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Organizational Culture, Innovation, and Competitive Performance: A Multi-Level Dynamic Model

Christoph Loch
IESE, University of Navarra, and PHBS Business School, Shenzhen, cloch@iese.edu

Konstantinos Ladas
Judge Business School, Cambridge University, k.ladas@jbs.cam.ac.uk

Stylianos Kavadias
Judge Business School, Cambridge University,s.kavadias@jbs.cam.ac.uk

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Abstract. We develop a dynamic evolutionary model of innovation culture and its organizational effects at three levels. At the front-line level, informal bottom-up innovation ideas are driven by unplanned interactions governed by cultural norms, as front-line employees sort themselves into idea generator or implementor behaviors. Management cannot directly control innovation interactions and thus culture, but it can imperfectly nudge it by influencing a sharing norm at the second level. At the third level, the culture influences the innovation performance and productivity of the firm and is thus relevant for the organization's competitiveness. This modeling approach disentangles how top-down strategy interacts with implicit front-line dynamics of cultural evolution, in the context of innovation. Unguided culture does not lead to maximum firm performance. Management guidance may or may not improve performance, and industry competition may select higher performing cultures, which then spread through the industry under some circumstances. We characterize under which conditions management has a strong influence on culture and performance and under which conditions performance is driven more by forces outside of management's control.

Key words: innovation culture, competition strategies, cultural evolution, group selection, population dynamics, evolutionary game theory

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1. Introduction

Culture is widely seen as an important influence on organizational performance. It is commonly defined as a "set of basic assumptions learned by a group [company] as it solves its problem of external adaptation and internal integration" (Schein 2010, p.18). Culture can be important in helping an organization to effectively respond to changes in the environment, as well as in aligning employee actions towards organizational goals. This is especially critical for innovation, as innovation cannot be fully processized (or automated) but relies partially on voluntary bottom-up creative efforts (Van de Ven et al. 2000), and as many companies find, innovation efforts are hard to formally incentivize (Klingebiel 2022). However, determining the culture's "basic assumptions" is far from straightforward. They are fraught with underlying trade-offs and are influenced by multiple different factors (Barney 1986, Pisano 2019).

Literature on the *management* of culture has sometimes adopted one of two polar views: on one side, culture is seen as a set of assumptions that evolve outside of management's control, possibly even dominating the ability to formally direct work and deliver performance (this is the reasoning behind the famous quip attributed to Peter Drucker on "culture eating strategy for breakfast"). Another side views culture as a set of behavior habits designed by management to optimize performance (an example is the recommendation by Christensen et al. (2013) that management needs to cultivate a culture of disruptive ideas). This perspective views the company culture as subservient to management choices. These polar views appear in fields ranging from economics (Hermalin 2001, Gibbons et al. 2021b) to strategic management (Van den Steen 2010) to organizational theory (Howard-Grenville et al. 2020, Koçak and Puranam 2023) and evolutionary anthropology (Boyd and Richerson 1985). This is reflected in discussions of innovation culture: is its core freeing up bottom-up initiatives as in the Skunkworks (Rich and Janos 1994) or as in 3M's free researcher time (Nayak and Ketteringham 1986), or is its core the processized innovation factory (Pisano 1997) or the "Mendelian manager" who, while not able to incentivize detail behavior, can rationally select the best of competing front-line initiatives (Levinthal 2021)?

To inform this debate, we represent the core elements of an organizational culture in a formal model. Culture serves two functions: first, external adaptation to an environment that changes over time and requires the creation of new offers (formal products, or processes). These new offers require at least two key competencies: the generation of new ideas and the translation of such ideas into implemented practices that contribute to the functioning whole. Second, internal integration of individual efforts is needed to deliver effective offers, by employees combining their differing competences through formal or informal interactions. Culture is fundamentally a front-line dynamic stemming from mutual interactions and influences among employees – informal rules govern who interacts with whom, how the interacting individuals are rewarded for their efforts, or how individuals learn from past behaviors. Informal rules operate in parallel with official top-down processes and may support or hinder them (Nelson and Winter 1985).

Viewed through these core culture elements, the literature debate translates into a question about the extent to which senior management can productively influence the two functions of culture (adaptation and integration) and to what extent culture is informal and front-line driven. Managerial attempts to impose culture top-down may be ineffective because of the sheer complexity of a large number of self-interested individuals who may or may not interact and share diverse, and hard to monitor and control, competences. Management can always impose processes and standards, but culture represents a significant residual performance driver. This is especially true in innovation, where creative output occurs partially through informal interactions, such as the infamous "water-cooler conversations" (Smith et al. 2005, Newton et al. 2019). These interactions tend to be not fully controllable or predictable. Formal incentives for innovation, through compensation is an unresolved challenge,[2] since creativity often requires trial-and-error iterations and embodies the risk of failure. Nor can a "Mendelian manager" (Levinthal 2021) reduce the problem by selecting the "best ideas that arise" because these ideas may never come to management's attention if the cultural rules are dysfunctional. Management is thus constrained and may need to operate through subtle "nudges" of behavior in the hope of improving performance.

Therefore, our formal analysis starts with a structure that represents the interplay between the top-down directional nudges and the front-line dynamics of unstructured creative encounters and individual collaboration choices. It is a multi-level population dynamics model of an organization with employees, management, and industry competition. We identify conditions under which management has a strong influence on culture and organizational performance (as a part of the literature claims) and when this is *not* the case.

At the individual level, employees choose (on top of their routine process tasks) voluntary discretionary activities, which either generate novel ideas or build upon others' ideas to integrate them into the formal organizational offers. Organizational performance is enhanced by the ability of employees to introduce innovations that match a changing business environment[3]. The mix of idea generators and idea implementors emerges dynamically when people choose their preferred work mode based on (social) rewards and/or interaction dynamics. At the organizational level (firm level), senior management is able to "nudge" the creative work of the employee population, but without being able to either fully measure or control the individual interaction dynamics and choices. Nudging happens by encouraging interactions among individuals and by encouraging sharing informal rewards (such as respect or status). At the industry level, culturally enabled performance influences the organization's competitive success in a fight for market share.

Our model operationalizes culture through norms/behaviors that (a) shape how individual employees interact with others to produce value, (b) govern how value is shared between collaborators, and (c) cannot

[2] Pay-for-performance schemes might bias innovators toward more conservative strategies (e.g., incremental innovation), while fixed pay schemes might reduce the overall innovation effort (Manso 2011, Ederer and Manso 2013).

[3] Empirical studies have suggested that in some manufacturing companies up to 75% of all productivity gains are the results of bottom-up ideas suggested by front-line employees (Sting and Loch 2016, Cornelius et al. 2021).

be prescribed in detail by centralized decisions (by management, or a ruler, or any central authority).[4] As a result of these norms, the population sorts itself into groups of behaviors (implementors and idea generators) in equilibrium. Our model formalizes a view of culture operating in parallel to top-down strategy, in which management is neither able to enforce "optimal" employee behavior through incentive design or selection of ideas, nor is management completely impotent as in organizational ecology (Hannan and Freeman 1977). Our model proposes a conceptualization of a pathway of how culture translates all the way from individuals' front-line interactions, to collective organizational performance, and to competitiveness at the industry level. The model captures that management of course matters, but so does the population-driven element of culture that cannot be controlled. Culture neither "eats strategy for breakfast" nor is easily subservient to strategy.

The model results suggest that an *unguided* culture, in which spontaneous informal interactions among diverse and equally rewarded employees take place without any influence from management, causes collective underperformance. This underperformance emerges from an evolutionary equilibrium population mix that overemphasizes the behavior that happens to generate the higher individual payoff. This result echoes classic insights from cultural evolution theory (Rogers 1988, Boyd and Richerson 1995) in anthropology and sociology, where higher payoff behaviors for individuals do not necessarily improve population performance.

We examine how management can guide culture (if only weakly and directionally) (Augier and Teece 2009), for example, by supporting interactions between employee groups (idea-generators and implementors), and/or by encouraging informal norms of sharing rewards (respect and status). We show that even small shifts of social rewards in the right direction can increase performance or, if in the wrong direction, decrease performance. Achieving "optimal" sharing norms would require the ability to manipulate employees' interactions at a fine-grained level, which is usually prohibitively expensive or infeasible. We show specifically that trying to replicate the sharing norms with incentives is expensive. Managerial interventions become less effective in frequently changing environments and when the cost differential between the two types of behavior (idea-generators and implementors) is small. Managerial nudging loses power when the innovation value is large, in which case the employee's choices in equilibrium are naturally more aligned with the organization's overall performance.

Finally, the model suggests that industry-level competition may have the power to discipline senior management into performance-enhancing interventions. At the industry level, multiple organizations compete for market share (Cournot competition); for simplicity of exposition, market offerings are perfect substitutes, and the bottom-up generated ideas (the culture) influence performance and competitiveness through

[4] Without the third element, cultures could be replaced by processes or incentive schemes, which seems empirically not to be the case. In evolutionary anthropology models, a key element of culture is also that the norm is the imitation of observed behaviors by other group members. But we do not see this as a definitional element, as other disciplines have defined culture without it.

cost advantages. Competition *selects* organizations with relatively high performance and thus creates evolutionary pressure on organizational culture. The model suggests that such evolutionary selection pressures can suffice to push an industry towards an evolutionary stable "dominant culture" equilibrium in the long run. However, convergence can be disrupted by irregularly occurring changes in the business environment. This may cause industries to spend a large fraction of time in transience toward the equilibrium, and if the environmental changes are frequent enough, equilibrium may never be reached. Changes in the business environment can cause cultural dispersion to persist even under strong competitive pressure.

Section 2 briefly overviews previous work; Section 3 presents individual-level interaction structures; Section 4 introduces management-level interventions; and Section 5 adds the industry level, where multiple organizations compete for market share. Finally, Section 6 draws conclusions.

2. Summary of Previous Work

The importance of culture for corporate performance seems to be widely acknowledged: Guiso et al. (2015) find empirically that culture increases performance, if it *is perceived by employees* as trustworthy and ethical (rather than just being externally advertised). Martinez et al. (2015) observe that culture has an effect on performance and diagnose a need and an opportunity for economics and management research on culture. Sørensen (2002) discusses how the strength of corporate culture and the volatility of the business environment affect performance variability. Managers widely assume that culture is relevant for performance (Graham et al. 2022).

Although culture is acknowledged to matter, there is only loose agreement on what it *is* precisely, and very little agreement on whether it is a tool for management or a front-line dynamic uncontrollable by management.

Let us first discuss widely-known conceptualizations of culture. Schein (2010, p.18) complements the earlier cited definition by saying, "*(...) which has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems.*" This implies that culture embodies "norms" of behavior selected in by past successes over time and generations; these norms concern both intra-organizational behaviors (internal integration) and output-related problem-solving activities (external adaptation).

This definition is consistent with the views developed, in parallel, across several disciplines ranging from anthropology to economics. Evolutionary anthropology, a field that has empirically and theoretically investigated culture in tribes and communities over 50 years, defines culture as "the transmission from generation to generation through teaching and imitation, of knowledge, values, and other factors that influence behavior" (Boyd and Richerson 1985, p.2). In evolutionary anthropology, imitation is the key culture enabler. Some economists have echoed that "... culture is more than shared information: through shared practices and habits of thought, it provides the method, context, values, and language of learning, and the evolution of group and individual competences" (Hodgson 1996, p.255).

These definitions contain several common themes that are important for the study of culture and organizational performance. First, culture embodies any type of knowledge (not only values or social interaction norms, but also knowledge about processes and technology). Second, cultural behavior norms are often implicit and only partially conscious. In the words of Nelson and Winter (1985, p.99 and p.105), "The routinizing of activities in an organization constitutes the most important form of storage of the organization's specific operational knowledge. (...) There is no need for anyone to know anyone else's job, neither is there any need for anyone to be able to articulate or conceptualize the procedures employed by the organization as a whole." The "values" of being willing to cooperate with others are learned action templates more than rational decisions (Bowles et al. 2003, Cordes et al. 2008). Third, the definitions recognize that culture is a multi-level dynamic phenomenon (Vega-Redondo 1993, Sjöström and Weitzman 1996, Boyd and Richerson 2010, Wilson and Sober 1994, Levinthal 2017): groups (often) do not choose (not to mention optimize) their behaviors; they merely aggregate cultural behaviors of members through these members' collaborations and interactions[5]. Employees make decisions only about how and with whom to imitate or interact, and management can only broadly guide them. The aggregated group-level population equilibria are reached by selection at the group level. Culture explicitly embodies multi-level selection pressures.

