X-efficiency vs adaptive efficiency: an analysis of firm survival

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We analyze firms' adaptive choices in changed circumstances. Adaptation is the process of developing new norms, which diverts mental energy from production. Highly specialized firms have higher adaptive costs, and so may not survive a change. Firms can lower these costs by increasing adaptive capacity in advance of the change. Adaptive capacity measures the ability to manage the emotional and mental challenges of confronting change. Building adaptive capacity diverts resources from production, giving the illusion of x-inefficiency. Greater homogeneity of product markets decreases firms' abilities to adapt to change and to invest in adaptive capacity, leading to more exit when circumstances change.

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Economics has long examined the nature of human decision making and its effects on economic performance. The study of decision making has been multidisciplinary and includes studies of rationality and revealed preferences (Houthakker 1950), heuristics and biases (Tversky and Kahneman 1974; Thaler 2000) and neuroeconomics (Camerer, Loewenstein, and Prelec 2005 -- hereafter, CLP; Fehr and Rangel 2011) as well as other topics. Examinations of the effects on performance have also included multiple disciplines, such as studies of creative destruction (Schumpeter 1942), knowledge and adaptation (Hayek 1945), firm survival (Tushman and Anderson 1986; Christensen and Bower 1996), institutional adaptation (North 2005; Dessein, Galeotti and Santos 2016) and adaptation and leadership (Heifetz 1994). We add to this research by combining recent findings in the psychology and neuroscience of decision making with those on adaptation to study why firms do or do not adapt to economic changes.

More specifically, we examine how four fundamental limiting resources – time, mental energy, attention, and mental capacity, which we call the TEAM constraints – bind human decision-making.[1] Humans have limited mental energy and capacity, which constrain the amount of information that can be processed and how much can be remembered. Conscious awareness is limited to one thing at a time, so that time and awareness also limit conscious decision-making. We examine how humans develop biases, heuristics, mental frameworks, and norms – which we call the BHMN mechanisms – as mechanisms for optimizing given these TEAM constraints. Biases[2] and heuristics enable humans to filter information and use mental short cuts that seem to work most of the time. Mental

[1] Information could be a fifth constraint. We assume that all information is obtainable, but doing so is prohibitively costly because of the other constraints.

[2] The word "bias" has taken on a negative connotation, but its etymology includes the sense that biases are expedient or short cuts.

frameworks use accepted patterns to impose order on information and decisions. And norms allow humans to coordinate their biases, heuristics and mental frameworks without exhaustive communication and mental processing.

We apply the use of BHMNs to understand why businesses and other institutions fail to adjust to changed circumstances. It is well known that individuals and institutions[3] sometimes dissolve or at least lose effectiveness when context changes. Perry (2014) observes that only 12.2% of firms making the Fortune 500 list of the largest companies (based on total revenue) in 1955 were still on the list in 2014. Those that had exited the list had gone bankrupt, merged, or shrunk relative to other firms. Christensen and Bower (1996) believe that some firms decline because they fail to adapt to changed circumstances. Sears, a leading retail firm in the mid 1960s, failed to adapt to discount retailing and home centers. IBM, once the leading provider of mainframe computers at best weakly adapted to the development of minicomputers, leaving that market to Data General, Wang, and Hewlett-Packard. These suppliers in turn failed to make the transition to the personal computer market, which was initially led by Apple, Commodore, Tandy, and IBM. Xerox developed xerography and led the industry for large copiers, but failed to become a significant provider of desktop copiers.

The study of the process of change (or the lack thereof) in individuals and institutions has grown in prominence. Tushman and Anderson (1986) and Henderson and Clark (1990) find that technological changes that decrease the value of earlier firm competencies often lead to new firms entering markets, potentially replacing existing firms. Christensen and Bower (1996) argue that incumbent firms become too connected with large customers that embrace old

[3] Following North (2005), we define an institution as a set of formal and informal norms that describe how people in the institution behave and interrelate. This includes the political structure (i.e., how the organization makes political choices and formal economic incentives) and the social structure (i.e., the norms and conventions that define informal incentives).

technologies, thereby leading the firms to forgo technology changes. These perspectives leave unanswered why firms, and their customers in some circumstances, make the choices that preclude economic survival and adaptation.[4] North (2005) explains that institutional change is triggered when novel experiences challenge human success and investigates how institutions change.[5] He highlights the importance of an organizational entrepreneur[6] orchestrating changes in norms and rules. North's view implies that firms fail to change because of the failures of organizational entrepreneurs.

Heifetz (1994) also emphasizes the role of an individual in institutional change and identifies threats to accepted and valued norms as primary barriers. These threats trigger reactions commonly associated with grieving (Kübler-Ross 2009; Smollan and Sayers 2009), including denial, anger, fear, or depression and people resist change as a result.[7] He studies how persons practicing leadership, specifically adaptive leadership in his terminology, challenge deeply held beliefs and practices in an organization to assist it in confronting disruptions and making changes that are necessary for survival.

CLP (2005) describe the neuroeconomics of change processes in individuals, highlighting the cognitive and affect (or emotional) processes of decision making, how these processes vary between individuals who are more efficient or less efficient at particular activities, and the mental energy required for individuals to

[4] Igami (2018) also studies the hard drive industry and finds that successful firms moved manufacturing outside the United States, while failing firms did not.

[5] Following North (2005) we define a novel experience as one where a person observes data that exposes him or her to conflicts between personal beliefs and reality.

[6] An organizational entrepreneur is someone who seeks to challenge existing beliefs and practices and to orchestrate adaptive learning. (Heifetz, 1994, pp. 15-27; North 2005, p. 60) This incorporates Kotter's change leader, who has formal authority, and Heifetz's person practicing leadership, who may or may not have such authority. (Kotter, 1990, pp. 3-18; Heifetz, 1994, p. 20)

[7] Heifetz (1994) contrasts adaptive challenges with technical challenges, which he defines as problems that are acceptable in the existing institutional norms and so can be addressed by experts, such as engineers, economists, lawyers and accountants.

adapt their cognitive and emotional responses to new circumstances. Emphasizing the cognitive aspect, Byers (2014) explains that challenges to fundamental ways of understanding are resolved through deep thinking, which he defines as the basic, creative and non-sequential thinking system that is built into human biology.

