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Tight and Loose Coupling in Organizations

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Abstract: Some industries have consumers who seek novelty and firms that innovate vigorously and whose organizational structure is loosely coupled, or easily adaptable. Other industries have consumers who take comfort in the traditional and firms that innovate little and whose organizational structure is tightly coupled, or not easily adaptable. This paper proposes a model that explains why the described features tend to covary across industries. The model highlights the pervasiveness of equilibrium inefficiency (innovation can be insufficient or excessive) and the nonmonotonicity of welfare in the equilibrium amount of innovation.

Keywords: loose coupling, tight coupling, demand for novelty

1 Introduction

Some industries have consumers who seek novelty and have firms that innovate vigorously and whose organizational structure is loosely coupled in the sense that it easily adjusts to the changes in the economic environment. The tech industry in the Silicon Valley is like this. Consumers expect regular upgrades to gadgets; the startup culture and high employee mobility breed firms ready to take advantage of the latest changes in the economic environment. Other industries have consumers who take comfort in the traditional and have firms that innovate little and whose organizational structure is tightly coupled in the sense of being slow to adjust to the changes in the economic environment. The manufacturing industry was like this in Japan in the second-half of the twentieth century, during the industrialization stage. De-facto lifetime employment was common, and the firm's organizational structure was rigid. This paper develops an equilibrium model in which consumers' novelty seeking, firms' innovativeness, and the loosely coupled organizational structure all tend to covary. The focus is on explaining the covariation, not why some industries are more innovative than others.

The paper builds on the informal literature in organizational economics on loose and tight coupling. The concept of coupling has been popularized in

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economics by Roberts (2004) and introduced into organizational theory by Weick (1976), who had borrowed the term from Glassman (1973). Loose and tight coupling stand for weak and strong interdependence of units within an organization. Loose coupling, while possibly suboptimal for the current environment, enables the firm to adjust quickly to the changes in the environment. Tight coupling, while optimal for the current environment, hampers such adjustment.

The present paper formalizes some aspects of the concepts of tight and loose coupling and confirms the intuition that loose coupling prevails when the environment changes rapidly, or is volatile. The formal model enables one to take the analysis further and explore the relationship between the firm's choice of the type of coupling and its choice of the innovation rate. In particular, would more innovative firms be loosely or tightly coupled? Are there multiple equilibria? That is, can industries with identical fundamentals exhibit different innovation rates, coupling styles, and volatilities? If so, can these multiple equilibria be Pareto ranked? Are equilibria Pareto efficient?

The posed questions are addressed in a model that has discrete time and an infinite horizon. Each period, a firm produces an item, which a consumer buys. The item can come in one of several styles, and each period, the consumer has a taste for a particular style. His taste changes every period with some probability, interpreted as the degree of his novelty seeking. The introduction of novelty seeking is a means to operationalize the volatility of the economic environment.

The firm's behavior is governed by two elements of **organizational design**: the innovation rate and the coupling type. The **innovation rate** is the probability with which the firm changes the item's target style, the style that it aims to produce in a given period. The **coupling type** specifies whether the firm's organizational structure is loose or tight. The organizational design is chosen once and for all at time zero by the firm's founder.

Tightly and loosely coupled firms are distinguished by how they hire experts. Each expert specializes in producing an item of a particular style. A **loosely coupled** firm fires the expert it employed last period and hires an expert who specializes in the current target style. Thus, a loosely coupled firm always employs a single expert.[1] A **tightly coupled** firm retains a last-period expert who specializes in the last-period target style and hires a new one, who specializes in the current target style. Thus, a tightly coupled firm may end up employing two experts who specialize in different styles. Such experts are assumed to work badly together; they produce an item that the consumer does not value. By

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1 One can interpret the infinitely-lived loosely coupled firm as a sequence of distinct firms generated by a sequence of spinoffs, startups, and exits.

contrast, two experts in the same style work well together and produce an item that the consumer values more than the item that a single expert would produce – provided the experts match the consumer's taste.

When choosing the organizational design, the firm's founder faces a trade-off. When the consumer's taste changes, to keep up, the firm must innovate and hire experts in the new style. To do so, a tightly coupled firm – in contrast to a loosely coupled one – must experience an unprofitable period, in which the employed experts specialize in different styles. The advantage of being tightly coupled, however, is that, once the firm settles on the two experts who specialize in the style that matches the consumer's taste, these experts produce a more valuable item than a lone expert in a loosely coupled firm would. Thus, the founder optimally chooses tight coupling and low innovation rate when the volatility of the environment is low, and loose coupling and high innovation rate when the volatility is high. As a result, loose coupling and high innovation rate emerge as complements.

The founder's problem is embedded into equilibrium in which the consumer's demand for novelty is assumed to be increasing in the firm's innovation rate. The interpretation is that the consumer gets habituated to novelty and demands more of it if he sees more innovation. Multiple equilibria are possible because of the positive feedback loop; a greater demand for novelty calls for more innovation, which induces an even greater demand for novelty.

An equilibrium with more innovation and a greater demand for novelty need not exhibit higher welfare, defined as the sum of the firm's and the consumer's payoffs. By assumption, the consumer demands novelty, not better quality; he simply gets bored with old styles. Hence, the firm must keep running (i. e., innovating) merely to stay in place (i. e., to have the consumer value its output).

Equilibrium inefficiency is pervasive. Generically, any equilibrium that has less than the maximal feasible innovation rate is inefficient and can have either excessive or insufficient innovation. Inefficiency arises because, when selecting the innovation rate, in the spirit of the competitive-equilibrium paradigm, the founder neglects the equilibrium effect of his choice on the consumer's demand for novelty.[2] At an inefficient equilibrium, the founder can decrease the uncertainty about whether the consumer's taste will change in a given period by either innovating less and thereby reducing the probability with which the consumer's taste changes or innovating more and thereby increasing the probability with which the consumer's taste changes. The resulting smaller uncertainty makes it easier for the firm to target the consumer's taste. The equilibrium

2 This neglect is a result if the model is interpreted as having a continuum of firms, so that each firm's founder regards his firm as incapable of appreciably affecting the demand for novelty.

story is a bit more subtle than this because the firm affects the demand for novelty with the same tool (the innovation rate) that it uses to target the consumer's taste; nevertheless, the described (envelope-like) argument suffices to see the profitability of a marginal deviation. This increased profitability translates into a welfare improvement because it is assumed that the firm prices to extract the consumer's surplus, and so welfare coincides with the firm' profit.

The model's results rely on the assumption that the firm's organizational design is chosen once and for all. The critical element of this assumption is that the organizational design changes less frequently than the consumer's taste does. That a firm's innovation rate may be slow to adjust to current market conditions is confirmed by Steenkamp, ter Hofstede, and Wedel (1999): "Gillette has a policy that 40 % of its sales must come from the entirely new products introduced in the last five years." That the coupling type can be slow to adjust is suggested by by Gompers, Lerner, and Scharfstein (2005), who observe that the start-up culture (loose coupling) persists over generations of firms: "Our analyses suggest that the breeding grounds for entrepreneurial firms are more likely to be other entrepreneurial firms. In these environments, employees learn from their co-workers about what it takes to start a new firm and are exposed to a network of suppliers and customers who are used to dealing with start-up companies." In similar spirit, Saxenian (1994) documents the persistence of high engineer turnover in the Silicon Valley. The persistence of low worker turnover (tight coupling) in the context of permanent-employment practices in the twentieth-century Japanese firms is described by Milgrom and Roberts (1994).

2 Model

Time is discrete and indexed by $t \geq 0$. The timeline in Figure 1 outlines the model's features. At time zero, the firm's founder chooses an innovation rate, θ_I, and a coupling type, θ_L. These are chosen while treating the volatility, δ, as given, even

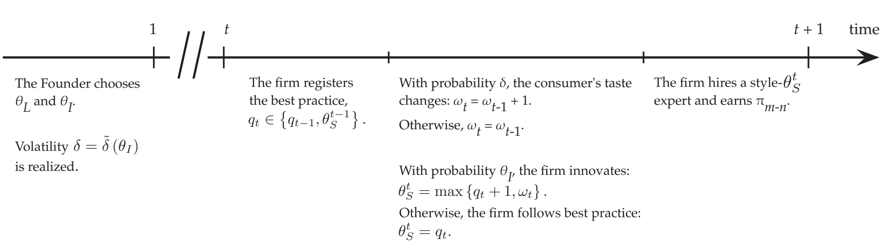

Figure 1: The timeline.

though δ depends on θ_I according to $\delta = \tilde{\delta}(\theta_I)$, for some function $\tilde{\delta}$. The interpretation is that the firm represents an atomless unit measure of identical firms, each of which, indexed by $i \in [0, 1]$, when choosing its innovation rate $\theta_I(i)$, cannot affect the aggregate innovation rate, $\theta_I \equiv \int_0^1 \theta_I(i)\, \mathrm{d}i$, which affects δ.

At each time $t \geq 1$, the firm seeks to match the consumer's taste process $\{\omega_t\}$, a moving target modelled as a Markov process in $\mathbb{N} \equiv \{1, 2, \ldots\}$ and incremented with probability δ. To match the taste, the firm experiments with new product styles. These styles comprise the target-style process $\{\theta_S^t\}$, which is an outcome of reinforcement learning with the experimentation parameter θ_I. To operationalize reinforcement learning, an auxiliary process $\{q_t\}$ keeps track of the best practice, where q_t is the best candidate for the most lucrative style among the styles that have been tried out up to time t. A deviation from the best past practice q_t to a new style θ_S^t with $\theta_S^t > q_t$ is interpreted as experimentation by means of innovation. The adjustment cost associated with switching production to a new style and the maximal profit the firm can achieve once it has mastered a style (both parametrized by conditional profits π_0, π_1, and π_2) depend on the coupling type θ_L. Relative to a tightly coupled firm, a loosely coupled firm faces both a lower cost of adjustment (i. e., firing and hiring experts) and a lower maximal payoff from mastering a style.