The role of "management" is the level of organizational decision making that sits between individuals and intergroup competition (at the industry level, or the multi-tribe level in anthropology). Its role is contested: Can management rationally drive the organization (group) level actions (as commonly assumed in economics and management), or is management driven by the cultural dynamics (as often assumed and observed in anthropology)?

Some empirical studies see evidence that leaders can shape a firm's culture at will. For example, a survey of 1,348 senior executives in North American companies finds that 55% *believe* that the CEO has the most influence on driving the firm's culture (Graham et al. 2022). However, other empirical studies see corporate culture as driven primarily by the external environment, such as industry characteristics or customer requirements (Gordon 1991, Chatman and Jehn 1994). Consistent with the latter view, a recent study by Li et al. (2024) attributed only a modest effect on the change in corporate culture to the corporate leaders.

Models of culture exhibit a similar conceptual divide between a top-down and a bottom-up view. Economics models of corporate culture have largely viewed the firm (its management and shareholders) as being in the driver's seat. One view is that of "an equilibrium of conventions" (from which no one chooses to deviate), or common expectations (such as driving on the right or left side of the road) (Kreps 1990, Weber and Camerer 2003). Beyond this coordination effect, cultures are seen to be *chosen* in order to support efficiency (see Section 4.1.2 Hermalin 2001), or introduce integrity, reputation, or clarity (Martinez et al. 2015,

[5] A "beliefs" view has been proposed both in organizational theory and economics, in which culture comprises beliefs and preferences (O'Reilly and Chatman 1996): if people share these, they will make decisions that point in the same direction, and this will reduce agency problems and increase delegation (Van den Steen 2010). While this is a relevant aspect of culture, being "aligned or not aligned" insufficiently captures work dynamics between people of differing roles.

Guiso et al. 2015), or to give management the selection choice among proposed ideas (Levinthal 2021). Based on this chosen positioning, firms engage in competitive games that lead to equilibrium positions. This fundamental view of firm behavior can be characterized as contracting with members (employees) to align them (even if imperfectly through incomplete contracts) behind the firm's position, and competitive gaming against other firms to arrive at an advantageous performance. A variant of this view focuses on the role of the CEO: Dessein and Prat (2022) build a model in which the CEO either builds or depletes a stock of cultural capability (unspecified informal constructive efforts by employees motivated by the CEO's behavior). Building this cultural stock has short-term costs but long-term benefits; it again views culture as entirely driven from the top. Some adjacent literature has also considered how culture is morphed and shaped in organizations through management actions (Gibbons et al. 2021a, Li and Van den Steen 2021, Van den Steen 2010).[6] Koçak and Puranam (2018) examine a different form of managerial "nudging," where employees interact in a repeated game (such as matching, stag hunt, battle of the sexes and prisoner's dilemma) without exactly knowing payoffs but have a prior (of what the best action is) and learn in each period based on observed payoffs. Management does not affect the payoffs but can influence the perception of "which game we are playing" (the "prior") and the strength of learning; a simulation model suggests that management manipulating the priors toward cooperation helps only if the employees have no interest conflict. Finally, Hirshleifer and Plotkin (2021) use cultural evolutionary models to examine the effects of transmission of cultural traits and selection bias, at a firm level, on "moonshots" and investment booms.

In contrast, sociologists have conceded that culture has complicated dynamics that cannot be simply chosen and "optimized" (as if one were installing a complex production machine), because its network dynamics are partially opaque to management (Howard-Grenville et al. 2020). However, they still emphasize the managerial choice to align the members (Weber and Dacin 2011, Koçak and Puranam 2023). Evolutionary anthropology has been most decisively on the front-line side of cultural models. Culture is driven by interactions among members of the population, and management (in this context, the tribal chiefs or the noble class in a larger group), while influential, are another set of cultural actors pursuing their own interests, who are thus part of the multi-level dynamics but not as much "in charge" as in economics (Henrich et al. 2015).

Our study attempts to bring together these different viewpoints within an evolutionary framework that explicitly considers multi-level selection. We contribute to the different viewpoints as follows: we introduce a conceptual model that acknowledges the (fundamentally) spontaneous and voluntary front-line characteristic of individual cultural (socially influenced) behaviors. This unruliness is (imperfectly) channeled by management with the aim of influencing these behaviors and the resulting organizational performance. Moreover, we account for the fact that these dynamic interactions between top-down and bottom-up are

[6] Harrison and Carroll (1991) analyzed a simulation model of culture transmission in organizations. But this is a partial view that models employees joining (being socialized) or defecting, and thus focusing on their cultural "homogeneity," but without any discussion of the performance effects of culture.

subject to selection forces at the individual level (making the employee mix of different innovation behaviors emergent) and at the level of an industry (industry competition selecting for the imperfect managerial guidance that allows a firm to compete successfully).

Our model insights complement previous normative efforts (Li and Van den Steen 2021, Gibbons et al. 2021a, Van den Steen 2010) that attempt to explain enculturation, that is, the process by which a population of individuals converges to a culture of common beliefs and norms. The previous models closest to ours in spirit are Brahm and Poblete (2021, 2024), which examine the value of culture for organizational adaptation. Our model explicitly considers multi-level selection and the feedback loop created by market competition that selects a higher performing culture. Our work also complements a recent set of management studies considering formal governance mechanisms that balance top-down and bottom-up innovation activities to achieve higher company performance (Kim et al. 2014, Sting and Loch 2016, Hutchison-Krupat and Kavadias 2015, Schlapp et al. 2015, Loch and Kavadias 2011). These studies focus on formal incentive-based mechanisms as opposed to our focus on the informal effects of culture on performance and do not consider associated population dynamics or the resulting industry dynamics.

3. Front-Line Dynamics Among Individual Employees

3.1. The Base Model

We start with a parsimonious representation of the innovation culture in a firm's technical functions (such as R&D, IT, or engineering). The firm employs knowledge workers who perform assigned tasks of different types (such as project management, testing, or coordinating with outside parties). Assigned tasks are the basic prescribed work, on top of which the knowledge workers engage in additional, voluntary informal activities of information exchange and idea creation. Creativity cannot be imposed; it is volunteered (Van de Ven et al. 1988), and this happens through informal interactions. For example, people meet at the water-cooler or coffee station and talk; there, creative matches may be made and initiatives born. Or, people meet within their assigned teams, which are usually constructed based on skill mix rather than how well people get on, and they are sometimes willing to engage with one another to create new ideas. The culture of participating in such creative activities unlocks additional performance opportunities, in addition to the planned performance of the assigned work. These opportunities are often significant, as we mentioned earlier, and impact organizational competitiveness.

During such spontaneous creative exchanges, employees fall into two types: some people, let us call them "(idea) generators" (G), create novel ideas with the potential to develop into new market offerings or new processes—generators are known to arise even in relatively routine parts of an organization, such as production lines or call centers. Other people, let us call them "implementors" (I), prefer to perform the funding and process work to turn proposed ideas into real implemented procedures or artifacts that are incorporated into formal processes or products and produce value (Basadur et al. 2023). Employees mostly self-select

into such informal roles, often with the ability to revise their choices over time[7]. At a given point in time, the fraction of implementors in the population is x, and the fraction of generators $1-x$. This fraction may change, as the type of informal work that people engage in is not fixed; it depends only partially on capabilities but also on their personal choices, which may be motivated by the work environment, interactions with colleagues, formal or informal incentives, and opportunities that arise. Denote by x' the fraction of implementors in the *next* period of time.

An idea generator keeps thinking about problems and potential solutions, which requires a resource amount C_G to generate an idea or a rough prototype (for example, from own experiments or from contact with the outside world). It is not guaranteed that a generator always finds the best possible ("optimal") idea suitable to the current external state (e.g., of technology or of customer requirements), but the generator does find *one* idea that works[8]. Generators are limited in that they produce only ideas and prototypes; they do not have the resources or the tools to deliver an implemented output (product or process).

Implementors, on the other hand, expend C_I resources to take a prototyped idea (produced by a generator) to implementation, which may generate revenue or reduce costs for the organization. We denote by $2V$ the value of the output produced by those voluntary (water-cooler or within teams generated) interactions. It accrues at the level of the organization but can be linked to the originators and results, for example, formally in the form of an idea contest prize, or informally via reputation. The cost structure $0 < C_G < C_I < V$ expresses the fact that the testing and transfer cost of an idea implementor is higher than the search cost of the generator. This is consistent with the observation that early stage innovation is usually less expensive than later development (Thomke and Fujimoto 2000).

The firm operates in an unpredictably changing business environment; for example, a new technology might appear, new regulations might be imposed, or the geopolitical situation might change. The environment may change from one period to the next with probability γ; for example, if $\gamma = 5\%$, the environment changes on average once every 20 periods. When a change occurs, the firm's performance depends on whether its offering and/or conduct is adapted to the changing environment, as the previous conduct is no longer accepted or competitive. Reflecting bounded rationality, we assume that the actors (management and employees) do not know *ex ante* whether the environment has changed; they need to interact with it to discover whether it changed or not.

In each period, employees meet for informal interactions on the issues at hand or to exchange ideas (on top of their assigned routine work, as we have discussed). Such informal interactions may happen between

[7] We proceed as if in a given period, an employee chose one of the two roles, revising his/her decision each time period, but not mixing strategies within the same time period. This is because instantaneous switching within a period would be inconsistent with the choice representing a real difference in working style (which requires, for example, setup costs). Technically, the whole model could be interpreted as agents choosing a mixed strategy within a time period, so the population fraction x becomes a per-period fraction of time spent by each agent, and the equilibrium becomes a stable fraction of time allocated by agents.

[8] In Appendix A we relax this assumption and consider "fallible" generators who find a suitable solution only with probability α. We show that the resulting model and its results are structurally similar to the model we present in this section, with a subtle twist.

generators only, implementors only, or with mixed participants. This spontaneous (unplanned) stream of one-on-one interactions reflects one key aspect of the culture within the firm: in our base model, we start with a situation where the interaction pairs form randomly involving any worker types. This represents a perfectly *unbiased* (open) culture, where people talk to anyone with equal probability (Smith et al. 2005), as opposed to in-groups of generators versus implementors thinking "us versus them" (we examine what happens in this more typical case in Section 4.1). This represents the water-cooler conversations, but even in scheduled meetings, such regular random exchanges can help to share informal and tacit information.

The population, as described by the mixture of behaviors, *evolves* over time based on individual in-period (social) rewards (or payoffs). For example, if implementors in a particular period achieve, on average, a higher payoff than generators, then individual employees may switch to the more successful way of engaging in innovation initiatives.[9] Management *cannot* usually mandate or control this type of problem solving work because it is unstructured, unplanned, and outside the regular assigned tasks.

These dynamics are analogous to Darwinian evolution in which fitness-based selection among individuals with differing characteristics plays a role in determining the emergent composition of a population. In a cultural evolution setting, individuals within the population (here employees) interact and receive fitness payoffs (here workers pursue ideas, in interaction with other workers, and receive social rewards for output that is produced by getting the ideas transferred into formal procedures). These interactions can be described by population games, also termed *evolutionary games* (Maynard Smith 1982, Weibull 1997), which determine how the population composition evolves from the game interactions and a selection rule. In our case, this rule naturally arises from individual workers preferring to pursue ways of working that result in higher (social) rewards.