The literature reveals that changed circumstances present three types of challenges: (1) Challenges to how institutions are organized and how they conduct their work (system challenges); (2) Challenges to how people think and their expertise (cognitive challenges); and (3) Challenges to how people feel about their situations (affect challenges).[8] These three types of challenges appear to always be present and to be intertwined when changed circumstances threaten norms, and perhaps even threaten the continued existence of an institution.

We add to this literature by explicitly modeling each challenge and the interactions. We apply the development and modification of BHMNs. To illustrate, suppose that if there were no constraints a person would achieve utility $\overline{U}(\boldsymbol{\beta}_1)$ given the vector of parameters $\boldsymbol{\beta}_1 \in \mathbb{R}^m$. But the TEAM constraints $\boldsymbol{k} \in \mathbb{R}^m$ limit the person to only achieving utility $\underline{U}(\boldsymbol{\beta}_1, \boldsymbol{k}) < \overline{U}(\boldsymbol{\beta}_1)$. By developing BHMNs, $\boldsymbol{h}_1$, decision-making requires less TEAM, enabling the person to achieve utility $\widehat{U}(\boldsymbol{\beta}_1, \boldsymbol{k}, \boldsymbol{h}_1) \geq \widehat{U}(\boldsymbol{\beta}_1, \boldsymbol{k}, \boldsymbol{h}_i)\ \forall i \neq 1$, where $\underline{U}(\boldsymbol{\beta}_1, \boldsymbol{k}) < \widehat{U}(\boldsymbol{\beta}_1, \boldsymbol{k}, \boldsymbol{h}_1) < \overline{U}(\boldsymbol{\beta}_1)$. But suppose parameters change to $\boldsymbol{\beta}_2 \in \mathbb{R}^m$, such that the person could improve utility by changing BHMNs, i.e., $\exists i \neq 1$ such that $\widehat{U}_2(\boldsymbol{\beta}_2, \boldsymbol{k}, \boldsymbol{h}_1) < \widehat{U}(\boldsymbol{\beta}_2, \boldsymbol{k}, \boldsymbol{h}_i)$. Should the person change his or her heuristics, biases, etc.? Doing so comes at a cost, which raises the possibility that the change is not worthwhile. Similarly, a firm may face situations where a change in its

[8] Social psychologists define three areas individuals use in their social interactions: affect (feelings), behavior (interactions), and cognition (thoughts). Both affect and cognition are critical to one's ability to adapt to changing circumstances.

environment may make the firm's norms, employees, and systems suboptimal. But is it profit maximizing for the firm to change? Are there situations where the firm should simply close?

This understanding of constraints on decision-making allows us to analyze adaptation costs and adaptive efficiency, which considers the appropriate capacity an individual, organization, or economy possesses to adapt to changed circumstances, such as the development of a disruptive technology.[9] Threats to BHMNs often trigger negative affect because, in a sense, human emotions protect them. For example, norms could be viewed as valued traditions, the giving up of which triggers sadness. Or an individual's role in an institution might be because of the quality of the person's biases, heuristics, and mental frameworks in the context of the institution, and a change threatens that role, triggering fear. Other biases and heuristics might be protected by ideas that they are just, so that threats trigger anger. As a result of this emotional shield, it may seem easier for individuals and firms to maintain BHMNs that are inconsistent with emerging market realities than to adapt. Overcoming resistance to change generates costs and consumes resources that could be devoted to production, whose effects on profit may challenge a firm's financial viability. Because of this challenge to viability, a firm might choose to prepare itself in advance by increasing its adaptive capacity, which lowers the cost of adapting should circumstances change. Some firms find that investing in adaptive capacity is profit maximizing, but others do not, with the differences being determined by dissimilarities in their innate abilities to build such capacity, their expectations of the cost of adaptation, their abilities to internalize versus externalize the costs of adaptation, and the

[9] Christensen and Bower (1996) coined the term *disruptive technology*. They separate new technology into two categories: sustaining and disruptive. Sustaining technology relies on incremental improvements to an already established technology. Disruptive technology lacks refinement, often has performance problems because it is new, appeals to a limited audience, and may not yet have a proven practical application.

effects on profits pre-change and expected profits post-change. Some firms find it optimal to dissolve rather than change.

We demonstrate our findings with two models. Our first model is simplified and yet demonstrates many of our results. Our second, richer model examines adaptive capacity and adaptive change in individuals and aggregates these into a model for institutions. Drawing upon research in neuroscience, psychology, and behavioral economics, our second model finds that individuals and firms make tradeoffs, sometimes subconsciously, between adaptive change and current production. They also make tradeoffs between current production and investing in adaptive capacity. Current production provides current rewards and seems relatively effortless to experts, while adaptive behavior and investing in adaptive capacity create current stress and provide potential benefits only in the future. These tradeoffs explain why some people fail to adapt to changed circumstances even in the face of compelling reasons to adapt.

A firm is more efficient with its adaptation if individuals adapt in similar ways at the same pace, all other things being equal, but individuals vary in their innate abilities to change. Firms choosing to adapt also choose between incurring additional costs to help less adaptive employees or releasing them.

This paper proceeds as follows. The next section presents a simple model that illustrates some of our main findings. Section II draws upon neuroscience, psychology, and behavioral economics to describe the processes of adaptive change, and analyzes a more complex model that incorporates these insights. Section III is the conclusion.

I. A Simple Model of Adaptive Change and Efficiency

A. The Model

When adapting, an individual devotes resources to observing and engaging with novel experiences and adjusting beliefs according to those experiences. Heifetz (1994) calls this adaptive learning or adaptive work, which involves both cognitive and affect processes (CLP 2005).[10] The cognitive work re-examines and changes beliefs about "What is?" in order to develop new practical frameworks for decision making. The affect processes reconsider and modify how adaptive challenges trigger feelings of fear, sadness or anger. New and accepted norms are the outcome of adaptive learning, but the new norms come at a cost because adaptive work consumes energy,[11] mental capacity and time that could be devoted to other activities, such as producing products. (Just and Carpenter 1992; Chabris and Simons 2010; Kahneman 2011)

An individual can lower costs of adaptive learning by building adaptive capacity in advance. More adaptive capacity lowers the resources (energy and mental capacity) and time that it takes to alter beliefs and norms. An individual can prepare him- or herself for confronting possible adaptive challenges by, for example, devoting time to studying outside his or her field of expertise, experiencing other cultures, and practicing managing emotional responses.