To summarize, at time 0, the firm's founder chooses θ_I and θ_L, which induce the firm's behavior at later dates. The only other endogenous parameter is δ, which is determined mechanically, at equilibrium, at which (θ_I, θ_L) induce the very δ the founder anticipates when choosing (θ_I, θ_L). The taste process $\{\omega_t\}$ can be interpreted as the state process, to which the firm's target-style processes $\{\theta_S^t\}$ adaptively responds. The rest of the section fills in the details.

2.1 Consumer

The taste of an infinitely-lived consumer evolves according to a stochastic process $\{\omega_t\}_{t \geq 1}$, where time-t **taste** ω_t has an outcome in N.

Each period, the consumer buys an item, whose value to him is determined by the expertise of the experts who produce it. He values the item at π_{n-m} if it has been produced by $n \in \{0, 1, 2\}$ experts in style ω_t and $m \in \{0, 1, 2\}$ experts in any other styles. These values satisfy

Condition 1. $\pi_2 > \pi_1 > \pi_0 = \pi_{-1} = \pi_{-2} = 0.$

Condition 1 implies that, if the consumer's taste changes from ω_t to $\omega_{t+1} \neq \omega_t$, then the very item that he valued at $\pi_2 > 0$ at t he values at $\pi_{-2} = 0$

at $t+1$.[3] Two experts in style ω_t produce a more valuable item than a single expert in style ω_t does (i. e., $\pi_2 > \pi_1$). Experts in different styles produce a worthless item (i. e., $\pi_0 = 0$).

The taste process $\{\omega_t\}$ is a Markov chain depicted in Figure 2. The chain satisfies, for $\omega_0 = 1$ and for all $t \geq 1$, $\Pr\{\omega_t = \omega_{t-1} + 1\} = \delta$ and $\Pr\{\omega_t = \omega_{t-1}\} = 1 - \delta$, for some **volatility** parameter $\delta \in [0,1]$, which captures the consumer's **desire for novelty**. Parameter δ is determined by an increasing and differentiable **demand for novelty** function $\tilde{\delta}: [0,1] \to [0,1]$, which associates with the firm's innovation rate θ_I (described shortly) a unique volatility $\delta = \tilde{\delta}(\theta_I)$.

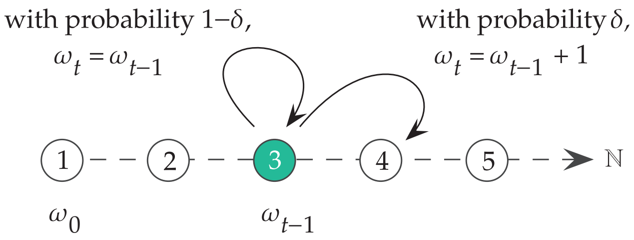

Figure 2: The evolution of the consumer's taste.

In words, the consumer enjoys promiscuity in his consumption of styles. Once ripe for change, he stops enjoying the current style and regains enjoyment only if he consumes the successor style. These novelty-seeking preferences resemble, but are not equivalent to, habit-formation preferences (see, e. g., Abel 1990). The distinguishing feature of novelty-seeking preferences is that the consumer who dislikes novelty (i. e., δ is low) will be hurt by being forced to consume new styles in rapid concession, whereas the consumer who forms habits is always better off from consuming increasing quantities or qualities.

2.2 Firm

An infinitely-lived firm's time-t **action**

$$a^t \equiv \left(a_1^t, a_2^t\right)$$

is in the set $A \equiv (\{0\} \cup \mathbb{N}) \times (\{0\} \cup \mathbb{N})$. The action's interpretation is that, in any period t, at no cost, the firm can employ at most two experts, indexed by

3 That is, the item is produced by a pair of experts whose expertise matches the consumer's taste at t, but not at $t+1$.

$j \in \{1, 2\}$. The expertise of expert j is denoted by a_j^t and either indexes a style in $\mathbb{N}$ or has $a_j^t = 0$, meaning that expert j's position is left vacant. Expert j is a **match** (for the consumer's taste ω_t) if $a_j^t = \omega_t$, is a **mismatch** if $a_j^t \neq \omega_t$, and is absent if $a_j^t = 0$.

The firm is assumed to price discriminate perfectly, and so its profit from selling the item produced by n matching and m mismatching experts is π_{n-m}, which is also the consumer's valuation. Using the equivalent notation $\pi(n-m) \equiv \pi_{n-m}$ (for type-setting convenience), the firm's period-t profit can be written as

$$\Pi\left(a^t|\omega_t\right) \equiv \pi\left(\sum_{j \in \{1,2\}}\left(\mathbf{1}_{\left\{a_j^t = \omega_t\right\}} - \mathbf{1}_{\left\{a_j^t \in \mathbb{N} \setminus \{\omega_t\}\right\}}\right)\right), \qquad [1]$$

where the argument of π is the difference between the numbers of matches and mismatches.

The firm's behavior is influenced by its organizational design, chosen at time zero by the firm's founder. An **organizational design** is an element (θ_L, θ_I) in the set $\{0, 1\} \times [0, 1]$, where

- the **coupling type** $\theta_L \in \{0, 1\}$ is the probability (restricted to 0 or 1 without loss of generality) with which, in any period t, the firm's coupling is loose; with probability $1 - \theta_L$, the firm's coupling is tight;
- the **innovation rate** $\theta_I \in [0, 1]$ is the probability with which, in any period t, the firm innovates.

The firm's period-t behavior is influenced also by the **target style** $\theta_S^t \in \mathbb{N}$, which is the item's style that the firm intends to match in period t by hiring experts in style θ_S^t. All the three variables $\left(\theta_L, \theta_I, \theta_S^t\right)$, which affect the firm's behavior, are summarized in Figure 3.

The firm's period-t employment strategy is a given stochastic function $\alpha : \mathbb{N}^2 \times \{0, 1\} \to A$ that maps period-$(t-1)$ and period-t target styles $\left(\theta_S^{t-1}, \theta_S^t\right)$ and the coupling type θ_L into the types of experts employed at time t:

$$\alpha\left(\theta_S^t, \theta_S^{t-1}|\theta_L\right) = \begin{cases} \left(\theta_S^t, 0\right) & \text{with probability } \theta_L \\ \left(\theta_S^t, \theta_S^{t-1}\right) & \text{with probability } 1 - \theta_L. \end{cases}$$

The interpretation of the specified strategy is summarized in Table 1. If coupling is **loose** (which occurs with probability θ_L), the firm employs a single expert, who matches θ_S^t. If coupling is **tight** (which occurs with probability $1 - \theta_L$), the firm retains one expert, of type θ_S^{t-1}, from the last period and hires another expert to match the current target style, θ_S^t.

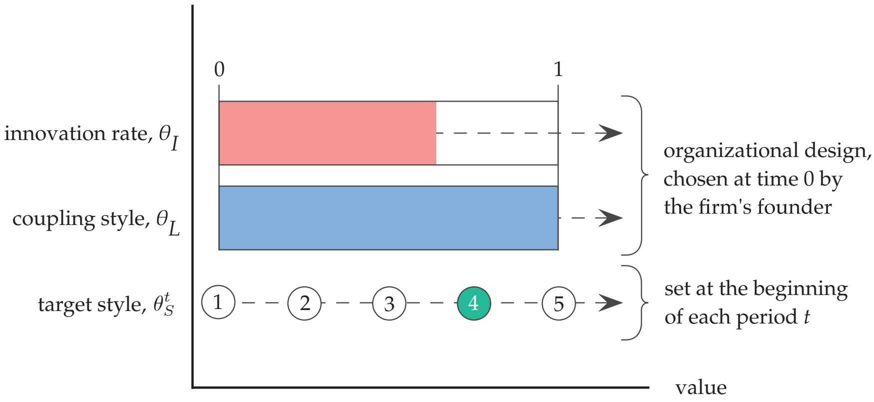

Figure 3: Time-t determinants of the firm's behavior.

Table 1: The experts' types in period t.

Coupling	Expert types	Interpretation
Loose	θ_S^t	Fire the past expert
Tight	$\theta_S^{t-1}, \theta_S^t$	Retain an expert

The employment strategy α can be motivated by a search friction in the labor market for experts. This friction precludes the firm from identifying and hiring more than one expert in the course of a single period. The firm is thus left with two options: retain one previous-period expert and replace the other (this is the case of tight coupling) or fire all last-period experts and hire a new one (this is the case of loose coupling). The two cases deliver the firm sizes of two experts and one expert, respectively.[4]

In the light of the employment strategy that it induces, the coupling type θ_L can be interpreted to parametrize the firm's degree of self-disruption (the term coined by Christensen 1997). The firm with $\theta_L = 1$, periodically fires its experts and starts all over again. If this firm's target style remains unchanged, the firm hires simply to rebuild what it destroyed the previous period. If the firm's target style changes frequently, however, self-disruption enables the firm to turn over

4 An alternative motivation for α appeals to a convex internal adjustment cost (e. g., of personnel retraining), instead of a search friction.

its expert force quickly, which is especially valuable when the economic environment is volatile (i. e., the consumer's taste is fickle), as will be shown.