The population game works as follows: a mixed-type interaction (generator/implementor or implementor/generator) produces the payoff $V - C_I$ for the participating implementor and $V - C_G$ for the generator. This payoff is independent of whether the environment has changed or not because, by assumption, the generator always manages to find a suitable "solution" to the current environment, and the implementor incorporates it into the organization's procedures or products. A generator/generator interaction produces payoff $-C_G$ for each participant, because neither has the tools to produce an implemented solution. The payoff of an implementor/implementor interaction depends on whether the environment has changed between the last and current periods. If the environment has not changed (which happens with probability $1 - \gamma$), the interaction produces payoff $V - C_I$ for each individual. If the environment has changed (which happens with probability γ), the payoff for implementors falls to $-C_I$, since they have not produced sufficiently

[9] It is quite common in organizations that people's problem-solving work is not rigid, and they change how they approach it over time, depending partially on social influences and partially on opportunities – although there are some people who are much better at one or the other activity, many people can do either.

novel ideas to match the changed environment. The payoffs for the participating individuals are summarized in Table 1.[10]

	I	G
I	$(1-\gamma)V - C_I$	$V - C_I$
G	$V - C_G$	$-C_G$

Table 1 Symmetric normal-form evolutionary game between implementors and generators. The payoffs displayed accrue to the player on the left.

In summary, the base model's culture is characterized by (a) voluntary interactions among front-line employees who each choose a working style (I or G), (b) who share the value (zero or $2V$) that arises from an interaction, and (c) management supports this sharing but does not interfere otherwise.[11]

With a fraction x of implementors, $W_I(x)$ and $W_G(x)$ denote the expected per-period individual rewards of implementors and generators, respectively, and $\widehat{W}(x) = xW_I(x) + (1-x)W_G(x)$ denotes the mean reward of the organization (employee population). $\widehat{W}$, the mean productivity, is a measure of the organization's overall performance. These are:

$$W_I(x) = V - C_I - \gamma V x \tag{3.1}$$

$$W_G(x) = Vx - C_G \tag{3.2}$$

$$\widehat{W}(x) = -(1+\gamma)Vx^2 + (2V - \Delta c)x - C_G, \tag{3.3}$$

where $\Delta c = C_I - C_G$. Note that W_I decreases in x, while W_G increases in x. In each period the fraction of implementors is determined according to an evolution rule captured by the following difference equation, also known as the discrete-time replicator dynamics equation (Hofbauer and Sigmund 1998):

$$x' = \left(\frac{W_I(x)}{\widehat{W}(x)}\right) x. \tag{3.4}$$

Equation (3.4) indicates that the dynamics of x are governed by individuals with higher payoff tending to replace individuals with lower payoff. When $W_I > \widehat{W}$ then $x' > x$, that is, some generators leave and are

[10] This is a payoff table in the immediate term, as the workers do not change their behavior immediately. But they do change their behavior gradually over time, moving toward a game equilibrium.

[11] Actually, the fact that the employees meet randomly may well be the result of management influence, as people often spontaneously prefer to meet people like themselves rather than mix randomly. We will discuss this in the next section.

replaced (at least partially) by implementors, or some generators might switch to implementor behavior. The reverse happens when $W_I < \widehat{W}$, leading to $x' < x$ (Cavalli-Sforza and Feldman 1981).[12]

To understand how organizational performance is influenced by organizational culture, we seek the long-term convergence point (or fixed point) of Equation (3.4), for which $x' = x$. Let $\Delta x = x' - x$. This is the most suitable way to capture the population dynamics and document whether and where these dynamics converge. From equation (3.4),

$$\Delta x = \frac{x[W_I(x) - \widehat{W}(x)]}{\widehat{W}(x)} = \frac{x(1-x)[W_I(x) - W_G(x)]}{\widehat{W}(x)}. \tag{3.5}$$

The front-line population equilibrium point, x^*, satisfies $\Delta x^* = 0$. This implies that in our evolutionary game, the possible equilibria are (i) $x^* = 0$, (ii) $x^* = 1$, and (iii) $W_I(x^*) = W_G(x^*)$. Evidently, a firm that has only implementors (i.e., $x^* = 1$) in its technical function is vulnerable to any change in the environment. Similarly, a firm that has only generators (i.e., $x^* = 0$) in its technical function is not effective in turning ideas into productive changes in its procedures. This implies that the pure strategies $x^* = 0$ and $x^* = 1$ cannot be meaningful stable equilibria. Therefore, the only stable equilibrium is given by:

$$x^* = \frac{V - \Delta c}{(1+\gamma)V}. \tag{3.6}$$

This equilibrium is in the range $[0, 1]$ as long as $0 < \Delta c < V$, which is not restrictive as long as an implementor's work is productive, namely $V > C_I > \Delta c$.

Note that $\partial x^*/\partial V > 0$, or in other words, the higher the reward of the implemented idea, the more implementors the organization ends up with in equilibrium. Note also that $\partial x^*/\partial \gamma < 0$; when the environment becomes more variable, the equilibrium shifts toward generators, while in low-variability environments the frequency of implementors increases. Also, $\partial x^*/\partial(\Delta c) < 0$; the larger the cost differential, the more the equilibrium shifts towards generators. The following proposition summarizes the findings so far:

PROPOSITION 1. *Voluntarily random (unbiased) interactions among front-line knowledge workers who equally share the produced value result in an equilibrium mix of implementors and generators described by Equation* (3.6)*. The mix shifts (i) toward implementors when the output value increases, (ii) toward generators when the environment becomes more variable, and (iii) toward generators when the cost differential between implementors and generators increases.*

[12] Replicator dynamics mimic the effect of natural selection. Of course, one could consider other game dynamics. For example, dynamics may be governed by imitation, but rules such as "*imitate actions that perform better with a probability proportional to the expected gain*" have been shown to reduce to a replicator dynamics formulation. *Payoff monotonic* is another class of game dynamics in which the growth rates of different strategies are ranked according to their payoff (see Hofbauer and Sigmund (1998, p86-100) for an overview of game dynamics classes). As many classes of game dynamics reduce to variants of replicator dynamics, and as we want to keep the exposition simple, we use replicator dynamics.

The mean performance (fitness) of the organization in equilibrium is:

$$\widehat{W}(x^*) = \frac{V - \Delta c}{1+\gamma} - C_G. \tag{3.7}$$

From Equation (3.3), we can articulate the derivative and find the maximizer of the mean performance of the population, x^{**}, with the maximum mean performance:

$$x^{**} = \frac{2V - \Delta c}{2(1+\gamma)V} \quad \text{and} \quad \widehat{W}(x^{**}) = \frac{(2V - \Delta c)^2}{4(1+\gamma)V} - C_G. \tag{3.8}$$

Equations (3.6) and (3.8) imply that $x^* < x^{**}$, which in turn means that $\widehat{W}(x^*) < \widehat{W}(x^{**})$. This is the second key finding of our base model, namely that the performance of an open (unguided) culture in equilibrium, as given by (3.3), is *not* the maximum possible performance the organization could achieve.

PROPOSITION 2. *An open culture, in which agents randomly interact across types without guidance and equally share the produced value, leads to suboptimal organizational performance due to overemphasis on idea generators in the population mix.*

The underperforming mix of the population in equilibrium $\left(\widehat{W}(x^*) < \widehat{W}(x^{**})\right)$ that results from the spontaneous front-line dynamics is driven by employee myopia: The cultural element that allows employees to choose their working style and to seek the highest individual fitness (payoff) is not aligned with the performance of the population; specifically, the front-line driven equilibrium has "too many" idea generators. Thus, Proposition 2 leaves room for management interventions and suggests that the culture is not "automatically" productive but needs to be somehow "guided" in order to benefit the organization as much as possible. Figure 1 illustrates such an instance of an unguided culture dynamic: the front-line equilibrium has too few implementors and exhibits lower performance than the best mix.

Why can this not be easily overridden by management? Suppose a firm starts with an imposed half of its knowledge workers being generators. Suppose that management even has the capacity to identify and match them perfectly. Thus, every generator will be matched to an implementor in the first period. But generators have a lower cost and thus a higher net benefit, and therefore some implementors will shift their behavior in the next period. Behavior will keep shifting (and this *cannot* be controlled by management because people have to volunteer their ideas) until the expected reward for generators equals that for implementors. The only way out of this would be for management to restructure knowledge personnel every period, which is too wasteful to be feasible.

Appendix B introduces additional incremental innovations produced when implementors interact with implementors, and the IP value produced when generators interact with generators, to check the robustness of the insights. The qualitative results of our base model remain the same.

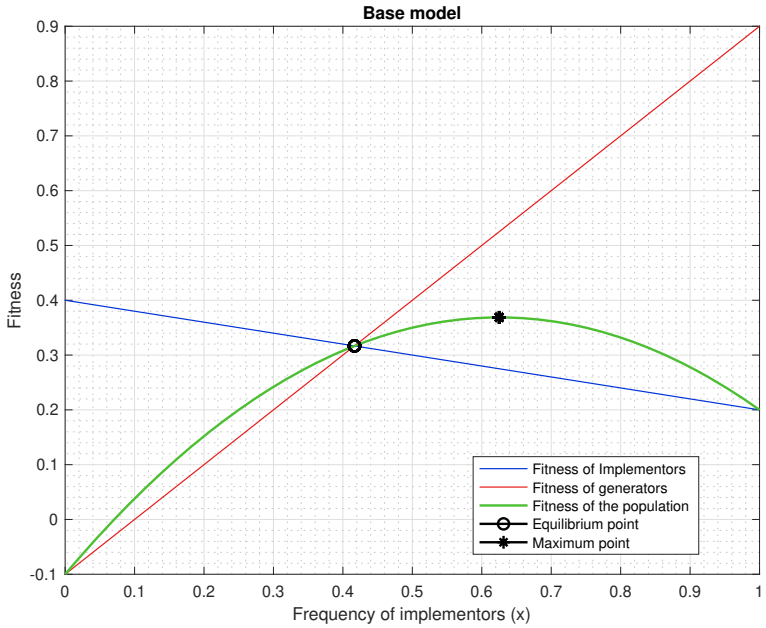

Figure 1 Expected fitness of idea implementors, idea generators, and mean population performance as a function of the implementor frequency. In this example, $V = 1$, $C_I = 0.6$, $C_G = 0.1$, $\gamma = 0.2$. The equilibrium point and the point of maximum population performance are marked

3.2. Culture as Social Learning and Imitation

An environment shift has the effect that interacting pairs of implementors work with obsolete starting ideas that are no longer productive. However, the base model has implicitly assumed that after one period, *somehow* (even without having worked with an idea generator) these implementors catch up with the relevant environmental knowledge and are then able to produce the full value $V - C_I$. This instantaneous knowledge transfer could be achieved, for example, through circulated technical notes and procedures, initiated by the generators in the organization, and then internalized by implementors. One might question how long this formalization of the new technical or environment knowledge might take, but assuming such a slower knowledge diffusion would not change the qualitative structure of our results.

A different way of how knowledge transfer ("catch-up") to the implementors might happen is through *social learning* (namely imitation), which is a core element of culture, according to the anthropological view (Boyd and Richerson 1995). Knowledge about environmental change and its impact diffuses from generators to implementors through broader personal encounters and relationships, beyond collaborating in water-cooler chats, as represented in the base model. We capture this effect as follows: the likelihood that an implementor builds on the right idea is proportional to $(1 - x)$, the percentage of generators in the population.[13] The payoff matrix of our base model is modified such that the implementor/implementor

[13] A more involved formal treatment of the same effect is the following: a pair of implementors in period t, after a technology shift, produces value if at least one of them has interacted with a generator in the previous period $(t - 1)$ when the shift happened. This

interaction payoff is "discounted" by $(1-x)$ because they only achieve the payoff with the probability that they build on an environmentally suitable idea: The expected performance of generators and implementors

	I	G
I	$(1-x)(1-\gamma)V - C_I$	$V - C_I$
G	$V - C_G$	$-C_G$

Table 2 Symmetric normal-form game between implementors and generators. The payoffs displayed accrue to the player on the left.

is:

$$W_{G,S}(x) = Vx - C_G$$
$$W_{I,S}(x) = -(1-\gamma)Vx^2 - \gamma Vx + V - C_I$$

The equilibrium point, x_S^*, satisfies $W_{I,S}(x_S^*) = W_{G,S}(x_S^*)$, so x_S^* solves the following equation:

$$(1-\gamma)V{x_S^*}^2 + (1+\gamma)Vx_S^* + \Delta c = 0.$$

Provided that $\Delta c < \frac{(1+\gamma)^2}{4(1-\gamma)}V$, the population dynamics converge to the following equilibrium:

$$x_S^* = \frac{\sqrt{(1+\gamma)^2V^2 - 4(1-\gamma)V\Delta c} - (1+\gamma)V}{2(1-\gamma)V}. \tag{3.9}$$

Figure 2 shows that the dynamics of the cultural mix of implementors and generators qualitatively remain the same as before. The resulting equilibrium (x_S^*) is lower than the base case, because the payoff of the implementor/implementor interactions is depressed. This finding is consistent with previous findings in anthropology (Rogers 1988, Boyd and Richerson 1995) where culture is also modeled as imitation and where cultural dynamics by themselves are also not optimal.