Institutions adapt when their employees devote time and energy to novel experiences, adopt new norms when appropriate, and align those norms across the organization, including changes in organizational structure and communications methods. (Aggarwal, Posen and Workiewicz 2016; Heifetz 1994; North 2005)

[10] We examine the psychology and neuroeconomics of adaptive learning and adaptive capacity more fully in section II.

[11] Unless otherwise specified, we use the term "energy" to mean mental energy. We will sometimes specify mental energy where we believe doing so is important for clearity.

This means that the organization incurs costs that could be put to use producing current products, which makes the organization appear less X-efficient (or technically efficient)[12] than it would be otherwise. But the adaptive learning is necessary for creating alignment of individual and institutional norms that make it possible to successfully operate in new circumstances (Taylor and Helfat 2009).

Our simple model examines a situation where an initial heterogeneous product x is replaced by another heterogeneous product y. The replacement is exogenous. A firm changing from producing the initial product to the new product engages in adaptive work. While producing x a firm can lower its future cost of adaptive work to produce y by building adaptive capacity.[13] As we demonstrate in our analysis, some firms find it profitable to do this. Other firms find it more profitable to dissolve than to convert to producing y. Still other firms find it less costly to abruptly change norms than to build adaptive capacity.

More formally, there are N possible firms that seek to maximize individual profit, with $n \in \{1 \ldots N\}$ representing one of the firms. $x_n \geq 0$ and $y_n \geq 0$ are the outputs of firm n. The demand for x_n is given by a well-behaved, continuous inverse demand function $p_n(\theta^x, \mathbf{z}, \mathbf{X}) \geq 0$, such that $p_n{}' < 0$ and $p_n{}'' > 0$, that is known to all firms. (To simplify notation we adopt the form *arg'* to denote the derivative of any function that has only one argument, or the derivative of prices with respect to output.) $\mathbf{z}$ is a vector of parameters determining demand. Similarly $\phi_n(\theta^y, \mathbf{z}, \mathbf{Y}) \geq 0$ is the continuous inverse demand function for y_n, such that $\phi_n{}' < 0$ and $\phi_n{}'' > 0$, which is also known by all firms. $\overline{\theta}^x > \theta^x > 0$ and $\overline{\theta}^y > \theta^y > 0$ respectively represent the exogenously determined degrees of

12 X-efficiency refers to cost minimizing behavior with respect to production, maintained by individuals and firms under conditions of imperfect competition. The term first was used by Leibenstein (1966). A firm incurring costs to grow adaptive capacity will give the illusion that it is x-inefficient because the firm could produce the same amount of output at a lower overall cost.

13 Aggarwal, Posen and Workiewicz (2016) identify developing adaptive routines as a form of adaptive capacity.

heterogeneity in x and y, where $\overline{\theta}^x$ and $\overline{\theta}^y$ represent the points of heterogeneity where each firm would be a monopoly. **X** and **Y** are respectively the output vectors of x and y. Marginal revenue is increasing in θ^i, $i = x, y$, at a decreasing rate, i.e. $\frac{\partial(p_n - p_n' x)}{\partial \theta^x} > 0$, $\frac{\partial^2(p_n - p_n' x)}{\partial \theta^{x^2}} < 0$, $\frac{\partial(\phi_n - \phi_n' y)}{\partial \theta^y} > 0$, and $\frac{\partial^2(\phi_n - \phi_n' y)}{\partial \theta^{y^2}} < 0$. We assume that the effects of θ^i on marginal revenues are uniform across firms. Because y represents a technology advancement over x, we assume that customers value y more than they do x, all other things being equal.

The total amount of time in our simple model is normalized to 1 such that $0 < \alpha < 1$ is the exogenously determined amount of time from the start of the production of x until y replaces x. y is produced for a period of time of length $1 - \alpha$. α is known by all firms.

All costs for firms are either production costs or fixed costs. Labor is the only production cost and $w > 0$ is the exogenously determined wage rate, which is constant. We assume that it takes one unit of labor to produce one unit of output. We also assume that firms vary in their fixed costs for producing x such that firms with a lower value of n have lower fixed costs than those with higher values of n: Let $K_n = n \cdot k > 0$ represent n's fixed cost of producing x.[14]

$a_n \geq 0$ is n's choice for the amount of investing in adaptive capacity that it requires of its workers, which is observable by all firms. We assume that workers are homogeneous in their abilities and that their efforts are costless to observe. If a firm's workers engage in adaptive work, they do so uniformly during the time they produce x, so the adaptive capacity of n is $A_n \equiv \alpha \cdot a_n$.

We assume that the fixed costs of a firm producing y include the costs of preparing to produce the product. For firms that produced x this includes the cost

[14] We refer to these higher-cost x-producing firms as being less efficient than lower cost firms even though the cost levels are exogenous.

of adaptation. Greater adaptive capacity lowers these costs. As we describe further in Section II, there is evidence to suggest that firms that were highly efficient at producing x, i.e. firms that are more highly specialized, have farther to adapt than firms with lower efficiency and so have higher adaptation costs. We incorporate these features into the fixed costs of producing y: Let $F_n(A_n) \equiv \begin{cases} (N^+ - n) \cdot f(A_n) & \text{if } x_n > 0 \\ (N^+ - n) \cdot \hat{f} & \text{if } x_n = 0 \end{cases}$, where $N^+ > N$ and $\hat{f} > 0$.[15] For simplicity we assume that adaptive capacity does not affect production costs for y. Adaptive capacity lowers fixed costs at a decreasing rate such that $f' < 0$ and $f'' > 0$. The highest and lowest values for f are given by $f(0) = \overline{f} > f(\infty) = \underline{f} > 0$.

Firms that do not produce a product do not incur the associated fixed costs. Costs are common knowledge among the firms.