The interpretation of the innovation rate θ_I stems from the way it affects the target style, which follows the stochastic process $\{\theta_S^t\}$. This process is an outcome of a reinforcement-learning dynamics (Sutton and Barto 1998). Technically, θ_I controls the probability of the transition towards the higher target style in the process $\{\theta_S^t\}$. To describe the stochastic process $\{\theta_S^t\}$, define an auxiliary, **best-practice**, process $\{q_t\}_{t\geq 0}$, where q_t registers the style that was targeted in the past and targeting which in the current period would have generated a superior profit. Formally, for some $q_0 \in \mathbb{N}$ and for $t \geq 1$,

$$q_t = \begin{cases} \theta_S^t & \text{if } \theta_S^t = \omega_t \\ q_{t-1} & \text{otherwise.} \end{cases} \qquad [2]$$

The initial condition q_0 in eq. [2] determines whether the firm begins by knowing the consumer's taste ($q_0 = \omega_0$) or not knowing it ($q_0 \neq \omega_0$).[5] Condition $\theta_S^t = \omega_t$ in eq. [2] is equivalent to saying that the firm's period-t profit is weakly higher if all experts match θ_S^t than if all experts match θ_S^{t-1}. In this sense, the firm registers the best practice among past practices, perhaps, by imitating (unmodelled) similar firms that have experienced the highest profit.[6]

In any period t, with probability θ_I, the firm **innovates** on the best practice q_t, whereas with probability $1-\theta_I$, the firm repeats the best practice:

$$\theta_S^t = \begin{cases} \omega_t + \mathbf{1}_{\{q_{t-1}=\omega_t\}} & \text{with probability } \theta_I \\ q_{t-1} & \text{with probability } 1-\theta_\mathrm{I} \end{cases}, \qquad t \geq 1. \qquad [3]$$

According to eq. [3], innovation leads to catching up with the consumer's taste (i. e., $\theta_S^{t+1} = \omega_{t+1}$) if the best-practice is lagging behind (i. e., if $q_{t-1} < \omega_t$), and leads to overshooting the consumer's taste otherwise (i. e., if $q_{t-1} = \omega_t$).[7]

5 It will be assumed that $q_0 = \omega_0$, but the case $q_0 \neq \omega_0$ will be used in intermediate calculations.
6 The central role of imitation in organizational economics is summarized by Sevon (1996): "[E]very theory of organizational change must take into account the fact that leaders of organizations watch one another and adopt what they perceive as successful strategies for growth and organizational structure."
7 Note that, in the case of overshooting, θ_S^{t-1}, not θ_S^t, will be recorded as the best practice at the end of the period, as is indicated by (2). Thus, before it innovates, the firm cannot be ahead of the consumer in style, and once it has innovated, the firm can be at most one style ahead (which is a convenient analytical simplification).

2.3 The Founder's Problem

The **founder's payoff** as a function of the organizational design $\bar{\theta} \equiv (\theta_L, \theta_I)$ is denoted by $F(\bar{\theta})$ and is defined to be the limit of the expected present discounted value of the firm's profits, denoted by $V(\bar{\theta}; \beta)$, as the discount factor $\beta \in (0, 1)$ converges to 1:

$$F(\bar{\theta}) \equiv \lim_{\beta \to 1} V(\bar{\theta}; \beta), \tag{4}$$

where

$$V(\bar{\theta}; \beta) \equiv E\left[(1-\beta)\sum_{t=1}^{\infty} \beta^{t-1} \Pi\left(\alpha\left(\theta_S^t, \theta_S^{t-1} | \theta_L\right) | \omega_t\right) | \bar{\theta}, q_0 = \omega_0\right]. \tag{5}$$

The right-hand side of eq. [5] depends on $\bar{\theta}$ directly and also indirectly, through the target-style process $\{\theta_S^t\}$, which it induces. The initial condition $q_0 = \omega_0$ in eq. [5] means that, in period 1, unless it innovates, the firm matches the consumer's taste. By inspection of eq. [5] when $\beta \to 1$, the founder's payoff is the long-run average profit, or equivalently but informally, the expected profit in a "randomly" chosen period "far enough" in the future.

An **optimal organizational design** solves the **founder's problem**

$$\max_{\bar{\theta} \in [0, 1]^2} F(\bar{\theta}). \tag{6}$$

2.3 Equilibrium

Definition 1: A volatility $\hat{\delta}$ and organizational design $(\hat{\theta}_L, \hat{\theta}_I)$ (along with the induced target-style process $\{\hat{\theta}_S^t\}$) constitute an **equilibrium** if

1. $\hat{\delta}$ is induced by the demand for novelty: $\hat{\delta} = \tilde{\delta}(\hat{\theta}_I)$.
2. $(\hat{\theta}_L, \hat{\theta}_I)$ solves the founder's problem in eq. [6].

Part 1 of Definition 1 requires that the volatility that the founder takes as given agree with the volatility (novelty seeking) that the firm's innovation rate provokes in the consumer. That the founder takes the volatility as given is implicit in part 2 of the definition.

3 Optimal Organizational Design

The organizational design is **optimal** if it solves the founder's problem [6].

3.1 The Founder's Value Function

The founder's problem in eq. [6] is solved in two steps. First, maximize a loosely coupled and a tightly coupled firms' payoffs separately by selecting an optimal innovation rate θ_I for each of them. Second, set $\theta_L = 1$ if the loosely coupled firm's maximized payoff is the weakly greater of the two, and set $\theta_L = 0$ otherwise. This subsection fixes an organizational design (θ_L, θ_I) and derives the expression for the founder's payoff, which is then subjected to the described two-step procedure.

It is convenient to recursively rewrite the definition of the expected present discounted profit defined in eq. [5]. For brevity, denote this value by V_+. An auxiliary expected present discounted profit is denoted by V_- and is defined to differ from V_+ only in that the expectation in eq. [5] is conditional on $q_0 \neq \omega_0$, instead of $q_0 = \omega_0$. The implicit equation for V_+ is

$$\begin{aligned} V_+ = {} & (1-\delta)(1-\theta_I)[(1-\beta)(\theta_L\pi_1 + (1-\theta_L)\pi_2) + \beta V_+] \\ & + (1-\delta)\theta_I\beta V_+ + \delta(1-\theta_I)\beta V_- + \delta\theta_I[(1-\beta)\theta_L\pi_1 + \beta V_+], \end{aligned} \qquad [7]$$

where Condition 1 has been used to substitute $\pi_0 = \pi_{-1} = \pi_{-2} = 0$. The first line in eq. [7] captures the case in which the firm matches the consumer's taste if neither the consumer's taste nor the target style has changed (i. e., $\omega_t = \omega_{t-1}$ and $\theta_S^t = \theta_S^{t-1}$), which occurs with probability $(1-\delta)(1-\theta_I)$. In this case, a loosely coupled firm (whose probability is θ_L) employs one matching expert, whereas a tightly coupled firm (whose probability is $1-\theta_L$) employs two matching experts. At the end of period t, the firm registers the style that matches the taste (i. e., $q_t = \omega_t$), and hence the continuation value is V_+. The only case in eq. [7] in which the continuation value switches to V_- occurs when the taste changes and the firm fails to innovate (i. e., $\omega_t \neq \omega_{t-1}$ and $\theta_S^t = \theta_S^{t-1}$), which has probability $\delta(1-\theta_I)$. The case in which the taste does not change but the firm innovates leads to the continuation value V_+ because the firm registers the previous period's target style as the best practice (i. e., $q_t = q_{t-1}$).

The implicit equation for V_- is constructed analogously

$$V_- = (1-\theta_I)\beta V_- + \theta_I[(1-\beta)\theta_L\pi_1 + \beta V_+]. \qquad [8]$$

In eq. [8], the first term captures the case in which the firm does not innovate and hence, having started out mismatching the consumer's taste continues mismatching it and expects the continuation value V_-. The second term captures the case in which the firm innovates and catches up with the consumer, irrespective of whether the consumer's taste changes in that period.

The system of linear eqs [7] and [8] admits a unique solution, whose component V_+ is of primary interest. From eq. [4], the founder's payoff is

$$F = \lim_{\beta \to 1} V_+ ,$$

where the argument of F has been suppressed. Explicitly computing and rearranging the expression in the above display can be shown to yield

$$F = \theta_L F_L + (1 - \theta_L) F_T, \tag{9}$$

where F_L is defined to be the founder's expected payoff conditional on $\theta_L = 1$, and F_T is defined to be the founder's expected payoff conditional on $\theta_L = 0$.[8] These two conditional payoffs are

$$F_L = \pi_1 \frac{\theta_I - (1-\delta)\theta_I^2}{\theta_I + \delta(1-\theta_I)} \tag{10}$$

$$F_T = \pi_2 \frac{(1-\delta)(1-\theta_I)\theta_I}{\theta_I + \delta(1-\theta_I)}. \tag{11}$$

In words, a loosely coupled firm's payoff, F_L in eq. [10], equals the payoff from employing an expert in the consumer's preferred style multiplied by the frequency with which such employment occurs.[9] A tightly coupled firm's payoff, F_T in eq. [11], equals the payoff from employing two experts in the consumer's preferred style multiplied by the frequency with which such employment occurs.