Thus, we still conclude that culture needs to be guided. Management can provide such guidance. Although management cannot perfectly understand, monitor, or "optimize" the creative activities of the employees, it *can* influence them. This is the topic of the next section.

happens with probability $(1-x_{t-1}^2)$. The derivation of the evolutionary stable equilibrium fraction of implementors (x^*) involves solving a fourth-order polynomial in x. This calculation is more cumbersome than the simpler version shown in the text and can be solved only numerically. Since it exhibits the same structural features, we can justify using the simpler version.

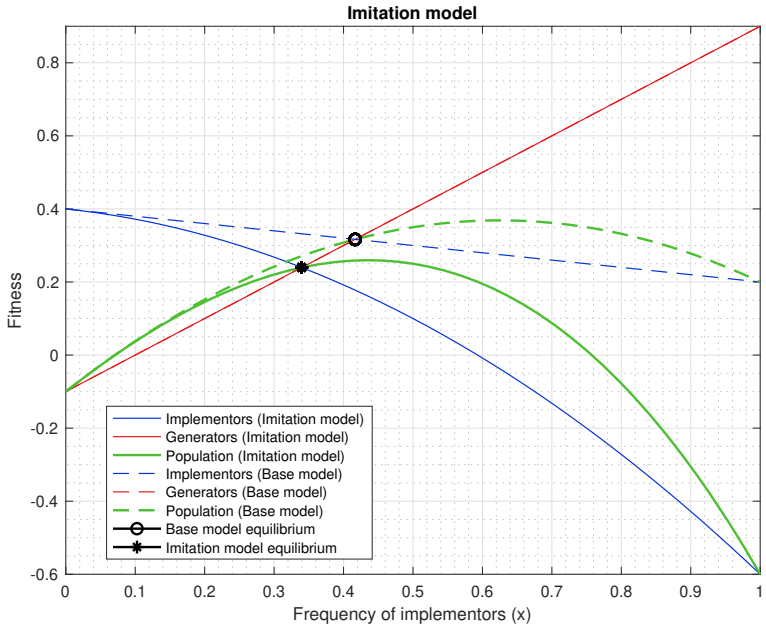

Figure 2 Expected fitness of implementors and generators and mean population performance as a function of implementor frequency with social learning. In this example, $V = 1$, $C_D = 0.6$, $C_R = 0.1$, $\gamma = 0.2$.

4. Group-Level (Management) Action

In the previous section, we saw how an open problem-solving culture may evolve through front-line interactions that are not (fully) visible or controllable by management. However, management *can* influence cultural dynamics, even if not perfectly. First, Section 4.1 explores what happens if management can influence how employees mix (non-randomly) for their idea exchanges. Management can also influence the value V that each employee gets from the successful completion of their efforts, in particular, how the overall value $2V$ is shared among the employees involved in the exchange. We examine this in Section 4.2, arriving at a core result of this article.[14] Finally, Section 4.3 examines incentive policies that management could pursue, to get better results than relying on influencing front-line sharing norms.

4.1. When Management Influences Who Interacts with Whom

We now examine how management might be able to *guide* who interacts with whom. It is a well-documented effect that individuals like to interact primarily with other individuals who are similar to themselves (Huston and Levinger 1978, McPherson et al. 2001). This is generally referred to as *group identity* (Tajfel 1970, 1982). We call it a "silo" effect in our context, because preferred interactions among similar people lead to silos, and socially perceived similarity can be caused not only by professions, but also by work styles.

[14] Management could also explore whether the overall value $2V$ could be increased. This is related to agency optimization decisions (Hart 1988, Holmstrom and Milgrom 1991). We assume that such decisions have already been made at the group level (the value $2V$ of "approved" informal initiatives by employees already incorporates agency optimization decisions). Thus, the value of informal exchanges is an economically meaningful quantity that cannot be changed "on a whim" in order to steer employees' habits.

In the presence of a silo effect, the employees do not *randomly* mix at the water cooler (Section 3.1). Rather, interactions among individuals of the same creative behavior (generators or implementors) happen with a higher probability than between behaviors. Denote by $m \in [0,1]$ a measure of the degree to which pairing between individuals tends to favor interactions between individuals of the same type (Bowles 1998). Then denote with $\mu_{II} = m + (1-m)x$ the probability that an implementor will interact with another implementor: When $m = 0$, then $\mu_{II} = x$, which corresponds to random pairing. If $m > 0$, then $m + (1-m)x > x$, or an implementor is more inclined to interact with another implementor than in random pairing.[15] Consistently, $\mu_{IG} = 1 - \mu_{II} = (1-m)(1-x)$. In a similar fashion, $\mu_{GI} = (1-m)x$, and $\mu_{GG} = m + (1-m)(1-x)$.

The payoffs of the interactions between implementors and generators are the same as in the base model (see Table 1). The expected payoffs in the silos become, respectively:

$$W_{I,m}(x) = (1-m\gamma)V - C_I - (1-m)\gamma V x \tag{4.1}$$

$$W_{G,m}(x) = (1-m)Vx - C_G \tag{4.2}$$

The equilibrium x^*_m satisfies $W_{I,m}(x^*_m) = W_{G,m}(x^*_m)$ and is given by:

$$x^*_m = \frac{(1-m\gamma)V - \Delta C}{(1-m)(1+\gamma)V} \tag{4.3}$$

The equilibrium is in the range $(0,1)$ provided that $m < \min\left\{\frac{V-\Delta c}{\gamma V}, \gamma + \frac{\Delta c}{V}\right\}$. We can now show that $\partial x^*_m/\partial m = \big((1-\gamma)V - \Delta c\big)/\big((1-m)^2(1+\gamma)V\big) > 0$; in other words, the stronger the silos, the higher the equilibrium fraction of implementors. The mean performance of the firm at equilibrium is:

$$\widehat{W}_m(x^*_m) = \frac{(1-m\gamma)V - \Delta c}{1+\gamma} - C_G. \tag{4.4}$$

Compared to (3.7), siloing *reduces the mean performance* of the organization. Moreover, $\widehat{W}(x^*) - \widehat{W}_m(x^*_m) = m\gamma V/(1+\gamma)$. This implies that the reduction in performance due to siloing increases not only with the strength of the silo effect m but also with the degree of variability of the environment γ. The more variable the environment, the more detrimental the effect of siloing. The next proposition summarizes the effects of silo culture on the equilibrium mix and organizational performance.

PROPOSITION 3. *An increasing silo effect shifts the population mix toward more implementors and leads to lower organizational performance.*

Given the strong evidence that some siloing bias is typically present in organizations (think of "creative types preferring to talk to other creative types"), this identifies a performance-enhancing influence lever by management: management can try to encourage the "open culture" from the previous section–the base

[15] One can think of m as a *coefficient of relatedness*, which has been used in biology, for example Hamilton (1964, 1975).

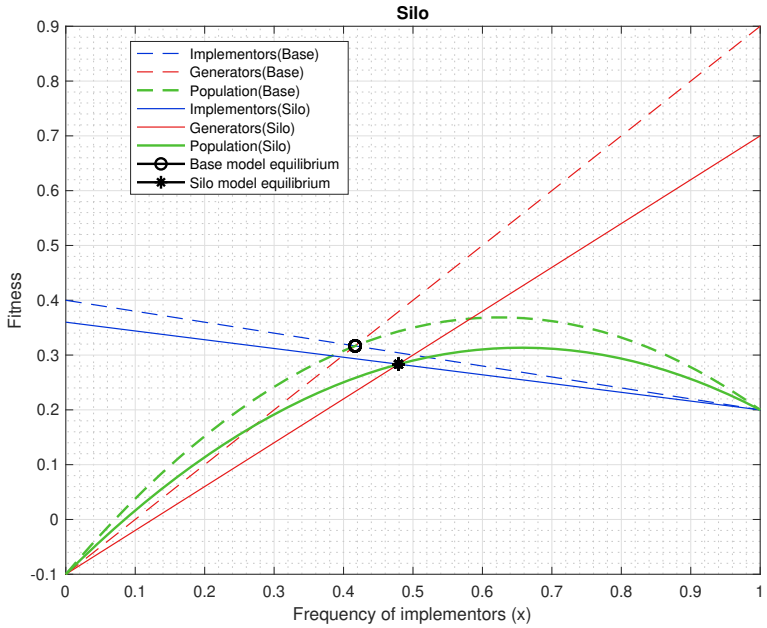

Figure 3 Expected fitness of implementors and generators and mean population performance as a function of implementor frequency. In this example, $V = 1$, $C_I = 0.6$, $C_G = 0.1$, $\gamma = 0.2$, and $m = 20\%$.

model turns out to capture the highest-performing mixing situation. Management can do this by encouraging innovation-related employees to mix as much as possible. To the extent that management can identify generators and implementors, it might directly organize events (e.g., inviting identified idea generators to implementation events). If generators cannot be perfectly identified (which often is the case), management might try to organize approximations of perfect mixing, for example, by encouraging group events where the chances of generators meeting implementors are high. But the insights from the previous section hold: because management can only partially control the front-line dynamics of (creative) culture, it needs to understand the general nature of the underlying dynamics in order to affect changes in the right direction.

4.2. When Culture Includes a Norm of Value Sharing

Whenever collaborating employees contribute different amounts or kinds to a common endeavor, the question of sharing the benefits arises (Varian 1974). In our base model, implementors expend more effort than generators, as measured by the resources expended, $C_I > C_G$, while they "receive" equal rewards, namely half of the overall value $2V$. If one could take these costs at face value, a compensation scheme could be devised. However, these costs only partially correspond to "budgets" and cannot be used to assign relative value contributions. This is because they do not create value directly but merely trigger downstream changes in formal procedures and, moreover, because the input of the generators in helping the organization to adapt to external environmental changes is critical but not directly measured. In this situation, with some parallels to "team production," the convention is to use team-based rewards (DeMatteo et al. 1998), which motivates the equal-reward assumption V in the base model.

Therefore, the *values* side of culture (the how-to-get-along dimension in the words of Schein (2010)) is relevant in such situations. Culture is capable of maintaining a socially defined relative value judgment of the two types of contributions. Like the informal innovation behaviors of the workers, this relative value judgment arises from the bottom-up and cannot be imposed by management. The cultural value judgment may be partially visible to management, and management may be able to nudge it, for example, by publicly praising people who have innovated and helped others. But in essence, the relative value is defined socially.

We incorporate a value-sharing norm into our base model in the following way. Suppose that an implementor who executes a generator's idea receives an additional "recognition fee" δ, which represents a value-sharing norm that acknowledges his/her (more costly) effort to transform an idea into an impact-producing output. This fee may be (or usually is) non-monetary; it may take the form of respect or status, which, in turn, may be expressed by symbolic privileges or by how people are being addressed (perhaps with admiration). Whenever a lower relative prestige status is perceived as a cost to those who admire others, this is actually a transfer (Henrich and Gil-White 2001, Huberman et al. 2004). This fee δ could be positive (the generator acknowledges the implementor) or negative (the generator is acknowledged by the implementor). Formally δ is added to the receiver's individual reward V. We associate the fee with a "norm" because it emerges from a social consensus rather than being imposed by management. This value-sharing norm is consistent with a communal sharing type of relationship between agents identified by Fiske (1992).

	I	G
I	$(1-\gamma)V - C_I$	$V + \delta - C_I$
G	$V - \delta - C_G$	$-C_G$

Table 3 Symmetric normal-form base-case game between implementors and generators with a fee δ from generators. The payoffs displayed accrue to the player on the left.