We can now express firm n's objective function as maximizing

$$\begin{aligned} \Pi_n \equiv \alpha\big(p_n \cdot x_n - w \cdot (x_n + a_n)\big) - n \cdot k \\ +(1-\alpha)\Big(\big(\phi_n - w\big) \cdot y_n\Big) - F_n(A_n) \end{aligned} \quad (1)$$

with respect to x_n, y_n, and a_n, subject to $x_n \geq 0$, $a_n \geq 0$, and $y_n \geq 0$. We assume competitive capital markets and normalize investors' opportunity costs to zero. Therefore profits must be weakly positive to induce a firm to produce $x_n > 0$, i.e. $\pi_n^x \equiv \alpha \cdot \big(p_n \cdot x_n - w \cdot (x_n + a_n)\big) - n \cdot k \geq 0$, else $x_n = 0$. Likewise profits must be weakly positive to induce a firm to produce $y_n > 0$, i.e. $\pi_n^y \equiv (1-\alpha) \cdot \big((\phi_n - w) \cdot y_n\big) - F_n(A_n) \geq 0$, else $y_n = 0$.

We apply a two-stage game. In the first stage each firm individually chooses how much x to produce (including the option of not producing) and its investment in adaptive capacity. In the second stage each firm decides the amount of y to

[15] We adopt the assumption $N^+ > N$ to ensure that all firms have fixed costs for producing y.

produce, including the option of not producing. We use subgame perfect Nash equilibrium as our solution concept.

We can now specify three definitions that will be useful for our analysis.

DEFINITION 1. *The* ***cost of adaption*** *or of adaptive work is the cost a firm incurs to adapt to changed circumstances, i.e., the total cost of the firm after the change less the total cost if the firm had not adapted, all other things being equal.*

DEFINITION 2. *The* ***profit from creating adaptive capacity*** *is the difference between the cost savings from, and the costs of building adaptive capacity.*

DEFNITION 3. *A firm is* ***adaptively efficient*** *if it makes profit-maximizing choices for adaptive capacity and adaption.*

In our simple model, the cost of adaptation is the difference in cost from producing x to producing y that a firm would not occur if it produced y but had not produced x, i.e. $(N^+ - n) \cdot \left(f_n(A_n) - \hat{f}\right)$, which may be positive, negative, or zero. The cost of adaptive capacity is $(N^+ - n) \cdot \left(\overline{f} - f(A_n)\right) - \alpha \cdot w \cdot a_n$, which may be positive, negative, or zero.

B. Analysis

Our analysis examines conditions for three basic scenarios and how these conditions affect firm's adaptive choices: The Full Survival Scenario (all x-producing firms also produce y); the Full Exit Scenario (none of the x-producing firms also produce y); and the Partial Survival Scenario (only some of the x-producing firms also produce y). The following definition is useful for examining these scenarios.

DEFINITION 4. *The **marginal firm**, $\hat{n}^i$ for product $i \in \{x, y\}$, is the firm that is indifferent to whether it produces the product, and that has the highest fixed costs of all firms optimally choosing to produce that product.*

With one exception, which we describe in the next paragraph, $\hat{n}^i$'s fixed costs of producing i are sufficiently high that ${\pi_n^i}^* = 0$. Because fixed costs for producing x are increasing in n and marginal revenues are equal across firms for a given output (because w and the effects of θ^x are the same across firms), all n to the left (conversely right) of $\hat{n}^x$ produce positive (conversely zero) amounts of x. Similarly, because fixed costs for producing y are decreasing in n, all firms to the left (conversely right) of $\hat{n}^y$ produce positive (conversely zero) amounts of y. By "to the left" (conversely, "to the right") we mean smaller (conversely larger) values of n.

Proof (to be in reviewer notes).

The firm's profit from providing x is $\pi_n^x \equiv \alpha \cdot \big((p - w) \cdot x_n - w \cdot a\big) - n \cdot k$ and for providing y is $\pi_n^y \equiv (1 - \alpha) \cdot (\phi - w) \cdot y_n - (N^+ - n) \cdot f(A_n)$. From first order conditions, ${x_n}^* = \frac{p-w}{-p'}$ and ${y_n}^* = \frac{\phi-w}{-\phi'}$. Solving for n when profits equal zero gives $\hat{n}^x = \frac{\alpha \cdot (p-w)^2}{-p' \cdot k}$ and $\hat{n}^y = \frac{(1-\alpha) \cdot (\phi-w)^2}{-\phi' \cdot f(A_n)} - N^+$. $\frac{\partial \pi_n^x}{\partial n} = -k < 0$ and $\frac{\partial \pi_n^y}{\partial n} = f(A_n) > 0$. QED

Under certain conditions a firm could produce x and receive positive profit, but would optimally choose to not produce x. Condition 1 provides the necessary and sufficient conditions. ${\pi_{\hat{n}^x}^x}^* > 0$ when Condition 1 holds, but is zero otherwise.

CONDITION 1. *The cost of adaption for* n *is greater than the profit it would receive while producing* x, *i.e.* $\left((N^+ - n) \cdot \left(f({A_n}^*|_{x>0}) - \hat{f}\right)\right) > \pi_n^{x^*}\big|_{x>0} > 0$.

Proof (to be in reviewer notes).

A firm produces y but not x even though producing during the initial period is profitable, if $\Pi_n|_{x=0,y>0} > \Pi_n|_{x>0,y>0} > 0$. This implies $(1-\alpha)\left(\left(\phi_n - w\right) \cdot y_n\right) - (N^+ - n) \cdot \hat{f} > \pi_n^x + (1-\alpha)\left(\left(\phi_n - w\right) \cdot y_n\right) - (N^+ - n) \cdot f(A_n) \Rightarrow -(N^+ - n) \cdot \hat{f} > \pi_n^x - (N^+ - n) \cdot f(A_n) \Rightarrow \left((N^+ - n) \cdot \left(f(A_n) - \hat{f}\right)\right) > \pi_n^x$. QED

DEFINITION 5. *The* ***marginal firm for building adaptive capacity*** *is the firm that is indifferent to whether it invests in adaptive capacity prior to the novel experience.*

In our simple model, the marginal firm is $\hat{n}^a = N^+ - \frac{w \cdot f'^{-1}\left(\frac{w}{N^+ - n}\right)}{\overline{f} - f\left(-f'^{-1}\left(\frac{w}{N^+ - n}\right)\right)}$, which is the x-producing firm that is indifferent to whether it invests in adaptive capacity.

Proof (to be in reviewer notes).