The following two subsections analyze separately the payoff-maximizing innovation rates for the loosely coupled and tightly coupled firms. This analysis, which is also of independent economic interest, will inform the founder's choice of coupling.

3.2 In a Loosely Coupled Firm, Optimal Innovation is Increasing in Volatility

Define the threshold

$$\delta_L^\star \equiv \frac{\sqrt{5}-1}{2} \approx 0.62. \tag{12}$$

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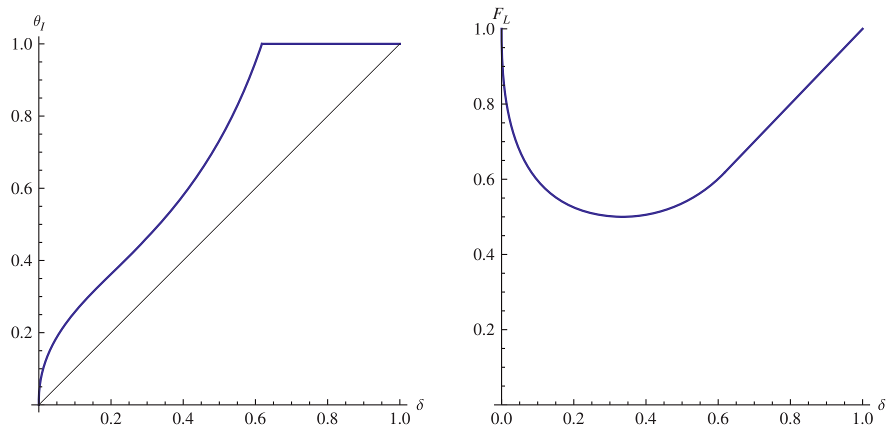
8 Because F in (9) is linear in. θ_L, there is no loss of generality in restricting the founder's choice of probability θ_L to $\{0, 1\}$.

9 The frequency refers to the stationary distribution over payoff-relevant outcomes induced by the processes $\{\theta_S^t\}$ and $\{w_t\}$.



(a) Optimal innovation rate.

(b) Founder's payoff at the optimal innovation rate.

Figure 4: Loosely coupled firm.

Lemma 1 describes how a loosely coupled firm's (**LCF**'s) payoff-maximizing innovation rate depends on volatility. Figure 4 illustrates this lemma.

Lemma 1: *A loosely coupled firm innovates more when the environment is more volatile; that is, the unique payoff-maximizing θ_I is increasing in δ weakly (strictly if $\delta < \delta_L^*$). Moreover, with θ_I maximized out, the loosely coupled firm's payoff is concave in δ, maximal at (and only at) both $\delta = 0$ and $\delta = 1$ and is minimal at $\delta = 1/3$. At $\delta \in \{0, 1\}$, the payoff is π_1.*

Proof: The strict concavity of the objective function F_L follows by differentiating eq. [10]:

$$\frac{\partial^2 F_L}{(\partial\theta_I)^2} = -\frac{2\delta(1-\delta^2)\pi_1}{(\delta + \theta_I(1-\delta))^3} < 0,$$

where the inequality is by Condition 1. Hence, on $[0, 1]$, F_L is uniquely maximized at the value of θ_I denoted by $\theta_{I,L}(\delta)$:

$$\theta_{I,L}(\delta) = \min\left\{\theta_{I,L}^{np}(\delta), 1\right\} = \mathbf{1}_{\{\delta < \delta_L^*\}}\theta_{I,L}^{np}(\delta) + \mathbf{1}_{\{\delta \geq \delta_L^*\}},$$

where[10]

$$\theta_{I,L}^{np}(\delta) = \frac{\sqrt{\delta(1+\delta)} - \delta}{1-\delta}. \qquad [13]$$

10 The subscript "*np*" hints that $\theta_{I,L}^{np}$ is "not a probability," because it can exceed 1.

Differentiating $\theta_{I,L}$, one can verify that $\theta_{I,L}$ is weakly increasing in δ and strictly so when $\delta < \delta_L^\star$.

Substituting $\theta_{I,L}$ into F_L gives the payoff

$$F_L(\delta) \equiv \left(\mathbf{1}_{\{\delta < \delta_L^\star\}} \frac{1 + 2\left(\delta - \sqrt{\delta(1+\delta)}\right)}{1-\delta} + \mathbf{1}_{\{\delta \geq \delta_L^\star\}} \delta \right) \pi_1.$$

By differentiating F_L in the above display, one can verify that F_L is weakly convex and is uniquely minimized at $\delta = 1/3$. By convexity, F_L is maximized at a boundary point; indeed, by substitution, F_L can be verified to be maximized at both boundary points, $\delta = 0$ and $\delta = 1$. □

In Lemma 1, LCF's payoff is maximal either when there is no volatility, and so the firm always matches the taste by never innovating, or when the volatility is maximal, and so the firm always matches the taste by innovating in every period. Both scenarios yield the same payoff because, in either scenario, the firm starts afresh each period, hiring experts one by one, to match the state.

3.3 In a Tightly Coupled Firm, Optimal Innovation is Increasing in Volatility

Lemma 2 describes how a tightly coupled firm's (**TCF**'s) payoff-maximizing innovation rate depends on volatility. Figure 5 illustrates this lemma.

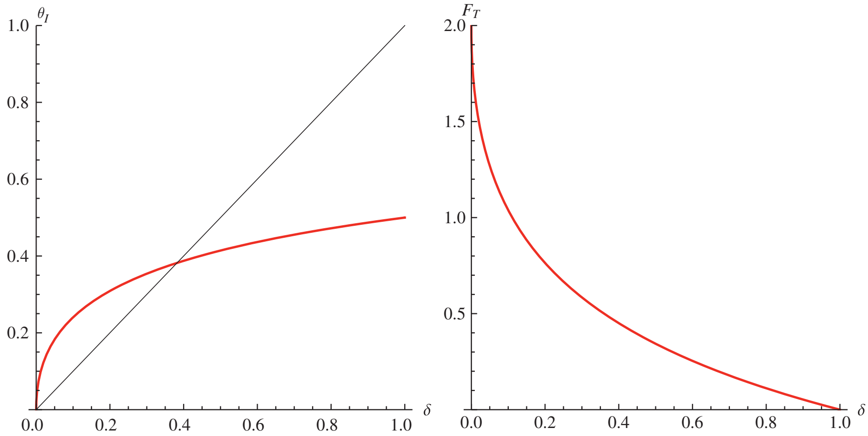
Lemma 2: *A tightly coupled firm innovates more when the environment is more volatile; that is, the unique payoff-maximizing θ_I is strictly increasing in δ. Moreover, with θ_I maximized out, the tightly coupled firm's payoff is strictly decreasing in δ and is maximal at $\delta = 0$, achieving the value of π_2.*

Proof: The strict concavity of the objective function F_T follows by differentiating eq. [11]:

$$\frac{\partial^2 F_T}{(\partial \theta_I)^2} = -\frac{2\delta(1-\delta)\pi_2}{(\delta + \theta_I - \delta\theta_I)^3} < 0,$$

where the inequality is by Condition 1. Hence, on $\mathbb{R}$, F_T is uniquely maximized at the value of θ_I denoted by $\theta_{I,T}(\delta)$:

$$\theta_{I,T}(\delta) = \frac{\sqrt{\delta}}{1 + \sqrt{\delta}}. \qquad [14]$$



(a) Optimal innovation rate.

(b) Founder's payoff at the optimal innovation rate.

Figure 5: Tightly coupled firm.

Substituting eq. [14] into eq. [11] gives

$$F_T(\delta) = \frac{1-\sqrt{\delta}}{1+\sqrt{\delta}}\pi_2,$$

which is strictly decreasing in δ, with $F_T(0) = \pi_2$ and $F_T(1) = 0$. □

By contrast to LCF, TCF does not enjoy the same payoff when $\delta = 0$ and when $\delta = 1$. Its payoff is higher when $\delta = 0$. When $\delta = 0$, TCF does not innovate, and its experts match the consumer's taste. When $\delta = 1$, whatever TCF does, it cannot avoid employing at least one mismatching expert, and so its payoff is zero.

3.4 The Firm is Loosely Coupled whenever Volatility is High

When $\delta = 0$, Lemmas 1 and 2, and Condition 1 imply that LCF's payoff is higher than TCF's: $\pi_2 > \pi_1$. When $\delta = 1$, the same lemmas and the same condition imply that LCT's payoff is higher than TCF's: $\pi_1 > 0$. Hence, by continuity, $\theta_L = 0$ if δ is near 0, and $\theta_L = 1$ if δ is near 1. Theorem 1 interpolates: the optimal θ_L is weakly increasing in δ. In addition, Theorem 1 establishes that the loose coupling and innovation are **complements** in the organizational design, meaning that, for any δ, the payoff-maximizing value of θ_I is weakly higher for LCF than for TCF.

Theorem 1: *In an optimal organizational design, the firm is tightly coupled if volatility is sufficiently low and is loosely coupled otherwise; that is, the optimal coupling type is* $\theta_L = \mathbf{1}_{\{\delta \geq \delta^*\}}$ *for some* $\delta^* \in (0,1)$. *Moreover, loose coupling and innovation are complements in the sense that the optimal innovation rate, too, is weakly increasing in volatility; that is,* θ_I *is weakly increasing in* δ.

Proof: Because the founder's objective function F in eq. [9] fails to be supermodular in $(\theta_I, \theta_L, \delta)$, the proof does not appeal to the monotone comparative statics results à la Topkis (1998) and is instead direct.

