} \quad \frac{1}{x} \sum_{t-x}^{t-1} \bar{O}_t = O^d \\ \mu \downarrow & > O^d \end{aligned} \quad (\text{b})$$

(C) Hiring and firing. We introduce a mechanism for labour turnover by combining the two previous assumptions. The management can fire poorly performing workers, i.e. employees whose individual output falls below a corporate threshold ($O_i < O^{min}$) for more than y periods. Employees can decide to quit their job positions if their level of satisfaction is below a minimum threshold ($S_i < S_i^{min}$) for more than y periods. S_i^{min} can be type-specific, i.e. it can be higher for O and SE agents and lower for C and ST agents.

Furthermore, the management can hire new employees to fill up empty positions in the firm (up to an arbitrary maximum of N employees). Newly hired employees start with maximum satisfaction levels and have a uniformly distributed random value type. Fluctuations in the labour force impact corporate output and, as a consequence, the management's implemented strategies. Alterations in the workforce composition affect the social norms and thus again agents' adaptive behaviour which might not be foreseen by the management.

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⁸The choice of a *type* of incentive scheme might be endogenised as well but this is left out of the current scope.