With the transfer δ, the payoffs of the employees change from the base model to Table 3. The expected fitnesses of implementors and generators are, respectively:

$$W_{I,\delta}(x) = V + \delta - C_I - (\gamma V + \delta)x \quad \text{and} \quad W_{G,\delta}(x) = (V - \delta)x - C_G. \tag{4.5}$$

Note that $W_{I,\delta}(x) = W_I(x) + \delta(1-x)$, and $W_{G,\delta}(x) = W_G(x) - \delta x$, which implies that $\widehat{W}_\delta(x) = xW_{I,\delta}(x) + (1-x)W_{G,\delta}(x) = \widehat{W}(x)$, in other words, the mean performance of the population with the value-sharing norm remains the same as in the base model. The equilibrium population mix x^*_δ is at:

$$x^*_\delta = \frac{V + \delta - \Delta c}{(1+\gamma)V}. \tag{4.6}$$

The equilibrium is in the range $(0,1)$ iff $-(V-\Delta c) < \delta < \gamma V + \Delta c$. As we would expect, $\delta > 0$ shifts the equilibrium toward implementors, and $\delta < 0$ shifts the equilibrium toward generators. The mean performance at equilibrium is:

$$\widehat{W}_\delta(x^*_\delta) = \frac{(V-\delta)(V+\delta-\Delta c)}{(1+\gamma)V} - C_G. \tag{4.7}$$

We again encounter the phenomenon that culture, now expressed by the value-sharing norm, is not by itself performance enhancing. In fact, a sharing norm of $\Delta c < \delta < \Delta c + \gamma V$ or of $-(V-\Delta c) < \delta < 0$ will lead to $\widehat{W}_\delta(x^*_\delta) < \widehat{W}(x^*)$. In other words, a firm with δ that either overcompensates an implementor or attributes more than half of the value V to a generator will perform worse, in equilibrium, than a firm with $\delta = 0$.

However, there is an optimal value of δ (call it δ^*) that maximizes the overall performance of the organization. Since $\widehat{W}_\delta(x) = \widehat{W}(x)$, the optimal value δ^* can be found by requiring $x_\delta = x^{**}$, resulting in $\delta^* = \Delta c/2$. At δ^*, the mean performance of the organization achieves the optimum, as specified in Equation (3.8). The optimal value-sharing norm sets the individual net payoffs in a mixed interaction pair (implementor and generator) equal at $V - \frac{1}{2}(C_I + C_G)$. In other words, individuals who collaborate and co-produce an output will realize equal net utilities despite the different input efforts. This resulting norm could be communicated as a "cultural narrative" in the organization. The following proposition summarizes this key finding.

PROPOSITION 4. *If there is a value-sharing norm in the organization, where the partner who has a higher benefit from the interaction "pays" the lower benefit partner a "fee" δ (most often in nonmonetary ways, such as status), there exists a $\delta^* \neq 0$, which maximizes the organizational performance. δ^* equalizes the net payoffs of the interacting partners. Other value-sharing norms may benefit or damageorganizational performance compared to the absence of a value-sharing norm.*

Figure (4) shows one example of the value-sharing model. We repeat that cultures and the informal status fee that people pay to one another may cause severe underperformance (an example is described in Weeks 1998), which in our context is represented by δ taking on a value that reduces the population performance. As is the case with the population composition of generators and implementors, management usually neither has the power to impose a δ nor knows enough about the subtle performance effects to choose the "right" δ. However, if a good value for the status royalty can be found (possibly by selective competitive forces at the industry level, which we will discuss later), culture can also enable high performance.

Over time, as well as compared across organizations, the value-sharing norm δ may therefore take values that look random (unintended) from the outside. This, then, raises the question of how organizations can establish a "productive" culture that leads to higher market performance. We turn to this in the next section.

We have separately discussed the two managerial interventions, influencing siloing and supporting a sharing norm δ. The two can be combined in one model formulation, which we demonstrate in Appendix C. All model insights hold (at the cost of more complex notation); one additional insight from the combined model is that the optimal sharing norm δ^* depends non-linearly on the level of siloing in the organization.

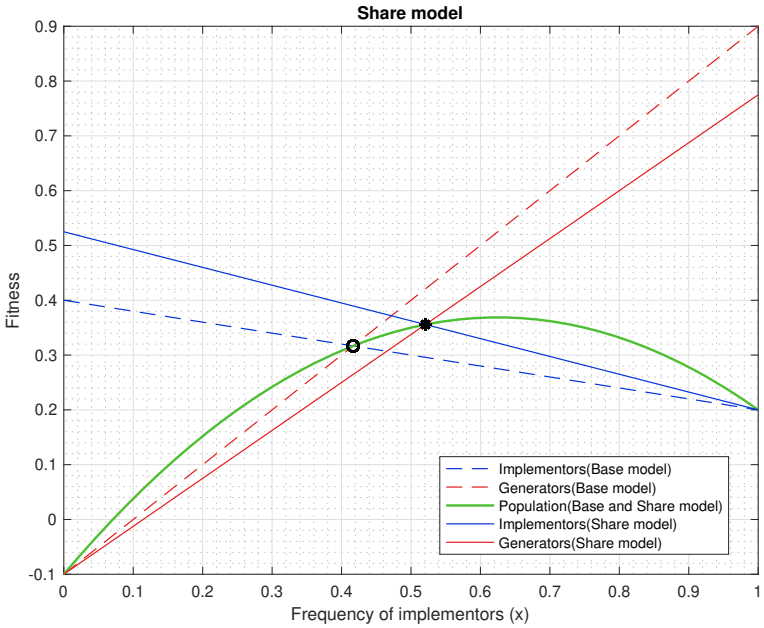

Figure 4 Expected fitness of implementors and generators and mean performance of the firm with the optimal value sharing norm. In this example, $V = 1$, $C_I = 0.6$, $C_G = 0.1$, $\gamma = 0.2$, and $\delta = 0.125$

4.3. When Management Applies Formal Incentives

In this section, we address the frequently asked question about the difference between culture and incentives or why management cannot simply incentivize the right collaboration between implementors and generators. An answer is that management does not know what workers do (with respect to their voluntary creative efforts), which is the same limitation that does not allow management to micromanage culture.

In order to conceptually compare incentives to culture, we now assume that management *can* distinguish implementors from generators and track their interactions, and therefore *can* pay the implementors the equivalent of the transfer fee δ as a formal incentive ρ. This incentive does not come as a (informal social) cost for the generator but is paid by management. Of course, such an endeavor requires a possibly high monitoring cost and time. In what follows, we do not consider such costs, in an analysis that is "biased" in favor of the incentive scheme.

Formally, a positive value $\rho > 0$ is added to the implementor's reward V only when an implementor cooperates with an idea generator (thus, management replicates the sharing norm, only that the generator does not pay for it). This incentive improves the implementor's fitness but also represents a cost that has to be subtracted from the overall company output. The problem of the manager then becomes how to choose the level of the incentive ρ to maximize the company's output.

The employee payoffs are shown in Table 4, analogous to Table 3, only that the implementor receives the incentive without the generator having to pay for it.

	I	G
I	$(1-\gamma)V - C_I$	$V + \rho - C_I$
G	$V - C_G$	$-C_G$

Table 4 Symmetric normal-form base-case game between implementors and generators with an incentive ρ given to implementors when they interact with generators. The payoffs displayed accrue to the player on the left.

As before, x is the fraction of implementors in the population. Then the expected fitnesses of implementors and generators as a function of x are respectively:

$$W_{I,\rho}(x) = V + \rho - C_I - (\gamma V + \rho)x \tag{4.8}$$

$$W_{G,\rho}(x) = Vx - C_G \tag{4.9}$$

The interactions between implementors and idea-generators will reach an equilibrium x^*_ρ that satisfies $W_{I,\rho}(x^*_\rho) = W_{G,\rho}(x^*_\rho)$ and is given by:

$$x^*_\rho = \frac{V + \rho - \Delta c}{(1+\gamma)V + \rho}, \tag{4.10}$$

where $\Delta c = C_I - C_G$. Compared with (4.6), note that $x^*_\rho < x^*_\delta$ when management offers implementors the same amount of reward as the norm δ, which is agreed freely between implementors and generators. This is because the incentive ρ is not paid by the generators and, leaving them better off, shifts the equilibrium towards them. Note also that the difference between x^*_δ and x^*_ρ increases as the environment becomes more variable. In Figure (5) we depict the fraction of implementors at equilibrium as a function of the incentive parameter ρ or the value sharing parameter δ.

Search costs C_I and C_G represent company resources (and are thus used in company performance evaluations). Thus, an incentive choice ρ (provided by management) makes the expected output of the company at equilibrium:

$$\widehat{W}_\rho(\rho) = x^*_\rho W_{I,\rho}(x^*_\rho) + (1 - x^*_\rho) W_{G,\rho}(x^*_\rho) - \rho x^*_\rho (1 - x^*_\rho) \tag{4.11}$$

Here, the term $\rho x^*_\rho(1 - x^*_\rho)$ accounts for the incentives given to implementors (when interacting with generators) to the detriment of management's remaining total output. The rational manager will choose the incentive level ρ^* that maximizes $\widehat{W}_\rho$, or, in other words, the optimum incentive level ρ^* will satisfy $\partial \widehat{W}_\rho / \partial \rho = 0$. The maximum achievable performance is the same in both cases, as this is the benchmark case that we have constructed (management uses the incentive to pump resources into the implementor group to get more performance, whereas the group with the right social value sharing δ uses it among itself). However, using an incentive, management needs to use much larger amounts in order to achieve the same result. If compared at par ($\rho = \delta$), the voluntary value-sharing norm is more efficient than an incentive.

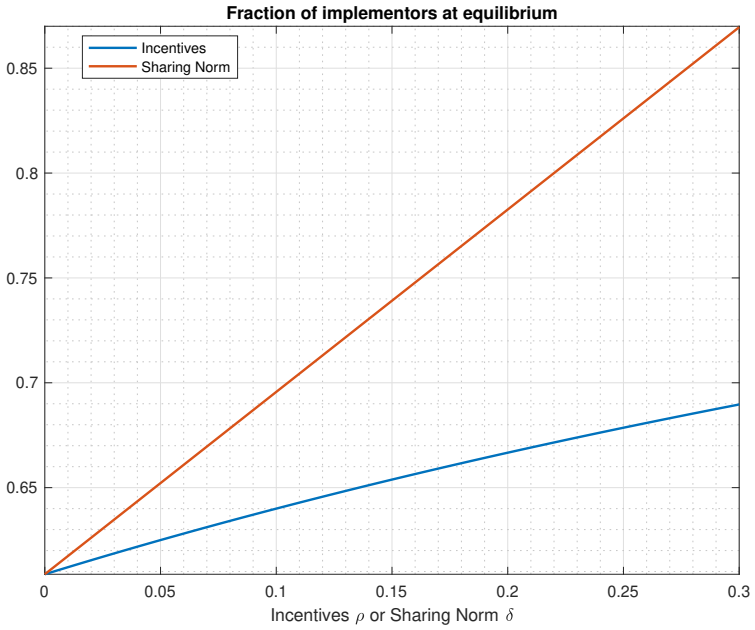

Figure 5 Fraction of implementors at equilibrium as a function of the incentive parameter ρ or the sharing norm δ. In this example, $V = 1.0$, $C_I = 0.6$, $C_G = 0.3$, and $\gamma = 0.15$.

5. Competition Among Firms

One force that may push organizations in the direction of a performance-improving culture is external competition, where firms that happen to have a productive culture enjoy a competitive advantage. In other words, cultures may not be *decided* or chosen by management but *selected in* by external competition. Some evidence for this has been empirically observed for a long time (Hannan and Freeman 1977). This is also observed by ecologists in the dynamics of human populations; ecologists refer to this as *multi-level selection* (with group selection as a special case). The essence of multi-level selection is that actions at the employee, management, and industry levels are interdependent; lower levels drive the higher levels while the higher levels constrain or prompt the lower levels.