Normalize $\pi_2 = 1$, so that $\pi_1 \in (0,1)$. Consider two cases: $\delta < \delta_L^*$ and $\delta \geq \delta_L^*$. if $\delta < \delta_L^*$, then

$$F_L(\delta) \equiv \frac{1 + 2\left(\delta - \sqrt{\delta(1+\delta)}\right)}{1-\delta}\pi_1$$

$$F_T(\delta) \equiv \frac{1-\sqrt{\delta}}{1+\sqrt{\delta}},$$

implying

$$\frac{\partial}{\partial \delta}\left(F_L(\delta) - F_T(\delta)\right) = \frac{\frac{1}{\sqrt{\delta}} + \sqrt{\delta} - 2 + \left(3 - \frac{1+3\delta}{\sqrt{\delta(1+\delta)}}\right)\pi_1}{(1-\delta)^2}$$

$$\geq \frac{\frac{1}{\sqrt{\delta}} + \sqrt{\delta} - 2 + \min\left\{0, 3 - \frac{1+3\delta}{\sqrt{\delta(1+\delta)}}\right\}}{(1-\delta)^2} > 0,$$

where the equality is by differentiation, the first inequality is by $\pi_1 \in (0,1)$, and the last inequality can be verified directly.

If $\delta \geq \delta_L^*$, then

$$F_L(\delta) = \delta \pi_1 \qquad \text{and} \qquad F_T(\delta) = \frac{1-\sqrt{\delta}}{1+\sqrt{\delta}},$$

implying

$$\frac{\partial}{\partial \delta}\left(F_L(\delta) - F_T(\delta)\right) = \pi_1 + \frac{1}{\left(1+\sqrt{\delta}\right)^2\sqrt{\delta}} > 0.$$

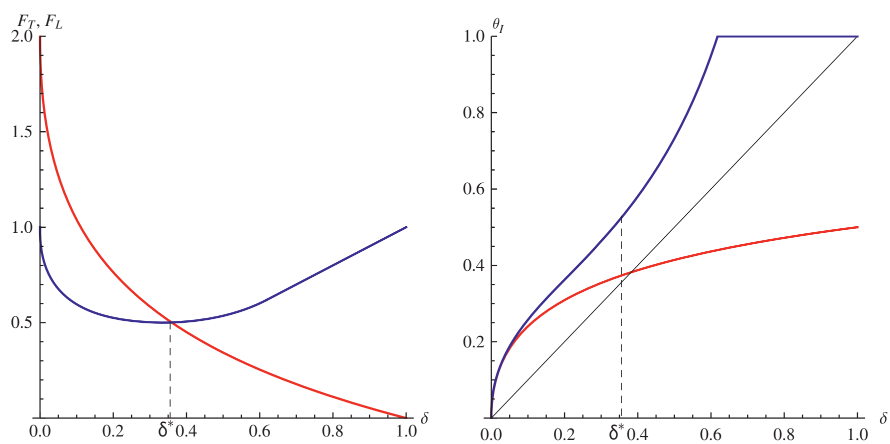
The above cases imply that F_L intersects F_T at most once and from below. That F_L intersects F_T is established by the continuity of both functions and by observing that $F_L(0) = \pi_1 < 1 = F_T(0)$ and $F_L(1) = \pi_1 > 0 = F_T(1)$. Hence, there exists a $\delta^* \in (0, 1)$ such that the founder sets $\theta_L = \mathbf{1}_{\{\delta \geq \delta^*\}}$.

To establish the complementarity of θ_L and θ_I, by Lemmas 1 and 2, it suffices to establish that $\theta^{np}_{I,L}(\delta) \geq \theta_{I,T}(\delta)$. Indeed, combini$F_T$ng eqs [13] and [14] gives

$$\theta^{np}_{I,L}(\delta) - \theta_{I,T}(\delta) = \frac{\sqrt{\delta(1+\delta)} - \sqrt{\delta}}{1-\delta} \geq 0, \qquad [15]$$

where the inequality is by inspection. □

Figure 6(a) combines Figures 4(b) and 5(b) to illustrate the optimality of loose coupling when volatility is high. Figure 6(b) combines Figures 4(a) and 5(a) to illustrate that the optimal innovation rate rises in volatility – discontinuously so at, when the coupling type optimally switches from tight to loose.



(a) The value function for loose coupling, F_L, intersects the value function for tight coupling, F_T, once and from below. As a result, loose coupling is optimal if and only if volatility δ exceeds some threshold δ^*.

(b) The optimal innovation rate of a loosely coupled lies above that for a tightly coupled firm; both rates are weakly increasing in volatility, δ. As a result, for optimal coupling, the optimal innovation rate is weakly increasing in δ and jumps upwards at δ^* when the coupling type optimally switches from tight to loose.

Figure 6: The founder-optimal choices of the coupling type and the innovation rate as volatility varies.

4 Equilibria

4.1 Existence, Multiplicity, and Stability

4.1.1 Existence

Let $\tilde{\theta}_I(\delta)$ denote the set of innovation rates that are optimal given volatility δ. The set is a singleton except at the (unique, by the proof of Theorem 1) δ such that $F_L(\delta) = F_T(\delta)$, in which case $\tilde{\theta}_I(\delta)$ has two elements. Call the set-valued function $\tilde{\theta}_I$ the **supply of innovation**. Then, Definition 1 can be rephrased: A volatility $\hat{\delta}$ and organizational design $\left(\hat{\theta}_L, \hat{\theta}_I\right)$ constitute an equilibr $\tilde{\theta}_I(\delta)$ium if $\hat{\theta}_I \in \tilde{\theta}_I\left(\hat{\delta}\right)$ and $\hat{\delta} = \tilde{\delta}\left(\hat{\theta}_I\right)$. The two conditions on $\hat{\theta}_I$ can be combined into one:

$$\hat{\theta}_I \in \tilde{\theta}_I\left(\tilde{\delta}\left(\hat{\theta}_I\right)\right).$$

Thus, an equilibrium exists if and only if the composition $\tilde{\theta}_I \circ \tilde{\delta}$ has a fixed point.

Theorem 2: *An equilibrium exists.*

Proof: Because $\tilde{\delta}:[0,1] \to [0,1]$ is continuous, it has a fixed point by Brouwer's fixed-point theorem.

The existence of a fixed point of $\tilde{\theta}_I$ follows by Tarski's fixed-point theorem. To apply Tarski's theorem, define the maximal selection from $\tilde{\theta}_I$ by $\tilde{\theta}_I^M \equiv \max \tilde{\theta}_I$. Because the function $\tilde{\theta}_I^M:[0,1] \to [0,1]$ is nondecreasing (by Theorem 1) and $[0,1]$ is a lattice, Tarski's fixed-point theorem implies that $\tilde{\theta}_I^M$ has a fixed point. Because $\tilde{\theta}_I^M \subset \tilde{\theta}_I$, also $\tilde{\theta}_I$ has a fixed point.

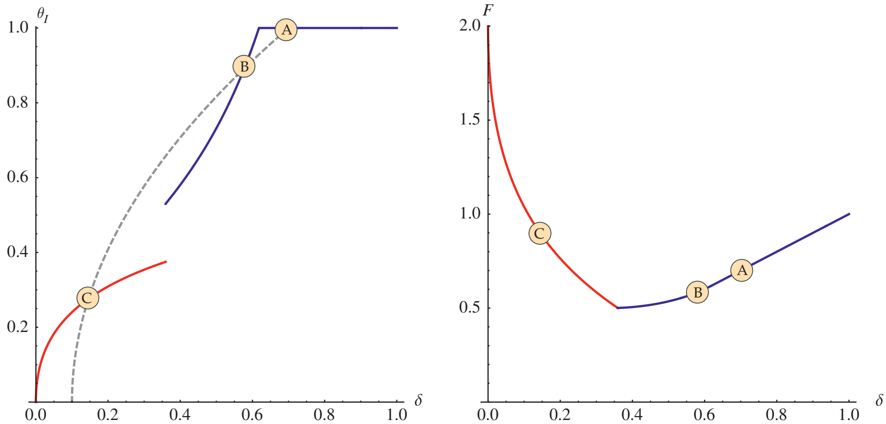
Because $\tilde{\delta}$ and $\tilde{\theta}_I$ each has a fixed point, the composition $\tilde{\theta}_I \circ \tilde{\delta}$ has a fixed point by the theorem of Raa (1984, 210). Hence, an equilibrium exists. □

4.1.2 Multiplicity

Equilibrium multiplicity arises naturally because both the supply and the demand for innovation slope upwards. The more the firm innovates, the more the consumer demands novelty, which encourages the firm to innovate even more. Figure 6 illustrates the multiplicity.

4.1.3 Stability

All equilibria in which the inverse demand function intersects the supply function from below are Lyapunov stable. In Figure 7(a), equilibria **A** and **B** are stable. In general, the minimal-innovation and the maximal-innovation equilibria are stable. Stable equilibria obey the "intuitive" comparative statics. That is, when the demand for novelty shifts so that, at any given level of innovation, the consumer demands marginally more novelty, the stable-equilibrium innovation rate marginally increases. The intuitive comparative statics are highlighted in the following observation.



(a) The dashed curve is the (inverse) demand for novelty, $\tilde{\delta}$. The solid discontinuous curve is the supply of innovation, $\tilde{\theta}_I$.

(b) The founder's payoff.

Figure 7: Equilibrium **A** has more innovation and higher welfare than equilibrium **B** Equilibrium **C** has least innovation and the greatest welfare among all equilibria.