This firm's profits from building adaptive capacity are zero, i.e. $(N^+ - n) \cdot \left(\overline{f} - f(A_n)\right) - \alpha \cdot w \cdot a_n = 0$. Solving for n gives $N^+ - \frac{\alpha \cdot w \cdot {a_n}^*}{\overline{f} - f({A_n}^*)}$. Optimizing (1) for adaptive capacity gives $-f'({A_n}^*) = \frac{w}{N^+ - n}$ and taking the inverse function gives ${A_n}^* = -f'^{-1}\left(\frac{w}{N^+ - n}\right)$ and ${a_n}^* = -\frac{f'^{-1}\left(\frac{w}{N^+ - n}\right)}{\alpha}$. QED

Firms to the right of $\hat{n}^a$do not invest in adaptive capacity because the marginal benefits of adaptive capacity are decreasing in n. The following condition is useful for examining the scenarios.

CONDITION 2. *$\theta^y \geq \overline{\theta}^y$, where $\overline{\theta}^y$ is implied by* $\frac{\left(\phi_n\left(\overline{\theta}^y\right)^* - w\right)^2}{-\phi_n\left(\overline{\theta}^y\right)^{*'} \cdot f(A_1{}^*)} = N^+ - 1.$

Proof (to be in reviewer notes).
$\frac{\partial \Pi_n}{\partial a_n} = -\alpha \cdot w - \alpha \cdot (N^+ - n) \cdot f'$, or $-f' = \frac{w}{(N^+ - n)}$. $-\frac{\partial f'}{\partial n} > 0 \Rightarrow -\frac{\partial^2 f}{\partial a^2} \cdot \frac{\partial a}{\partial n} > 0$. Then because $-\frac{\partial^2 f}{\partial a^2} < 0, \frac{\partial a}{\partial n} < 0$. QED

Full Survival Scenario.— In this scenario all of the firms producing x also produce y. Condition 1 is sufficient for this scenario because: (1) Firms 1 through $\hat{n}^x$ produce x; and (2) The degree of heterogeneity in y is sufficient for all firms to produce y, i.e. $\hat{n}^y < 1$. Were it not for Condition 1, at least some of the x-producing firms would not find it profitable to adapt and produce y. Definition 6 is useful for examining these firms' adaptive capacity choices.

DEFINITION 6. *The* ***marginal profit-constrained firm for building adaptive capacity****, $\tilde{n}^x$, is the firm that receives zero profit while producing x and whose investment in optimal adaptive capacity is the same as if it were not profit constrained, i.e.* $\pi^x_{\tilde{n}^x}{}^* = 0$ *where* $x_{\tilde{n}^x}{}^* = \frac{p^* - w}{-p^{*'}}$ *and* $a_{\tilde{n}^x}{}^* = -\frac{f'^{-1}\left(\frac{w}{N^+ - \tilde{n}^x}\right)}{\alpha}$.

Whether the x-producing firms invest in adaptive capacity depends upon the fixed costs of producing y and on the profitability of producing x, which is affected by the degree of heterogeneity in x. When $\hat{n}^a \geq \hat{n}^x$, all of the x-

producing firms build adaptive capacity, but the constraint that a firm must receive non-negative profit while producing x limits some firms' ability to build adaptive capacity. Firms 1 through $\tilde{n}^x$ choose the internal solution for the optimal adaptive capacity, $a_n{}^* = -\frac{f'^{-1}\left(\frac{w}{N^+-n}\right)}{\alpha}$, but firms from $\tilde{n}^x$ through $\hat{n}^x$ choose their output and adaptive capacity by equating the marginal revenue from x with the marginal benefit from lowering the cost of adapting to produce y, giving $a_n{}^* = -\frac{f'^{-1}\left(\frac{p^*+p^{*\prime}\cdot x^*}{N^+-n}\right)}{\alpha}$, which is less than the investment of each firm 1 through $\tilde{n}^x$.

Conversely, when $\hat{n}^x \geq \hat{n}^a$, firms 1 through $\hat{n}^a$ build adaptive capacity and firms from $\hat{n}^a$ through $\hat{n}^x$ do not. If $\hat{n}^a > \tilde{n}^x$, firms 1 through $\tilde{n}^x$ choose the internal solution for the optimal adaptive capacity and firms from $\tilde{n}^x$ through $\hat{n}^a$ choose their output and adaptive capacity by equating the marginal revenue from production with the marginal benefit from lowering the costs of adaptation. If $\tilde{n}^x > \hat{n}^a$ all firms 1 through $\hat{n}^a$ choose the internal solution for adaptive capacity.

The degree of heterogeneity in x affects the number of firms investing in adaptive capacity in the Full Survival Scenario by affecting $\hat{n}^x$ and $\tilde{n}^x$. Greater heterogeneity shifts both values to the right, leading more firms to invest in adaptive capacity when $\hat{n}^a \geq \hat{n}^x$ and more firms to choose the internal optimum for adaptive capacity when $\hat{n}^a > \tilde{n}^x$. The following condition is useful for subsequent analysis.

CONDITION 3. $\theta^x \geq \overline{\theta}^x$, *where* $\overline{\theta}^x$ *is implied by* $\frac{\left(p_n\left(\overline{\theta}^x\right)^* - w\right)^2}{-p_n\left(\overline{\theta}^x\right)^{*\prime}\cdot k} = N.$

A special case of the Full Survival Scenario is the situation where there are no new firms producing y, which means all firms produce both products. Conditions

2 and 3 are sufficient for this special case. The discussion for the general case of the Full Survival Scenario still applies, but with N replacing $\hat{n}^x$.

CONDITION 4. $(\theta^x, \theta^y) \epsilon \{(\theta^x, \theta^y) | 1 \leq \hat{n}^x(\theta^x) < \hat{n}^y(\theta^y) \leq N\}$.

Full Exit Scenario.— In this scenario none of the firms producing x also produce y. Condition 4 is a sufficient condition for this scenario. In effect the degree of heterogeneity for each product is sufficiently low that the number of firms producing x plus the number of firms producing y is less than N, which means that no firm produces both. No x-producing firm adapts and none build adaptive capacity.

CONDITION 5. $(\theta^x, \theta^y) \epsilon \{(\theta^x, \theta^y) | 1 \leq \hat{n}^y(\theta^y) < \hat{n}^x(\theta^x) \leq N\}$.