The reader may note that this has a conceptual implication for where the locus of effective decision-making lies - it is not (only) at the level of management who do things for possibly the wrong reasons, based on myths or beliefs from the past. Some cultural norms are maintained because the company pursuing them is favored by the external environment (in our case, the market). The market reasons may be different from the reasons that management believes are in play. The driver of the firm's market position is partially selected because of the industry competitive mechanism at play, not solely because of management's rational choice. Our model in this section incorporates this logic alongside choice.

Suppose that N firms indexed by $i = 1, 2, \cdots, N$ compete for market share. In every period t, each firm (explicitly or implicitly) chooses its value-sharing norm $\delta_i(t) \in [-(V - \Delta c), \gamma V + \Delta c]$ (in this range, the

machinery of culture can feasibly work). The choice of δ governs the firm's productivity $\widehat{W}(\delta_i)$, a link that is expressed through the firm's marginal cost C_i:

$$C_i = C_0 - \lambda \widehat{W}(\delta_i) \tag{5.1}$$

for $C_0, \lambda > 0$. The productivity range is $[W_L, W_H]$ where $W_L = -C_G$ (corresponding to the norm δ being too low or too high) and $W_H = [V - (C_I + C_G)/2]^2/[(1+\gamma)V] - C_G$ (corresponding to the best norm δ^*). The cost range is $[C_L, C_H]$, where $C_L = C_0 - \lambda W_H$ and $C_H = C_0 - \lambda W_L$.

Having established their marginal costs, the firms decide on output quantities and compete for market share. We assume that the parameters C_0 and λ are such that for every choice of δ in the permissible range, all N firms can participate in the market by producing a positive quantity $q_i > 0$ and earning positive profits. In each period, the firms enter into a one-shot Cournot game with price determined by total quantity $Q = \sum_{i=1}^{N} q_i$ according to $P = A - BQ$, with $A, B > 0$.

Suppose that at time t the firms have chosen sharing norms that result in costs $C_i(t)$, $i = 1, 2, \cdots, N$. The equilibrium price $P^*(t)$ and profits $\Pi_i(t)$ are (Mas-Colell et al. 1995, §12.C)

$$P^*(t) = \frac{A + \sum_{j=1}^{N} C_j(t)}{N+1} \tag{5.2}$$

$$\Pi_i(t) = \frac{[P^*(t) - C_i(t)]^2}{B}. \tag{5.3}$$

We now introduce selection pressure (in addition to quantity competition) in the form of a minimum threshold profit Π_0 (Dessein and Prat 2022). This may represent investors demanding a minimum return (threatening to exchange management otherwise), or a minimum debt repayment (which, if not paid, forces bankruptcy), or a "satisficing" profit (Winter 1971) above which firms do not feel any pressure to change.

The key is that firms with profits below Π_0 try to change their culture in an effort to lower their production cost. As we have discussed earlier, firms cannot set the sharing norm "optimally" but are only capable of picking a random value in the feasible range; however, managers can survey and benchmark to estimate the resulting new cost, and thus management can choose to keep the old norm if the new norm causes a worsening rather than improvement. This is consistent with a local search approach in the absence of knowledge of the global performance function (Levinthal 2021).

We can now formally express that when selection pressure is present (i.e., when some firms do not earn the threshold profit), the range of observed sharing norms around the optimum norm δ^* will probabilistically shrink. Moreover, if the selective pressure Π_0 or the number of firms increases (if there is market entry), the range of norms around δ^* that enable profits above Π_0 shrinks. Thus, the industry (weakly) converges toward the "best" industry sharing norm δ^*. The proof is in Appendix D.

PROPOSITION 5. *Under Cournot competition among firms, if there is selection pressure present (that is, if at least one firm earns a profit below the threshold Π_0), the firm cultures $\delta_i(t)$ exhibit the following behavior:*

a) $\max_i \delta_i(t+1) \leqslant \max_i \delta_i(t)$ *and* $\min_i \delta_i(t+1) \geqslant \min_i \delta_i(t)$.

b) The range of sharing norms that allows an above-threshold profit is $[\delta_L, \delta_H]$ *with:*

$$\delta_{H,L} = \frac{\Delta c}{2} \pm \sqrt{\frac{(\Delta c)^2}{4} + V^2 - (\Delta c)V - \left(C_0 + \lambda C_G - p^* + \sqrt{B\Pi_0}\right)\frac{1+\gamma}{\lambda}V} \tag{5.4}$$

If the profit threshold Π_0 *or the number of firms in the industry* N *increases, the range of profitable sharing norms* $[\delta_L, \delta_H]$ *decreases.*

This proposition states that as long as there is selection pressure (any firm earns a below-threshold profit), the industry narrows its range of cultures around δ^*. This process stops when selection pressure disappears (when all firms are above the threshold profit), but can start again if market entry or an increased profit threshold narrows the range of sufficiently productive cultures. This happens *not because managers learn about culture*; it happens even if managers are not informed about culture and pick a sharing norm at random. The efficient cultures are not chosen but *selected* into the population by the selective pressure arising from industry competition. If a subset of the management teams *are* able to interpret culture, even if only by being able to steer their culture by a small amount ϵ' biased in the right direction, then their firms will have an advantage. This advantage takes the form of a higher survival probability every period and a faster transition to the optimal efficient culture.

Although we have demonstrated the interaction of culture and selection at the industry level (multi-level selection) in the context of Cournot competition, the mechanics of the proposition suggest that the logic will also hold under other competition regimes, as long as there is a clear competitive effect of the cultural fitness of an organization. For example, in Appendix E.1 we show that the cultural norm δ^* is an evolutionary stable equilibrium (ESS), stable in the face of entry by mutants with different choices of sharing norms. Appendix E.2 shows that this remains true when firms engage in a differentiated Bertrand game (price competition rather than market share competition).

In sum, our model has a representation of spontaneous, front-line cultural dynamics in organizations, imperfect and noisy control attempts by management at the top of the organizations, and a mixture of selection and (imperfect) managerial choice at the competitive industry level. This suggests that both (choice-based) equilibrium characteristics (Hermalin 2001) and (selection-based) survival characteristics (Hannan and Freeman 1977) may coexist, which invites empirical examination.

A limitation of industry-level selection of cultural traits is that industries often do not enjoy environmental stability for very long. We started the model specification with regular technology changes, a change that occurs with probability γ every period (meaning that, on average, a technology change will happen once every $1/\gamma$ periods). However, an external shift shift may involve technology as well as regulation or market dynamics, which may lead to changes in other parameters of the model, such as value creation V, search costs C_I and C_G, and thus the spontaneous equilibrium of implementors and generators. This also changes

the optimal sharing norm, forcing the industry to search for a new equilibrium. If such fundamental industry changes (for example, from new business models) are relatively frequent, the industry may rarely reach an equilibrium, and a transient state may represent "business as usual." This (i.e. the level of dispersion of cultures within an industry as a function of core industry factors such as the cost of doing business or the market potential) is an empirically testable prediction of the model.

6. Discussion

The model developed in this article represents what evolutionary anthropologists call a multi-level selection model: responding to rather than anticipating and planning their environment, employees' interaction behaviors are selected at the front line level, and management's imperfect nudging of the cultural sharing norm is selected at the competitive industry level.

The multiple levels enable us to speak to the long-standing question of how powerful management is versus how powerful front-line organizational dynamics and culture are: We can use comparative statics to compare the importance of the dynamics at the three levels.

We characterize the maximum benefit from optimal nudging of the sharing norm over no nudging at all in Equation (4.7) (that is, $\delta = \delta^*$ versus $\delta = 0$). This is the value that management *can* bring under the constraints of the economic situation of the organization, taking industry competition as given:

$$U \equiv U(\gamma, \Delta c, V) = \frac{(\Delta c)^2}{4(1+\gamma)V} \tag{6.1}$$

Comparative statics show that $\partial U/\partial\gamma < 0$, which indicates that even the best possible managerial nudging loses power as the environment changes more frequently. Moreover, $\partial U/\partial(\Delta c) > 0$, which shows that the managerial nudging gains power as the cost differential between the two roles increases. Finally, we have $\partial U/\partial V < 0$, which indicates that managerial nudging becomes less effective with the size of the produced innovation value; when the stakes are high (V is large), the population self-organizes, at equilibrium, closer to a mix that produces the maximum performance, and thus management's leeway is limited. Finally, if management *can* purposefully move the sharing norm around (for example, because the management team is socially well integrated with the employees), and if management can convince people to collaborate across types (rather than speaking with one another only in silos), this will also increase management's power.

In parallel, the intensity of competition in the industry also produces selective pressure: the profit threshold Π_0, below which firms must change (or be replaced), as well as the number of competing firms, which pushes everyone's profit down toward the threshold, restrict the range of permissible value-sharing norms. In particular, we show in Section 5 that the combined selective pressure from profit threshold and crowdedness in the industry "compresses" cultures to become more similar and closer to the optimal value-sharing norm δ^*. This discussion is summarized in Figure 6.

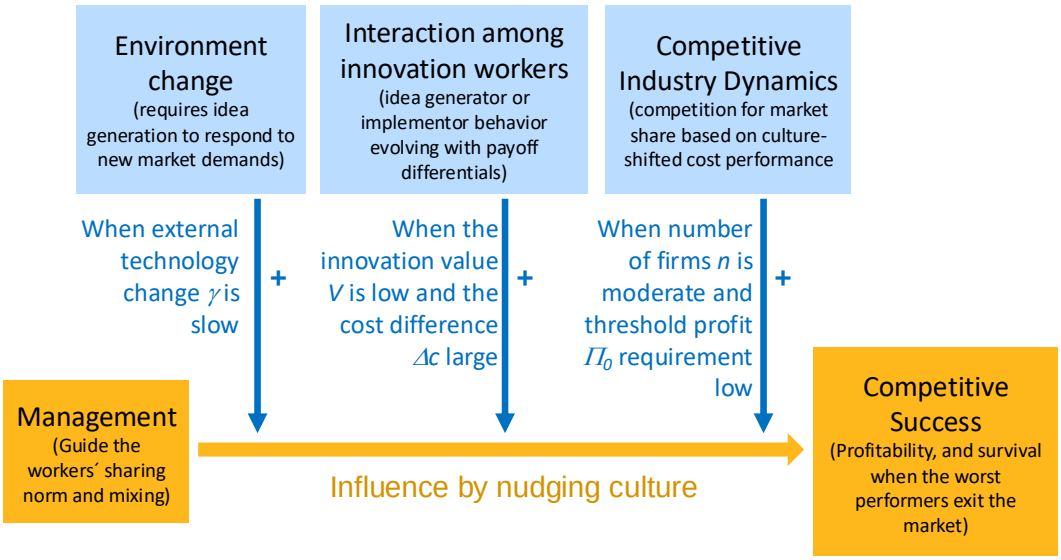

Figure 6 Model parameter constellations that strengthen management's influence on culture performance and competitiveness

To summarize this in different words, the CEO can successfully be the main driver of culture and performance only if the conditions of Proposition 6 are met. If this is not the case, the CEO cannot make a large difference and culture is likely to be driven by employee dynamics or competitive forces. This language allows us to put the inconsistent findings of the literature into a context: when can the CEO indeed shape a culture "stock" as Dessein and Prat (2022) assume, when are managers able to "design" culture for performance (Graham et al. 2022, Hermalin 2001), and when, in contrast, is culture better captured as a front-line force, as anthropologists have assumed?

7. Conclusion

The quip "culture eats strategy for breakfast" reminds us of the important interaction between front-line activities in an organization and the strategic position of the firm, and ultimately industry structure (Loch and Kavadias 2007). This article builds a multi-level culture evolution model that describes how a link between the front-line and industry structure may conceptually operate. In doing so, the model offers a framework through which the interaction between culture and strategy can be discussed – a discussion that has not yet arrived at a consensus view in either modeling or empirical literature.

The various conceptualizations of culture that we reviewed at the outset share a key principle: culture manifests itself through spontaneous front-line interactions among (large numbers of) employees, which aggregate to consistent behaviors. We build a model that accommodates such a view of interactions, especially voluntary collaboration among innovation workers, involving people with differentiated roles (idea

generators and implementors of bottom-up generated ideas). Most importantly, these phenomena influence the composition of front-line activities, and indirectly the overall performance of a company, in ways that are only partially determined by management.