Observation 1:. *If the consumer demands more novelty for every innovation rate, then the innovation rate in the smallest and in the largest equilibria weakly increases.*

4.2 Welfare Comparisons

Welfare is defined as the expected present discounted sum of the consumer's and firm's payoffs as the discount factor $\beta \in (0, 1)$ converges to one. This measure coincides with the founder's payoff because, by assumption, the firm price-discriminates perfectly, and so the consumer's payoff is zero. This measure has an alternative (informal) interpretation as the expected sum of the consumer's and firm's payoffs in any period that is chosen "uniformly at random."

4.2.1 Ranking of Equilibria

If the demand for novelty is such that $\tilde{\delta}(0) = 0$ (i. e., the consumer who sees no innovation demands no novelty), there exists an equilibrium that has $\delta = 0$ (no demand for novelty) and $\hat{\theta}_I = \hat{\theta}_L = 0$ (no innovation by the firm, which is tightly coupled). At this equilibrium, the founder's payoff is π_2, the highest possible, and so the welfare dominates welfare at any other equilibrium.

If instead the demand for novelty is such that $\tilde{\delta}(0) > 0$, the firm innovates at any equilibrium. Furthermore, an equilibrium with less innovation need not (but may) dominate an equilibrium with more innovation. Figure 7 illustrates the possibilities.[11] In this figure, as one moves from equilibria with less innovation to equilibria with more innovation, welfare at first decreases and then increases.

4.2.2 Inefficiency of Equilibria

An equilibrium is **efficient** if no organizational design can induce a higher welfare. An equilibrium is **inefficient** if it is not efficient.

Theorem 3: *"Generically" (in the consumer's demand for novelty, $\tilde{\delta}$) any equilibrium with the innovation rate $\hat{\theta}_I \neq 1$ is inefficient. An equilibrium with innovation rate $\hat{\theta}_I = 1$ may be efficient.*

Proof: Equilibria with $\hat{\theta}_I \in \left\{0, \frac{1}{3}\right\}$ are nongeneric with respect to small perturbations of $\tilde{\delta}$. In particular, $\hat{\theta}_I = 0$ requires $\tilde{\delta}(0) = 0$, which is nongeneric. Equilibria with $\hat{\theta}_I = \frac{1}{3}$ are similarly nongeneric because they require that $\tilde{\theta}_I$ and $\tilde{\delta}$ intersect at a particular point, which is perturbed when $\tilde{\delta}$ is perturbed.

By contrast, an equilibrium with $\hat{\theta}_I = 1$ is not nongeneric. For some π_1 and π_2, one can find an open set $(\underline{\delta}, \bar{\delta}) \subset \left(\delta_L^{\star}, 1\right)$ such that, for all $\delta \in (\underline{\delta}, \bar{\delta})$, $\tilde{\theta}_I(\delta) = \theta_{I,L}(\delta) = 1$, so that $\hat{\theta}_I = 1$ is equilibrium.

11 Figure 7 assumes $\pi_1 = 1$, $\pi_2 = 2$, and $\tilde{\delta}(\theta_I) = 0.1 + 0.6\theta_I^2$.

Assume henceforth that $\hat{\theta}_I \notin \left\{0, \frac{1}{3}, 1\right\}$. It will be shown that any equilibrium with $\hat{\theta}_I \notin \left\{0, \frac{1}{3}, 1\right\}$ is inefficient.

If an equilibrium has $\hat{\theta}_L = 1$, the equilibrium innovation rate $\hat{\theta}_I$ solves the fixed-point problem

$$\hat{\theta}_I \in \arg \max_{\theta_I \in [0,1]} F_L\left(\theta_I, \tilde{\delta}\left(\hat{\theta}_I\right)\right). \qquad [16]$$

By contrast, the "planner," who recognized the equilibrium dependence of $\tilde{\delta}$ on $\hat{\theta}_I$, solves $\max_{\theta_I \in [0,1]} F_L\left(\theta_I, \tilde{\delta}(\theta_I)\right)$. Hence, the planner's gain from a marginal increase in θ_I away from its equilibrium value of $\hat{\theta}_I$ is

$$\left.\frac{\mathrm{d}F_L\left(\theta_I, \tilde{\delta}(\theta_I)\right)}{\mathrm{d}\theta_I}\right|_{\theta_I = \hat{\theta}_I} = \left.\frac{\partial F_L\left(\theta_I, \tilde{\delta}(\theta_I)\right)}{\partial \theta_I}\right|_{\theta_I = \hat{\theta}_I} + \left.\frac{\partial F_L\left(\theta_I, \tilde{\delta}(\theta_I)\right)}{\partial \delta}\frac{\partial \tilde{\delta}(\theta_I)}{\partial \theta_I}\right|_{\theta_I = \hat{\theta}_I}$$

$$= \left.\frac{\partial F_L\left(\theta_I, \tilde{\delta}(\theta_I)\right)}{\partial \delta}\frac{\partial \tilde{\delta}(\theta_I)}{\partial \theta_I}\right|_{\theta_I = \hat{\theta}_I} \neq 0,$$

where the second equality follows because $\hat{\theta}_I \in (0,1)$, and so the first-order condition for problem [16] must hold, whereas the inequality follows from $\partial \tilde{\delta}(\theta_I)/\partial \theta_I > 0$ and from

$$\frac{\partial F_L\left(\hat{\theta}_I, \tilde{\delta}\left(\hat{\theta}_I\right)\right)}{\partial \delta} = \mathbf{1}_{\left\{\delta \geq \delta_L^*\right\}}\pi_1 - \mathbf{1}_{\left\{\delta < \delta_L^*\right\}} \frac{\left(1 + 3\delta - 3\sqrt{\delta(1+\delta)}\right)}{(1-\delta)^2\sqrt{\delta(1+\delta)}}\pi_1,$$

which is nonzero by $\hat{\theta}_I \neq 1/3$.

Analogously, if an equilibrium has $\theta_L = 0$, the planner's gain from a marginal increase in θ_I away from its equilibrium value of $\hat{\theta}_I$ is

$$\left.\frac{\mathrm{d}F_T\left(\theta_I, \tilde{\delta}(\theta_I)\right)}{\mathrm{d}\theta_I}\right|_{\theta_I = \hat{\theta}_I} = \left.\frac{\partial F_T\left(\theta_I, \tilde{\delta}(\theta_I)\right)}{\partial \delta}\frac{\partial \tilde{\delta}(\theta_I)}{\partial \theta_I}\right|_{\theta_I = \hat{\theta}_I} \neq 0,$$

where the nonequality uses

$$\frac{\partial F_T\left(\hat{\theta}_I, \tilde{\delta}\left(\hat{\theta}_I\right)\right)}{\partial \delta} = -\frac{\pi_2}{\left(1+\sqrt{\delta}\right)^2\sqrt{\delta}} \neq 0.$$

Thus, generically, any equilibrium with $\hat{\theta}_I \neq 1$ is inefficient.

It is easy to construct examples in which equilibrium with $\hat{\theta}_I = 1$ is efficient. □

The proof of Theorem 3 also contains the intuition. When the equilibrium innovation rate is small, the founder's payoff would rise if the consumer's demand for novelty decreased. Hence, if the firm's founder anticipated the effect of the firm's innovation rate on the consumer's demand for novelty, he would slightly decrease the innovation rate, thereby tempering the consumer's demand for novelty. Similarly, when the equilibrium innovation rate is large, the firm bets that the consumer will change his taste. In this case, if the founder anticipated the effect of the firm's innovation rate on the consumer's demand for novelty, he would slightly increase the innovation rate, thereby stimulating the consumer's demand for novelty.

Theorem 3 can be applied to the example in Figure 7. All three equilibria in that figure are inefficient. Indeed, the only candidate for efficiency is the highest-welfare equilibrium, **C**. This equilibrium is inefficient; welfare would be increased if the firm innovated marginally less, and as a consequence, the consumer demanded less novelty.

Theorem 3 focuses on equilibria with $\hat{\theta}_I \neq 1$. The theorem's conclusion can be strengthened if the demand for novelty is sufficiently small to rule out equilibria with $\hat{\theta}_I = 1$. The following corollary accomplishes that.

Corollary 1: *Suppose that the consumer's demand for novelty $\tilde{\delta}$ is bounded above by $\delta_L^\star$, defined in eq. [12]. Then, "generically" in the consumer's demand for novelty, any equilibrium is inefficient.*

Proof: By eq. [13], LCF's founder-optimal innovation rate satisfies $\theta_{I,L}(\delta) < 1$ for all $\delta < \delta_L^\star$. By eq. [14], TCF's founder-optimal innovation rate satisfies $\theta_{I,T}(\delta) < 1$ for all δ. As a result, $\delta < \delta_L^\star$ implies $\tilde{\theta}_I(\delta) \ll 1$.

By the corollary's hypothesis, $\tilde{\delta}(\theta_I) < \delta_L^\star$ for all θ_I, and so $\tilde{\theta}_I\left(\tilde{\delta}(\theta_I)\right) \ll 1$ for all θ_I. Hence, any $\hat{\theta}_I \in \tilde{\theta}_I\left(\tilde{\delta}\left(\hat{\theta}_I\right)\right)$ satisfies $\hat{\theta}_I < 1$; no equilibrium with $\hat{\theta}_I$ exists. Then, the corollary's conclusion follows by Theorem 3. □

Inefficiency relies on the "competitive" assumption that, when choosing the innovation rate, θ_I, the founder does not take into account that his choice affects the volatility through the consumer's equilibrium demand for novelty.