Partial Survival Scenario.— In this scenario some, but not all of the firms producing x also produce y. Condition 5 is a sufficient condition for this scenario as it ensures that the degree of heterogeneity for x or y is great enough for at least one of the products to ensure overlap in firms, i.e., firms from $\hat{n}^y$ through $\hat{n}^x$ produce both products, firms 1 through $\hat{n}^y$ produce only x, and firms from $\hat{n}^x$ through N produce only y.

Only the x-producing firms -- from $\hat{n}^y$ through $\hat{n}^x$ -- incur costs of adaptation and have an incentive to build adaptive capacity. The number that do build adaptive capacity, and their amounts of investment, depend upon the relative locations of $\hat{n}^a$, $\hat{n}^x$, and $\tilde{n}^x$. When $\hat{n}^a > \hat{n}^x$ and $\tilde{n}^x > \hat{n}^x$, then all of the x and y-producing firms build adaptive capacity and choose the internal solution, i.e. $a_n{}^* = -\frac{f'^{-1}\left(\frac{w}{N^+ - n}\right)}{\alpha}$. When $\hat{n}^a > \hat{n}^x$ and $\hat{n}^x > \tilde{n}^x$, all of the x-and-y-producing firms build adaptive capacity, but only firms $\hat{n}^y$ through $\tilde{n}^x$ choose the internal solution for $a_n{}^*$. Firms from $\tilde{n}^x$ through $\hat{n}^x$ choose lower levels of adaptive capacity, namely $a_n{}^* = -\frac{f'^{-1}\left(\frac{p^*+p^{*\prime}\cdot x^*}{N^+-n}\right)}{\alpha}$. Then when $\hat{n}^x > \hat{n}^a$ and $\hat{n}^a > \tilde{n}^x$, only firms $\hat{n}^y$ through $\hat{n}^a$ create adaptive capacity. Firms $\hat{n}^y$ through $\tilde{n}^x$ choose the internal solution for $a_n{}^*$ and firms from $\tilde{n}^x$ through $\hat{n}^a$ choose lower levels of adaptive capacity.

Observations 1-4 summarize our findings from our simple model.

OBSERVATION 1. *More homogeneity in x lowers the amount of profit maximizing adaptive work and adaptive capacity for the following reasons.*

OBSERVATION 2. *More homogeneity in y causes fewer firms to adapt and produce y in the Partial Survival Scenario. The degree of homogeneity in y does not affect an individual y-producing firm's investment in adaptive capacity.*

OBSERVATION 3. *Exiting, adapting and surviving, building adaptive capacity, not building adaptive capacity, and entering only the new product market are all consistent with adaptive efficiency.*

OBSERVATION 4. *When a firm is building adaptive capacity, its average total cost is higher than it would be otherwise, giving the illusion of x-inefficiency.*

II. The Natures of Adaptive Change and Adaptive Capacity

We now turn our attention to details of adaptation and adaptive capacity for individuals and institutions. Part A describes the literature that underlies our model, which we present in Part B. More specifically, Part A shows: (1) Decision-making is constrained by TEAM; (2) It is optimal for people and institutions to develop BHMNs to address the TEAM constraints; (3) Being an expert implies that a person's cognitive and affect habits are aligned with his or her work, and an expert institution's systems and norms are aligned with the organization's purpose, as are the cognitive and affect habits of the individuals in the institution; (4) The work of adaptation includes the awareness of novel experiences and the realignment of BHMNs to changed circumstances, and this work consumes scarce resources; (5) More specialized persons and institutions have higher costs of adaptation than do those that are more general in their abilities; and (6) Decisions to devote energy and mental capacity to adaptation are sometimes made below the level of conscious awareness using mental algorithms that may be costly to modify.

A. Adaptation and Capacity

We begin by describing how the mind makes decisions and adapts. Next we examine individuals' mental and energy limits and how they constrain adaptation. We then describe how individuals make decisions above and below thresholds of conscious awareness. Lastly we incorporate individual adaptive activity and constraints into a theory of adaptation for institutions.

Individual mental adaptation. — Adaptation in individuals involves changing both cognitive and affect processes. Regarding cognitive processes, North (2005) observes that each individual constructs a belief system that embodies mental constructs – his or her internal representation of the human landscape – about the political, economic, social, and natural context in which the individual believes he finds himself. These constructs affect how a person perceives and reacts to sensory data – visual, auditory, etc. – that he receives, as well as which data the person takes in[16] and which data he ignores. (Heifetz 1994, North 2005) These

[16] As we explain later in this section, some data is taken in and processed without conscious awareness by the individual.

mental constructs may include heuristics, although some heuristics may hard wired and thus unchangeable in an individual.

Adaptation involves changing these mental constructs, which are embedded in automatic cognitive processes. CLP (2005) explain that there are both automatic and controlled cognitive processes. Automatic cognition is fast and engages in pattern recognition and, because it requires less subjective effort than other mental processes, is used to engage in activities that the individual implicitly believes are known. Automatic cognition is good at modeling familiar situations, making short-term predictions, and making swift and generally appropriate initial reactions to challenges.[17] (Kahneman 2011) For example, an expert professional athlete relies largely on automatic processes (Gobet and Simon 1996) and the athlete's affect processes make decisions without the experience of high levels of emotion or effort. (CLP 2005) Athletes often describe the experience as being in the zone. Although an expert may direct substantial amounts of energy to the activity, no energy is needed to focus attention. (Kahneman 2011)

The act of learning a new sport or of new tactics in playing a known sport requires controlled processes. Controlled processes are serial and thoughtful, giving the subjective feeling of effort. A person uses controlled cognition when he or she believes an experience is unusual and so must think about what it is and what it means.[18] (CLP 2005) This would include processing unexpected data, such as the facts of a novel experience, and modifying automatic processes to gain expertise. Expertise is developed over time and when someone lacks a reference

[17] Automatic processes include some aspects of what Heifetz (1994) and North (2005) consider the what-is norms that the person adopts.