Our formal analysis captures the evolutionary stable mix of activities emerging at the front-line and characterizes how this mix changes, depending on key parameters (such as the stability of the industry environment and the cost differential between the activities). More variable environments encourage front-line interactions with a higher percentage of novel ideas, whereas a lower cost of implementation results in a higher fraction of implementation activities. Notably, these equilibrium shifts are not governed by managerial control but are the result of population dynamics among self-interested individual employees. The model suggests that "unguided" front-line culture results in a mix of activities that does not produce the highest possible company performance. This is consistent with findings in evolutionary anthropological studies and is robust to the presence of social learning and continuous improvement.

Management cannot micromanage employee interactions, neither by incentivizing activities nor by selecting "best" ideas. Management can influence the thrust of culture, but only in limited ways, of which we discuss two: first, if management can encourage employees to mix across categories, performance increases. The second way is the norm of value sharing between employees with different behaviors (how each behavior is rewarded). If management can encourage employees to (informally) reward the group with higher cost of contribution (in our base model this is the implementors), for example in the form of respect and status, performance will increase. Both managerial "nudging" interventions can improve performance even if they are only "roughly" right, but not optimal. We also show that, even under the over-optimistic assumption of unlimited managerial monitoring ability, explicit incentives will not be as effective as the bottom-up-driven mutual rewards because management has to overcompensate employees. Culture is, as a guidance system among employees, more effective, but at the price of not being fully controllable.

Although these conclusions come from a simple model, they can be used to highlight some limitations of popular and trendy concepts, such as "dedicated ideation spaces" to increase the generation of new ideas. Giving technical people room to talk about new ideas sounds good, but this may also motivate individuals with the propensity to generate new ideas (generators in our terminology) to meet other like-minded generators, contributing to siloing and reducing innovation performance.

As we stressed earlier, the model does not make detailed predictions, but rather provides a language within which to discuss how culture, management actions, and competitive pressure interact. This is a contribution, as the literature to date has looked at drivers at different levels of the firm and produced contradictory predictions that are difficult to compare; for example, the model by Dessein and Prat (2022) exclusively focuses on the manager (CEO), who either builds a stock of valuable culture or depletes it. At the same time, empirical work offers conflicting evidence, reporting a self-perceived managerial sense

of control over culture (Graham et al. 2022) or reporting that managers have only moderate control over culture (Li et al. 2024).

Our model adds to an emerging dialogue between evolutionary anthropology models of culture and recent sociological and economic models of culture. In evolutionary anthropology, the "group-level decision-maker" is weak (as tribal rulers may not try to maximize group fitness), and thus culture is driven by the organizational system more than by the leader (Henrich et al. 2015). In contrast, economics (Hermalin 2001) and also recent organizational theory (Weber and Dacin 2011, Levinthal 2021) have emphasized managerial choice in guiding culture. Our model shows that both mechanisms may be operating alongside each other: there *is* managerial choice at the group level, but it is incomplete and limited and may sometimes (when management is uninformed about culture) result in "randomness." This insight is theoretically relevant, bridging differing views of culture in the literature, but it is also relevant for a manager's reality, where it may be better to "go with the flow" and let culture evolve. Nudging culture may be better than trying to control it; bottom-up effects, if damaged, may reduce the organization's long-term performance.

The benefits from a productive culture do not "dominate" strategy (as the quip "eating it for breakfast" might imply), but are of significant strategic relevance. As our results also indicate, companies with an unproductive culture may *ceteris paribus* suffer a competitive disadvantage that results in a higher likelihood of disappearing from the market (by being taken over or outright failure). To reduce such extinction risks, a management team may proceed with attempts to guide its organization's culture that, even if imperfect and only directionally correct, may create a competitive benefit. Thus, companies with slightly better choices (or occasional luck) are selected by competition to be in the long-term stable oligopoly. In this way, industry-level long-term equilibria may result from the *selection* of imperfect managerial strategies alongside intentional heuristic managerial choices (Winter 1971). Our model allows us to articulate how managerial choice, even when imperfect, may interact with selection to create productive outcomes, and we offer some qualitative insights about when managerial choice matters the most (Figure 6).

This insight is again theoretically relevant, as it offers a bridge between a view of industry dynamics where firms enter and later die without changing (Hannan and Freeman 1977) and a view of rational strategic decision makers who rapidly find equilibria (Hermalin 2001) or rationally manage the portfolio of ideas produced by their employees (Levinthal 2021). Again, both views capture part of what is going on, while our model reminds us that we need to understand both sides. The model offers a conceptual logic explaining how the views interact, *how* managers can be influential, and how firms can change, while being less the masters of their own fates than they may like to think.

Finally, the limits that cultural evolution places on managerial intervention may slow an industry's speed of convergence toward a long-term equilibrium. Every time the environment changes (e.g., through technology, regulation, or market demographics), a new trajectory starts. Our model thus suggests the possibility that industries may spend most of their lives off-equilibrium, exhibiting consistent cultural dispersion that

leads to persistent performance differences. This is consistent with literature in strategy (such as Gibbons and Henderson (2016), Syverson (2011), Bloom and Van Reenen (2007)) and may offer additional research opportunities.

Models like the one developed here hold the potential to illuminate how the effects of micro-level managerial choices and large-scale industry dynamics for firm trajectories combine, and when which level of analysis may be more influential. Multi-level analyses of organizational decisions are important for understanding the complexity of drivers of firms' fates, but they have so far not been sufficiently considered.

Of course, our model is very simple and does not enable specific predicitions; it provides a language for having such a discussion. Based on such a model, other essential characteristics of culture can be incorporated (such as collaboration, norms of decision making, or risk taking propensity), and more realistic industry competition can be studied, where other differentiation factors matter (such as speed, or product differentiation, or service levels) and where culture influences those multiple differentiation dimensions. More complex models will need to be built to develop precise predictions, but the discussion will certainly be useful and important.

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Appendix

Online Supplement Appendix to Manuscript "Organizational Culture, Innovation, and Competitive Performance: A Multi-Level Dynamic Model"

Christoph Loch, Konstantinos Ladas, and Stylianos Kavadias

A. When idea generators don't always find an idea that works

In section 3.1 we have assumed that idea generators always find a suitable (not necessarily the optimal) solution to the current environment state. Here we relax this assumption, introducing "fallible" generators who successfully find a suitable solution only with a probability $\alpha > 0$. This probability affects the interactions of generators with implementors. For the interactions between implementors we assume that the results disseminate fast within the organization, so they are not affected. The implementor/generator payoff matrix is then shown in Table 5.

	I	G
I	$(1-\gamma)V - C_I$	$\alpha V - C_I$
G	$\alpha V - C_G$	$-C_G$

Table 5 Symmetric normal-form evolutionary game between implementors and generators when generators find a solution with probability α. The payoffs displayed accrue to the player on the left.

The ESS equilibrium x^*_α is then

$$x^*_\alpha = \frac{\alpha V - \Delta c}{(2\alpha + \gamma - 1)V} \tag{A.1}$$

The above equation determines the condition on the parameter α so that the equilibrium x^*_α is in the range $[0,1]$ which becomes $\alpha > \max\left\{\frac{\Delta c}{V}, \frac{1}{2}(1-\gamma), (1-\gamma) - \frac{\Delta c}{V}\right\}$. If this condition is not fulfilled, an unstable equilibrium results with either $x^*_\alpha = 0$ (all generators) or $x^*_\alpha = 1$ (all implementors).

We would intuitively expect that the equilibrium mix should shift toward implementors when generators are fallible and therefore experience lower expected rewards. But this is not the case, as the following equation shows which exhibits the change of x^*_α as a function of a change in α:

$$\frac{\partial x^*_\alpha}{\partial \alpha} = \frac{\Delta c - \frac{(1-\gamma)}{2}V}{V\left[\alpha - \frac{(1-\gamma)}{2}\right]^2} \tag{A.2}$$

This equation indicates that the equilibrium shifts into the expected direction only if $\Delta c > \frac{1}{2}(1-\gamma)V$. The reason is the alluded-to subtle interaction between generators and implementors: implementors *also* suffer when generators are fallible in the interaction, and if the cost differential is too small, then the implementors suffer *more* than the generators, and therefore, the equilibrium shifts the other way. In sum, the results are consistent with the base model, but highlight subtleties of interactions.

B. Continuous Improvement and Experimental IP

This section tests the robustness of the base model results under two modifications: first, we incorporate the idea that pairs of implementors may, in periods of continuity (without environmental change), be able to incrementally improve upon existing products/processes. In a period of environment stability, only incremental ideas are necessary, which implementors are able to produce. We assume that this increases the output value by a small percentage $0 < \epsilon \ll 1$. Second, we acknowledge that in periods of disruption, an idea generator may be able to generate *some* value even when interacting with another generator in spite of their disconnect from the formal procedures; this value is $V(1-\epsilon')$ with $0 \ll \epsilon' \leqslant 1$. For example, they may produce some value from experiments registered as *intellectual property* (IP), but not quite the full value V of a fully implemented idea. When $\epsilon = 0$ and $\epsilon' = 1$, the modified model reduces to the base model from Table 1. The interactions between implementors and generators under these modified assumptions produce the payoffs shown in Table 6.

	I	G
I	$(1-\gamma)(1+\epsilon)V - C_I$	$V - C_I$
G	$V - C_G$	$\gamma(1-\epsilon')V - C_G$

Table 6 Adapted symmetric normal-form evolutionary game between implementors and generators. The payoffs displayed accrue to the player on the left.

The equilibrium, x^*_+, retains the same structure and is now given by:

$$x^*_+ = \frac{(1-\gamma+\gamma\epsilon')V - \Delta c}{[(1-\epsilon+\gamma(\epsilon+\epsilon')]V} \tag{B.1}$$

The equilibrium population mix behaves qualitatively in the same way as before: $\partial x^*_+/\partial V > 0$, $\partial x^*_+/\partial \gamma < 0$, and $\partial x^*_+/\partial(\Delta C) < 0$. The equilibrium is shifted versus the base model in a way that is consistent with the logic of the base model: first, if $0 = \epsilon < \epsilon' < 1$ (i.e., the generators can now create at least some output), the equilibrium shifts toward more generators in the population (as their position becomes more attractive). But $\partial x^*_+/\partial \epsilon > 0$ and $\partial x^*_+/\partial \epsilon' > 0$, which means that as ϵ increases (the value of the implementors' incremental

improvement) and as ϵ' increases (the value of IP produced deteriorates), the equilibrium mix shifts towards implementors. In both cases, their expected payoff (fitness) increases relative to the generators. Both shifts of the equilibrium support the intuition of the base model: the employee type with the higher payoff (or lower cost in the base model) is more prevalent in the equilibrium, which is *not* normally consistent with maximum performance of the organization. Figure 7 depicts an instance of the dynamics of the model discussed in this section. This extension supports model robustness.

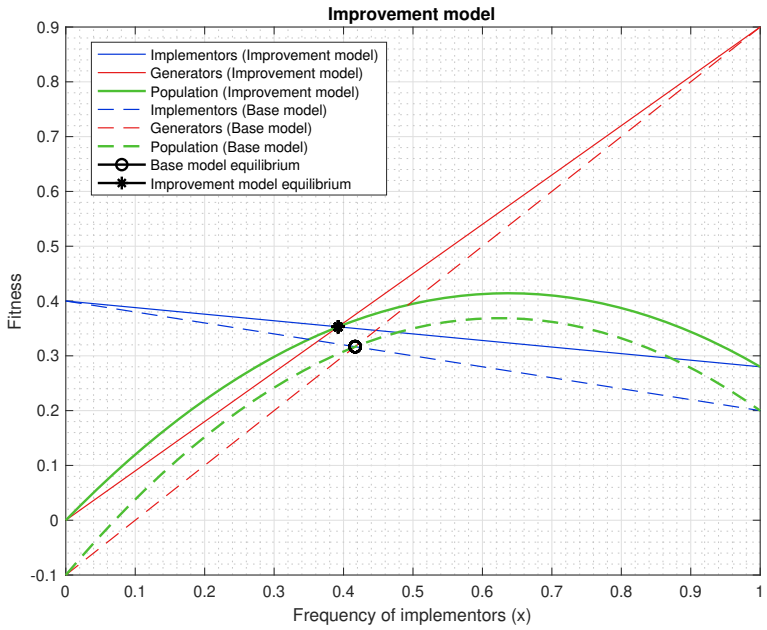

Figure 7 Expected fitness of implementors, generators, and mean population performance as a function of implementor frequency. In this example, $V = 1$, $C_I = 0.6$, $C_G = 0.1$, $\gamma = 0.2$, $\epsilon = 0.1$ (implementor incremental innovation increases the value by 10%), and $\epsilon' = 0.5$ (idea generator interactions produce 50% value).