5 A Brief Overview of Related Ideas

The presented model of organizational design echoes the ideas voiced in disparate contexts, including organizational theory and evolutionary biology.

5.1 Organizational Theory: Tight and Loose Coupling

The paper operationalizes the concepts of loose and tight coupling, discussed by Roberts (2004, Chapter 2). Various aspects of organizational design can be tightly or loosely coupled: information technology (e. g., standardized IT platforms vs. individually chosen platforms), production processes (e. g., just-in-time vs. inventory-dependent), and human-resource policies (e. g., permanent employment or low turnover vs. high turnover). The present paper focuses on the human-resource policies of low turnover (tight coupling) and high turnover (loose coupling).

Roberts (2004) emphasizes that the individual features of organizational design are often complements and ought not to be optimized independently of each other. In the present model, this complementarity emerges between coupling (loose or tight) and the innovation rate. As the consumer's novelty seeking varies, the coupling type and the innovation rate covary.

The intellectual roots of the concept of loose coupling go back to the bounded rationality paradigm, which emphasizes the constrained optimality of simple behavioral principles. In the context of bounded rationality, Simon (1969) anticipates loose coupling when he describes the merits of modularity in organizations. The terms "loose coupling" and "tight coupling" have first been used by Glassman (1973) to describe an evolved characteristic, the degree of interdependence of the components of living organisms and of societies. These concepts have been developed further and popularized in organizational economics by Weick (1976).

The lack of a tight definition of loose coupling and the traditionally informal nature of the discourse in organizational theory have freed the researchers to entertain rich interpretations but have hindered the synthesis of formal models of coupling. Informally, Cameron (1986) acknowledges that organizations face trade-offs between loose and tight coupling and may incorporate elements of both (which proves to be suboptimal in the model; see Footnote 8). Orton andWeick (1990) and Sanchez and Mahoney (1996) emphasize the role of loose coupling in organizations' adaptability to change (consistent with the conclusion of Theorem 1). Weick and Quinn (1999) link tight coupling to "a preoccupation with short-run adaptation rather than long-run adaptability," just as the present paper does by assuming that switching the types of all experts is harder for a tightly coupled firm than it is for a loosely coupled one.

In the organizational economics literature, coupling is usually studied in the context of several subunits within an organization.[12] By contrast, my model can

12 For example, Brusoni, Prencipe, and Pavitt (2001) use loose and tight coupling to describe the extent of the integration of production units in the aircraft industry. Rubin (1979) focuses on units within universities.

be interpreted to have a single unit. This assumption does not render the concept of coupling vacuous, because of the model's dynamic features. The firm's single unit today can be tightly or loosely coupled with the corresponding unit tomorrow. Indeed, dynamics is the only reason why the trade-off between tight and loose coupling emerges in any discussion of coupling in organizational economics.

The analyzed model does not purport to capture the broad usage of loose coupling encountered in the literature. Reading Orton and Weick (1990) suggests the following (still partial) conceptualization of this broad usage: Organizational units are loosely coupled if they are interdependent but to a lesser degree than is first-best optimal, where the first-best optimal maximizes the organization's objective function (e. g., profit) while, crucially, assuming unbounded cognitive ability of both the designer and the organization's members. Thus, loose coupling is observed when tight coupling – first-best optimal by definition – is impossible to discover or implement. This paper's model operationalizes the described broad concept by building on its critical element: bounded rationality. One can conceive of different kinds of bounded rationality, in a variety of contexts; the proposed operationalization selects but one, and in that, it is limiting.

Furthermore, no model can do complete justice to loose coupling, even in principle. According to Orton1990, loose coupling is a dialectical concept. A dialectical concept is defined to have multiple dimensions, which can be neither fully specified nor even enumerated.[13] As a result, a dialectical concept cannot be modelled formally. Instead, intentionally open-ended, it is intended to stimulate a continual conversation.[14]

The present paper contributes to such a conversation by focusing on but an aspect of loose coupling. Inevitably, omitted are such diverse phenomena as employees' sense of self-determination, reduced conflict, psychological safety, and job satisfaction and loneliness – all associated in the literature with loose coupling. Omitted are also alternative modes of coupling: between an organization and its customers, between finding solutions to applied problems and

13 On page 5 alone, Weick (1976) lists fifteen ways to think about loosely coupled systems – in a single paragraph.

14 Wittgenstein (1953) would have been keen to exhibit loose coupling, which has no more parsimonious representation than a tentative list of its usages, as a concept that is irreducible to the atoms of a perfectly logical language, such as mathematics or that envisaged by Wittgenstein (1922) (and later repudiated by Wittgenstein 1953). Related, the limited (at least in the short run) capacity of mathematical theories for capturing economic concepts with rich verbal traditions has been noted by Kreps (1996): "Anyone who relies on the [mathematical] translations alone misses large and valuable chunks of the original."

actually acting on these solutions, between various goals and missions of an organization, between intentions and actions, and along the vertical dimension in a hierarchical organization. Omitted is also the interpretation of loose coupling as a measurement error due to the researcher's inability to see the fine strings tightly tying together the organizational units. Instead, emphasized are bounded rationality and dynamics, whose centrality to loose coupling has been acknowledged by Orton and Weick (1990).

5.2 Organizational Theory: Corporate Culture

One can interpret the firm's organizational design as a component of corporate culture, consistent with the vision of corporate culture described by Kreps (1990). Because some contingencies are hard to foresee (or contract upon), corporate culture evolves as a collection of simple principles, which will likely not lead to first-best outcomes. In the present model, the coupling type and innovation rate are such principles; they do not lead to first-best outcomes, if only because the firm's innovation rate is independent of whether the firm's experts matched the consumer's taste in the previous period. Kreps (1990) also posits that corporate culture will be roughly aligned with the contingencies that are likely to arise, as it is in the present model.

5.3 Strategy: Creative Disruption

The model's LCF, which periodically fires its experts and starts all over again, resembles the self-disrupting innovator of Christensen (1997). Indeed, suppose we observe a long history during which the consumer's taste is unchanged, but this history is unrepresentative because the underlying demand for novelty is high. Initially, this history delivers a lower profit to LCF than it would have to TCF, which would not have periodically fire its experts. So in a sense, LCF "self-disrupts," but it does so only to rebuild what it has disrupted in the following period. Because the history of the unchanging taste is unrepresentative, however, LCF is bound to eventually outperform TCF. Thus, LCF may look unprofitable at first but is more profitable than TCF on average, in the long run – which is a defining feature of a successful self-disruptor, according to Christensen (1997).[15]

15 LCF's periodic rehiring also fits Schumpeter's concept of creative destruction (Schumpeter 1942, Chapter 7).

5.4 Preference Theory: Novelty

In economics, the idea that individuals like novelty for novelty's sake goes back at least to Scitovsky (1977). Inspired by research in psychology,[16] he argues that if individuals' inherent desire for novelty is not satisfied by challenging work, latest gadgets, and fashion, this desire will find its outlet in violence. A constant stream of novelty is necessary to keep individuals content with peaceful co-existence. Hence, for Scitovsky, as in the present paper's model, economic change need not lead to economic growth.

A branch of marketing literature studies the determinants of consumer innovativeness, of which novelty seeking is a prominent component (Hirschman 1980; Tellis, Yin, and Bell 2009). Steenkamp, ter Hofstede, and Wedel (1999) survey consumer innovativeness in Europe and conclude that it varies with country characteristics, such as individualism. A way to operationalize the concept of novelty-seeking is to identify it with the willingness to adopt new goods as long as this willingness cannot be attributed to economic factors (e. g., income). The work of Erumban and de Jong (2006) is suggestive; they report that information-technology adoption within a country is positively correlated with that country's measure of individualism.

Habituation to novelty is a robust scientific fact (Cerbone and Sadile 1994). The model's assumption that the consumer's demand for novelty is increasing in the firm's innovation rate is consistent with this fact.

5.5 Evolutionary Biology: The Disposable Body Hypothesis

The founder's choice of whether to promote loose coupling instead of tight coupling resembles Nature's (i. e., Evolution's) choice of whether to equip an organism with a disposable body, instead of a perdurable one. Having considered the trade-off, Dawkins (1982, Chapter 14) concludes that the evolution of complex structures is more effectively accomplished by periodically rebuilding an organism, instead of tinkering incrementally with a growing or grown organism. The present paper makes an analogous argument for firms.

TCF resembles a perdurable-body organism. To adapt to the consumer's ever-changing taste for styles, TCF must endure the costly episodes of employing experts with conflicting expertise. By contrast, LCF resembles a disposable-body organism. LCF avoids the costly episodes of adaptation by undergoing periodic

16 Bianchi (2003) singles out Berlyne (1971) and Berlyne and Madsen, eds (1973) as Scitovsky's early influences.

regeneration, which is wasteful when the consumer's taste does not change. This regeneration is worth the waste, however, when the consumer taste is fickle.

The exploration of the evolutionary hypothesis is identified by Weick (1976) as one of the seven priorities in the study of loose coupling: "If one adopts an evolutionary epistemology, then over time one expects that entities develop a more exquisite fit with their ecological niches. Given that assumption, one then argues that if loosely coupled systems exist and if they have existed for sometime, then they bestow some net advantage to their inhabitants and/or their constituencies. It is not obvious, however, what these advantages are." In the model, these advantages are identified with increased adaptability to the volatile environment.