[18] Some choices to devote energy to cognition are conscious, but many are automatic and based upon biology and how these automatic processes are shaped over time. (CLP 2005; Kahneman 2011)

in an automatic system, he or she seems flat-footed, responds with greater emotion, and must use controlled processes to develop responses.[19] (CLP 2005)

While cognitive processes answer the question, "What is?" Individuals also form affect beliefs about relevance, answering the question, "What does this mean to me?" (North 2005) For example, cognitive processes can identify that an object barreling towards a pedestrian is a car and that the pedestrian could be killed, but it is the affect that provides valuation, such as concluding that injury is bad and worth physical effort to avoid. Affect processes are both automatic and controlled, meaning that an individual can change an affect response. (CLP 2005) Cognition and affect interact for experiencing differences in specific emotions and for altering the appraisal of an experience. (Schimmack and Crites 2005)

Decision-making almost always involves an interplay between controlled and automatic processes, and between cognitive and affect processes. The choice of which processes to use is a choice of degree and rarely excludes one of the processes. (CLP 2005)

Energy and mental capacity limits.— Cognitive effort, both automatic and controlled, requires energy and mental capacity, such as working memory and the amount of interconnections between intelligence centers of the brain.[20] (Just and Carpenter 1992; Hilger et al. 2017) Automatic processes use fewer of these mental resources than controlled processes for a given act, which is why an individual seems more productive when doing something in which he or she is an expert than in other circumstances.

[19] Our automatic and controlled dichotomy appears to parallel Kahneman's System 1, which he calls an "automatic system", and System 2, which he calls the "effortful system". (Kahneman 2011) A distinction between his characterization and ours is that we separate affect processes and cognitive processes, which he appears to group within each of his two systems.

[20] Some personal energy may be transferred forward from one production period to another, such as when a person rests. We omit this possibility to simplify our analysis.

At any point in time an individual has only limited amounts of energy and mental capacity and people vary in these endowments, as well as the efficiency with which they use energy for cognitive processes. (Chabris and Simons 2010; Kahneman 2011; Hilger et al. 2017) There are multiple demands on these limited resources. One is the work of producing current products, which we call labor,[21] which is a conscious choice that requires subjective effort.[22]

Affect also consumes energy. Affect is comprised of many systems, each of which has a different functional purpose and gives rise to different feelings. (LeDoux 1998) Responses to risk and ambiguity are two such responses. The brain responds negatively to risk, but it responds with even greater disapproval to ambiguity, which can be triggered by novel experiences.[23] (Hsu et al. 2005; Lo and Repin 2002)

When data are received, affect acts before cognition, creating the possibility of affect commanding all available energy, such as when a person loses emotional control or freezes with fear, keeping the logical-deliberative cognitive systems from regulating behavior. (LeDoux 1998; CLP 2005) This happens because the pathways between the neuro centers for senses and the neuro centers for affect are shorter than those connecting senses with analytical centers. The subjective experience is that emotions happen to the person (CLP 2005; Schimmack and Crites 2005) and that he or she has little direct control (LeDoux 1998). Thus the

[21] There are other possible activities, such as leisure, but we omit these for simplicity.

[22] A person has at least two pools of energy in any production period. One pool is physical energy and is available for production effort, but not for mental work. The other pool is available for both. Production necessarily draws from both pools such that devoting all of the second pool to mental work effectively stops production. We reach this conclusion based on empirical research that has shown: (1) Trying to regulate one's emotional response to an upsetting movie decreases physical stamina; (2) Suppressing forbidden thoughts leads people to \to give up quickly on unsolvable anagrams; and (3) Suppressing thoughts impair efforts to control the expression of amusement and enjoyment. (Muraven, Tice, and Baumeister 1998) It is unclear from research that physical and mental energy are distinct, so we combine them into a single expression.

[23] In some individuals novelty also triggers arousal, which provides emotional excitement and rewarding stimuli. (Berlyne 1960) Individuals sometimes experience this as a higher level of energy, but we interpret the arousal as a less negative disutility of effort for addressing novel experiences.

brain manages the amount of energy consumed by affect based upon processes that are beyond conscious decision making in the initial moment. (Hofmann, Schmeichel and Baddeley 2012) These processes are shaped by experiences and by the subjective effort that the person exerts to modify the processes. Changing these processes, as well as changing automatic cognitive processes, takes energy, time and repetition. (CLP 2005)

Choosing between automatic and controlled cognition. — Because adaptation engages controlled processes that consume more energy and mental capacity than automatic processes, it is important to understand how the mind chooses between automatic and controlled.

The choice sometimes occurs below the conscious awareness of the individual, so while it is true that the person uses automatic cognitive processes based on the belief that the situation is known, this is sometimes not a conscious choice on the part of the individual person. (Kahneman 2011) Indeed it is hard work for a person to override automatic processes with controlled processes because they compete for mental resources and attention, and the automatic processes get there first. (Gilbert 2002; Hofmann, Schmeichel and Baddeley 2012) To override automatic processes, such as when confronting a novel experience, the cognitive controlled processes must recognize that an initial impression is wrong and then deliberately correct the impression. This holds even when the novel experience is obvious and it is clear that the automatic response is inappropriate, and when the person has prior warning. (Gilbert 2002; CLP 2005)

The methods and criteria used to allocate energy between automatic and controlled cognition are not completely understood. What appears to be known is that the decision criteria conserve mental energy while maintaining mental effort. (Kool, McGuire, Rosen and Botvinick 2010) At the time energy is allocated between automatic and controlled processes it is unknown whether the opportunity cost of the energy devoted to controlled processes is less than the value of a more optimal decision, including the cost of the decision delay that results from the time consumed by controlled processes. The decision-making process balances a motive to maximize gains with a motive to conserve decision costs. This view helps explain such behavioral phenomena as effort-accuracy tradeoffs, reliance on fast and frugal heuristics, failures to consider all available alternatives, and the use of stereotypes. Because brains are energy conserving, people show a tendency to avoid making decisions that are computationally demanding and subjectively effortful, even if the choices are not intentional. (McGuire and Botvinick 2010)

Adaptation alters the heuristics used to make these tradeoffs and the automatic processes themselves. Hofmann and Wilson (2010) explain that this requires self-insight into mental experiences, which is often poor. As a result, the outcomes of adaptive work are uncertain.

Institution efficiency and adaptation. — An institution is technically efficient if: (1) Its norms are aligned with its purpose, which minimizes the amount of effort and acquired inputs that are needed to accomplish the purpose; (2) The institution encompasses people who are adapted to the norms such that their individual effort is minimized for the accomplished production; and (3) The norms align with external realities. Like an expert athletic team, the expert organization coordinates seemingly without effort as formal and informal norms are well understood and followed throughout the organization.

But when there is a change in economic circumstances, the established norms no longer align with reality. This misalignment causes the organization to be less effective even though the individuals may follow the norms perfectly.