C. When individuals interact with a silo level m and share value at level δ

In this section we assume that individuals interact with silo level $0 \leqslant m < 1$ and share value at level $\delta \geqslant 0$. The fitness of the idea generators and of the implementors are

$$W_I(m,\delta) = (1-\gamma m)V + (1-m)\delta - C_I - (\delta + \gamma m V)(1-m)x \tag{C.1}$$

$$W_G(m,\delta) = (1-m)(V-\delta)x - C_G \tag{C.2}$$

It is straightforward to show that the equilibrium $x^*(m,\delta)$ now depends on both m and δ and is given by

$$x^*(m,\delta) = \frac{(1-\gamma m)V + (1-m)\delta - \Delta c}{(1+\gamma)(1-m)V} \tag{C.3}$$

When individuals meet randomly ($m = 0$) and share value equally ($\delta = 0$), then the result is identical to the one in section 3.1. Also, when the individuals interact at random ($m = 0$) but share value at a level $\delta > 0$, the result is identical to the one in section 4.2. Finally, when the individuals share value equally but interact with some silo-level $m > 0$, the results are identical to the ones in section 4.1.

In a population where a fraction x behave as implementors and a fraction $1 - x$ as idea generators, the mean fitness is $\widehat{W}(m, \delta) = W_I(m, \delta)x + W_G(m, \delta)(1 - x)$. Note that $\widehat{W}(m, \delta)$ is maximized at $x^{**}(m, \delta)$ which is given by

$$x^{**}(m, \delta) = \frac{2V - \Delta c - m(1+\gamma)V}{2(1+\gamma)(1-m)V} \tag{C.4}$$

For a given level m of silo behavior, there exists a $\delta^*(m)$ that maximizes the mean population fitness or in other words solves the equation $x^{**}(m, \delta^*) = x^*(m, \delta^*)$. This equation gives

$$\delta^*(m) = \frac{\Delta c - m(1-\gamma)V}{2(1-m)} \tag{C.5}$$

As expected, when $m = 0$, the optimal δ coincides with the result found in section 4.2. It is straightforward to show that $\partial\delta^*/\partial m = [\Delta c - (1-\gamma)V]/[2(1-m)^2]$. When $\Delta c > (1-\gamma)V$ then $\partial\delta^*/\partial m > 0$ and when $\Delta c < (1-\gamma)V$ then $\partial\delta^*/\partial m < 0$.

D. Proof of Proposition 5

All forms with a profit at or above the threshold Π_0 do not change their sharing norm. If there are firms that do not earn the threshold profit, one of them must either be firm j with $\delta_j(t) = \max_i \delta_i(t)$ or firm k with $\delta_k(t) = \min_i \delta_i(t)$, or both: the firms with the sharing norms the furthest away from δ^* have the highest costs. Suppose now the firm with the lowest profit is firm j (the argument for firm k is analogous).

By the construction of the process by which the firm (or its replacement) changes the sharing norm, firm j performs a random draw from a distribution $F(\cdot)$ on the support of feasible sharing norms $[-(V - \Delta c), \gamma V + \Delta c]$. We show below that the profit falls off symmetrically around δ^*, therefore, we can write the probability of drawing a sharing norm with better profit than $\delta_j(t)$, $\delta_j(t+1)$ as: $0 \leqslant u_j = \Pr\{\delta^* - (\delta_j(t) - \delta^*) < \delta_j(t+1) < \delta_j(t)\} \leqslant 1$. With probability $(1 - u_j)$, the chosen new sharing norm will not improve the profit and thus, the firm will choose to stay with sharing norm $\delta_j(t)$. Therefore, the sharing norm of firm j weakly decreases toward δ^*. If all firms earn the threshold profit, then according to our change procedure,none of them will change its sharing norm, and thus the convergence stops.

Now we turn to what happens if the threshold profit Π_0 or the number of firms N increase. A firm's Cournot equilibrium profit is the squared difference of the Cournot price and the cost in Equation (5.3), and Equations (5.1) and (4.7) link the cost to the firm's cultural productivity and the sharing norm. Substituting in, we can write the firm's profit, and the threshold condition that it is equal to Π_0, in the following way:

$$C_0 - \lambda\frac{(V-\delta)(V+\delta-\Delta c)}{(1+\gamma)V} + \lambda C_G = P^* - \sqrt{B\Pi_0} \tag{D.1}$$

where P^* is the price at the Cournot equilibrium. Rearranging terms, we find that the critical values satisfy the equation

$$\delta^2 - (\Delta c)\delta - V^2 + (\Delta c)V + \left(C_0 + \lambda C_G - P^* + \sqrt{B\Pi_0}\right)\frac{1+\gamma}{\lambda}V = 0. \tag{D.2}$$

The roots of this equation yield (5.4) in the proposition. Note that the interval $[\delta_L, \delta_H]$ is symmetric around $\delta^* = \Delta c/2$ and that the interval shrinks if P^* gets smaller and if Π_0 becomes larger.

We finally show that the entry of a new firm causes the equilibrium price to shrink. Suppose that at a certain time period there are N active firms competing with ordered costs $C_1 < C_2 < \cdots < C_N < A$. The equilibrium price, P, is given by $P = (A + \sum_{j=1}^{N} C_j)/(N+1)$. The fact that all the firms are active implies that $P > C_N$. If a new firm enters with a competitive cost $C' < C_N < P$, then there are $N+1$ firms, the equilibrium price P' becomes

$$P' = \frac{A + \sum_{j=1}^{N} C_j + C'}{N+2} = \frac{N+1}{N+2}P + \frac{C'}{N+2} \tag{D.3}$$

Note that $P' \geqslant P$ implies that $C' \geqslant P$ which is not possible because we have assumed that the new firm enters if $C' < C_N < P$. Therefore, when the competition involves $N+1$ firms, $P' < P$.

If the competition involves N firms then the new equilibrium price, P', will be $P' = (A + \sum_{j=1}^{N-1} C_j + C')/(N+1)$. Again, $P' < P$ since $C' < C_N$.

If the competition, post entry, involves less than N firms (because the new firm enters at such a low cost that renders some of the high cost previous participant firms inactive) then again the new price $P' < P$, because the new price will have to be smaller than the lowest cost of the rendered inactive firm.

E. Evolutionary Stable Strategies (ESS)

E.1. Cournot Competition

As we have assumed in equation (5.1) a choice, δ, of the value sharing norm maps into the marginal production cost, c, according to the rule $c = c_0 - B(\delta)$, where $B(\delta) = \lambda\widehat{W}(\delta)$.

Assume a population of firms all playing strategy δ with marginal cost $c = c_0 - B(\delta)$ and a small fraction of "invaders" who choose a different strategy $\delta + \epsilon$, with $\epsilon \neq 0$, which results in a different marginal cost $c' = c_0 - B(\delta + \epsilon)$. The firms are paired at random and compete in a manner of Cournot (selecting quantities) in a market with inverse demand function $p = \alpha - \beta Q$, where α and β are exogenous parameters, p is the price, and Q is the total quantity. The normal-form game is given in Table (7).

The payoffs $\Pi(\delta, \delta)$ and $\Pi(\delta + \epsilon, \delta)$ in Table (7) are the symmetric and asymmetric profits at the Cournot equilibrium respectively and are given by

$$\Pi(\delta, \delta) = \frac{1}{9\beta}[\alpha - c_0 + B(\delta)]^2 \quad \text{and} \quad \Pi(\delta + \epsilon) = \frac{1}{9\beta}[\alpha - c_0 - B(\delta) + 2B(\delta + \epsilon)]^2 \tag{E.1}$$

The strategy δ is evolutionary stable (ESS) if $\Pi(\delta, \delta) > \Pi(\delta + \epsilon, \delta)$ for all ϵ. It is straightforward to see that the condition $\Pi(\delta, \delta) > \Pi(\delta + \epsilon, \delta)$ implies that $B(\delta) > B(\delta + \epsilon)$ for all ϵ, which, in turn, implies that $\delta = \delta^* = \arg\max\{B(\delta)\}$.

	δ	$\delta+\epsilon$
δ	$\Pi(\delta,\delta)$	$\Pi(\delta,\delta+\epsilon)$
$\delta+\epsilon$	$\Pi(\delta+\epsilon,\delta)$	$\Pi(\delta+\epsilon,\delta+\epsilon)$

Table 7 Symmetric normal-form game between firms with strategy δ and invaders with strategy $\delta+\epsilon$. The payoffs displayed accrue to the player on the left

E.2. Differentiated Bertrand Competition

Consider the case of two firms $i=\{1,2\}$ that produce differentiated products with costs c_1 and c_2 at prices p_1 and p_2 and compete on price (Betrand). The output of the firms q_1 and q_2 depends on the prices according to

$$q_1 = 1 - p_1 + \alpha p_2 \quad \text{and} \quad q_2 = 1 - p_2 + \alpha p_1 \tag{E.2}$$

where α is an exogenous parameter $0<\alpha<1$ that measures the degree of substitutability of the two products. Each firm chooses price to maximize profits $\Pi_i = (p_i - c_i)q_i$ for $i=\{1,2\}$. The first order conditions $\partial\Pi_1/\partial p_1 = 0$ and $\partial\Pi_2/\partial p_2 = 0$ determine the prices p_1 and p_2 at the Bertrand equilibrium which are given by

$$p_1 = \frac{2+\alpha+2c_1+\alpha c_2}{4-\alpha^2} \quad \text{and} \quad p_2 = \frac{2+\alpha+2c_2+\alpha c_1}{4-\alpha^2} \tag{E.3}$$

The profits of the two firms at the Bertrand equilibrium are then

$$\begin{aligned}\Pi_1(c_1,c_2) &= \frac{(2+\alpha-2c_1+\alpha c_2+\alpha^2 c_1)^2}{(4-\alpha^2)^2}\\ \Pi_2(c_1,c_2) &= \frac{(2+\alpha-2c_2+\alpha c_1+\alpha^2 c_2)^2}{(4-\alpha^2)^2}\end{aligned} \tag{E.4}$$

Note that in the symmetric case when $c_1=c_2=c$, the Bertrand price at equilibrium becomes $p_1=p_2=p=(1+c)/(2-\alpha)$ and the corresponding profits are

$$\Pi(c,c) = \frac{[1-c(1-\alpha)]^2}{(2-\alpha)^2} \tag{E.5}$$

As in the previous section, we assume that a population of firms follows the δ strategy and produce at a marginal cost c that depends on the firm's efficiency as dictated by the benefit gained at the mixed strategies equilibrium. In other words we suppose that $c = c_0 - B(\delta)$. An invader firm chooses a $\delta+\epsilon$ strategy and produces at cost $c' = c_0 - B(\delta+\epsilon)$. The firms are randomly paired and the resulting game is the one displayed in Table 7 where the profits are now given by the differentiated Bertrand formulas E.4 and E.5. For the strategy δ to be an ESS its is required

$$\frac{[1-(c_0-B(\delta))(1-\alpha)]^2}{(2-\alpha)^2} > \frac{[2+\alpha-(c_0-B(\delta+\epsilon))(2-\alpha^2)+\alpha(c_0-B(\delta))]^2}{(2-\alpha)^2(2+\alpha)^2}$$

Rearranging terms, the above inequality reduces to

$$-(2-\alpha^2)(\gamma - B(\delta)) > -(2-\alpha^2)(\gamma - B(\delta+\epsilon))$$

which in turn implies that $B(\delta) > B(\delta+\epsilon)$ for all ϵ. In other words, the strategy δ^* is the ESS strategy.