5.6 Evolutionary Theory: The Selfish Meme

In the model, the elements of organizational design (the innovation rate and the coupling type) and the target style can be interpreted as memes. Dawkins (1976, Chapter 11) introduces meme, an idea whose content contributes to its likelihood of being replicated. In the model, meme selection can be interpreted to occur at two frequencies. At the high frequency, at the end of every period, the firm designates for survival that target style which would have delivered the highest profit given the consumer's current taste. At the low frequency, the firm designates for survival that organizational design which leads to the highest expected profit in the long run given the volatility of the environment. In both cases, meme replication favors the more profitable memes.

The multiple-frequency approach to meme evolution has been espoused by Deutsch (2011, Chapter 15) to speculate why some societies progress and others stagnate. He surmises that individuals have a natural proclivity to innovate (i. e., to mutate high-frequency memes), which stagnant societies suppress with a (low-frequency) thou-shalt-not-innovate meme. This meme survives in a stagnant society better than it would have in a progressive one because of another (low-frequency), thou-shalt-not-reason-critically, meme, which ensures that innovative fallacies are not discarded in favor of innovative truths.

The model's direct counterpart for the (inverse of) thou-shalt-not-innovate meme is the innovation rate. The though-shalt-not-reason-critically meme has no direct counterpart in the model, but the coupling type plays a similar role by making the innovation meme more or less profitable. In particular, as the consumer's demand for novelty varies, loose coupling and high innovation rate covary, just as critical reasoning and innovation do in Deutsch's narrative.

6 Some Corroboratory Evidence

6.1 Hypothesis

Observation 1 predicts that if demands for novelty can be ordered across economies, then the highest and the lower equilibria across these economies obey the same order. Figure 7(a) suggests that also multiple equilibria in a single economy can be ordered, with higher innovation equilibria being associated with higher novelty seeking. This positive association prevails simply because the demand for novelty slopes upwards, and all equilibria lie on this curve. These observations inspire the following hypothesis.

Hypothesis 1. *Industries or countries that innovate more have consumers who seek novelty more.*

Of course, multiple theories may lead to Hypothesis 1. The empirical analysis that follows is suggestive, not dispositive. Its goal is to see whether evidence corroborating the hypothesis can be amassed. The analysis raises more questions about the measurement of innovation and novelty seeking than it answers.

6.2 Data

The unit of observation is a country in 2011. The drug prevalence, taken from the World Drug Report 2012, refers to the ratio of the number of afflicted individuals of ages 15 to 64 to the total population. The patent data are the 2011 entry from the OECD database.

6.3 Evidence

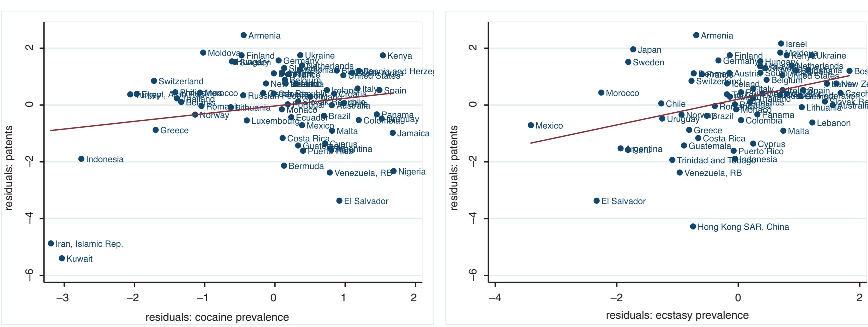
Bardo, Donohew, and Harrington (1996) observe that drug addictions and novelty seeking share a common neurobiological cause and review behavioral evidence for their correlation. Linden (2011) articulates the mechanism.[17] To reach the same amount of pleasure, individuals with genetically suppressed dopamine signaling need greater stimulation than the individuals whose dopamine signaling is not suppressed. Cocaine and Ecstasy (a.k.a. MDMA) are

17 See also "Is There a Link Between Creativity and Addiction?" by David Biello, Scientific American, 26 July 2011.

stimulants that compensate for the suppressed dopamine signaling by blocking dopamine reuptake, thereby activating dopamine receptors more effectively. Novelty activates the same pleasure circuitry in the brain as stimulant drugs do, and more so in the individuals susceptible to addictions.[18]

Inspired by physiological and behavioral links between addictions to stimulants and novelty seeking, one might regard cocaine prevalence and Ecstasy prevalence as **proxies for novelty seeking**. Per-capita patents are taken to be a **proxy for innovation rate.**

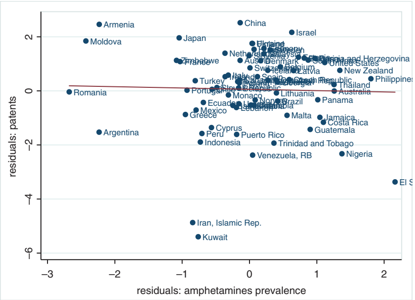
To assess Hypothesis 1, Figure 8 reports partial regression results: the residuals from regressing log per-capita patents on log-per-capita GDP plotted against the residuals from regressing log per-capita cocaine and ecstasy prevalence on log-per-capita GDP. Controlling for the GDP ensures that the positive relationship (if any) between patents and drug prevalence is not driven by income. Figure 8 documents a statistically significant positive relationship for Ecstasy, consistent with Hypothesis 1. For cocaine, the relationship is positive, but not statistically significant.



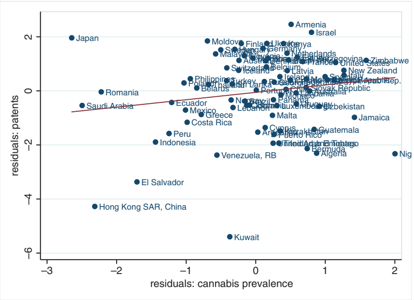
(a) Cocaine: slope = 0.27, p-value = 0.297. (b) Ecstasy: slope = 0.45 , p-value = 0.003.

Figure 8: Stimulants. Partial regression plots of log per-capita patents against log drug prevalence.

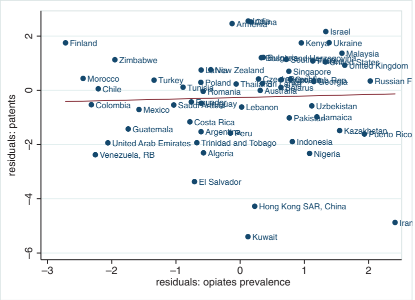
18 Sabol et al.(1999) report positive correlation between novelty-seeking traits and cigarette addictions, and credit variation in dopamine transmission as the common causal factor. Olsen and Winder (2009)report experiments in which disruption of dopamine signaling (in rodents) affects novelty seeking and cocaine intake similarly, without affecting heroin and food intake. The physiological research, which singles out cocaine and amphetamines as the correlates of novelty seeking, builds upon earlier psychology research, which documents correlation between novelty seeking and drug abuse in general (Zuckerman 1986).



(a) Amphetamines.



(b) Cannabis.



(c) Opiates.

Figure 9: Other drugs. Partial regression plots of log per-capita patents against log drug prevalence. None of the fitted linear relationships is statistically significant.

Figure 9 plots the relationship between patents and amphetamines, cannabis, and opiates. Opiates are depressants; cannabis are a bit of everything (stimulant, depressant, tranquilizer, and hallucinogen), but not much of a stimulant; "trip" reports in online forums indicate that amphetamine (when not referring to Ecstasy), a stimulant, causes a surge in energy but not the bliss (dopamine rush) reported by Ecstasy users. No statistically significant relationship is observed, consistent with the interpretation that amphetamines (except Ecstasy), cannabis, and opiates are poor proxies for novelty seeking.

7 Concluding Remarks

For equilibrium inefficiency, it is essential that the founder choose the organizational design while treating the consumer demand for novelty as given. Do firms tend to imitate – and do consulting firms tend to spread – the practice common in an exceptionally successful industry or the practice of an exceptionally successful firm? If the latter kind of imitation is significant, the model's assumption is justified, for then firms would tend to neglect equilibrium effects. Indeed, empirical evidence (Argote 2013, Chapter 6, and especially Haunschild and Miner 1997) favors the hypothesis that the probability of a business practice being imitated is affected by the characteristics (e. g., profitability, size, "status") of the firms using this practice, also when controlling for supra-firm characteristics, such as the number of firms that use this practice.

For equilibrium multiplicity, it is essential that the consumer's demand for novelty be increasing in the firm's innovation rate. The leading interpretation is literal: the consumer gets aroused by witnessing more frequent innovation (perhaps, as he is being inundated by advertisements) and gets bored with the styles quicker. An alternative interpretation is that consumers by night are employees by day; as the firm inculcates its employees to seek innovation in production, these same employees inevitably develop demand for innovation, or novelty, in consumption.

When present, the multiplicity of equilibria is a bad news for the model's predictive power. Highlighting this indeterminacy is precisely the point of the analysis. An industry's (or country's) innovativeness may be determined by the factors outside economics, such history.

The model makes the stark assumption that innovation is driven solely by the demand for novelty, never for quality. The economic reason for this assumption is to isolate and explore the logical implications of demand for novelty, a prominent feature of individual preferences. The technical reason is to model volatility in a simple manner. Demand for novelty can be a metaphor for other sources of volatility that may affect the firm's organizational design. Among these are competitors' behavior and innovation in supplier or complementary-product markets, as well as habit-formation preferences with a sufficiently strong habituation to quality.

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