An enterprise adapts to the new circumstances when its systems and personnel adapt. Therefore, for an organization to adapt at least some individuals must engage in the work of understanding the changed circumstances (awareness and learning), some must decide and manage the changes in formal norms (systems change), and all persons must change their individual beliefs and expertise (individual adaptation).

These three aspects of institutional adaptation consume resources and may meet with resistance. Novel experiences from changed circumstances are sometimes misinterpreted as anomalies and the organization may marginalize or dismiss the persons who call attention to the novel experiences and advocate for change. Once the organization's decision makers determine that circumstances have changed, it takes time and resources to determine an appropriate response and implement the chosen changes. There are also personal costs that may become part of the institution's costs: Changing institutional norms creates the potential for personal losses when, for example, the institutional change involves changed relationships and changed prominence of particular roles. (Heifetz 1994)

Adaptive capacity.— In our model, an institution's adaptive capacity includes devoting resources to organizational awareness of novel experiences, the adaptability of system design, and the capacity to alter norms. Organizational awareness includes dedicating individual energy for at least some persons to watching for novel experiences and maintaining norms that provide channels for communicating the experiences to others in the organization. Some systems for organizing production are more costly to change than others. In systems where the technical work is highly integrated and specialized, changing one aspect may trigger numerous changes in other steps of the production process. Similarly in systems where individuals derive personal value from their specific roles and relationships, changes can trigger negative affect that diverts energy from productive work.

In Section I we described adaptive capacity as something affecting the cost of adaptation. We now formalize a definition.

DEFINITION 7. ***Adaptive capacity*** *determines the cost to an individual or a firm to observe and assess the gap between beliefs and reality, and the cost of closing the gap, such that greater adaptive capacity results in lower costs of assessing and changing.*

Some adaptive changes are more costly than others, depending on the nature of the institution and whether the pre- and post-change environments' strongly or weakly favor highly specialized firms over more generalist firms. Henderson and Clark (1990) explain that technology changes that require changes to firm architecture are harder to make because architectural knowledge is embedded in routines and communications channels are costly to change. Aggarwal and Wu (2015) find that higher degrees of coordination within a firm raise its costs of adaptation.

Adaptation in economic systems has parallels in biology. Research in evolutionary biology finds that the more specialized a species, the less adaptive it is to changed circumstances. For example, a specialized species of animal might consume only vegetation type A for its diet, while a more generalist species consumes types A through F. If a drought were to largely kill off A for a season, the specialized animal species dies off, but the generalist adapts. Also, habitats vary in whether they support specialist species or generalist species. For example eucalyptus tree leaves are low in energy and toxic to many species, favoring the presence of a highly adapted koala bear that faces almost no competition for the food source, but that is also ill suited for any other food source. (Devictor, Julliard and Jiguet 2008; Futuyma and Moreno 1988)

B. Model and Analysis

We examine a game in which firms maximize individual profit over time given a constant discount rate δ, which is the same for all firms. There are $\bar{t}$ production periods. Similar to our simple model, during periods 1 through t^c, customers buy product x. They buy product y for the remaining periods. We design our model to examine how firms allocate scarce resources to determine whether and how much to produce, to prepare for the product change, and to adapt to the product change.

More formally there are opening moves by nature and then firms. In its move, nature chooses t^c, $\bar{t} > t^c > 1$; $t^s < t^c$, which is the time at which nature provides a signal about t^c (we explain this more below); θ^i $i \in \{x, y\}$, which represents the degree of heterogeneity of products as in the simple model, $\overline{\theta}^i > \theta^i > 0$; and each firm's employee mix, which we describe next. Firms can observe θ^i and each firm's employee mix, but not t^s and t^c.

There are N firms at the start of the game, each with the same number of employees, which we normalize to 1. Employees differ in their production and adaptation capabilities. A specialist employee, which we denote as S, requires less energy to produce x than does a more generalist employee, which we denote as G. Furthermore a generalist requires less energy to build adaptive capacity and to adapt to changed circumstances than does a specialist. Nature assigns each firm $1 \geq g(n) \geq 0$ generalist employees, which for convenience we treat as a continuous variable that is linearly increasing in n and that $g(1) = 0$ and $g(N) = 1$.

As in the simple model, the demand for x_n is given by a well-behaved, continuous inverse demand function $p_n(\theta^x, \mathbf{z}, \boldsymbol{X}_t) \geq 0$, $\phi_n(\theta^y, \mathbf{z}, \boldsymbol{Y}_t) \geq 0$ is the continuous inverse demand function for y_n, marginal revenue is increasing in θ^i at a decreasing rate, and the effects of θ^i on marginal revenues are uniform across firms. Because y represents a technology advancement over x, we assume that customers value y more than they do x, all other things being equal, and that if x and y were both offered in the same time period, in equilibrium consumers would choose y.

After nature moves, each firm chooses its organizational architecture for producing x, resulting in a one-time fixed cost $T_n \in \{\underline{T}, \overline{T}\}$, where $\overline{T} > \underline{T} > 0$. $\underline{T}$ represents a more specialized architecture and $\overline{T}$ represents a more general architecture. Organizational architecture affects costs of adaptation at time t^c. Let $C_n \equiv C(T_n, A_{n,t})$ represent the one-time fixed costs of adapting to produce y, where $A_{n,t}$ is the firm's adaptive capacity at time t for converting to producing y (as in the simple model), but is now defined as $A_{n,t} \equiv A_{G,n,t} + A_{S,n,t}$, where $A_{G,n,t} \equiv \sum_{\hat{t}=1}^{t} g(n) \cdot a_{G,n,\hat{t}}$, $A_{S,n,t} \equiv \sum_{\hat{t}=1}^{t} (1 - g(n)) \cdot a_{S,n,\hat{t}}$, and $a_{j,n,t}$ is the amount of energy that n requires employee type $j = \{G, S\}$ to devote to building adaptive capacity during period t. $C(\underline{T}, A_{n,t}) > C(\overline{T}, A_{n,t})$, all other things being equal, and $\frac{\partial C}{\partial A_{n,t}} < 0$ and $\frac{\partial^2 C}{\partial A_{n,t}{}^2} > 0$. T_n has no impact on the marginal effects of $A_{n,t}$ on C.

Within each production period, firms individually and simultaneously decide whether to produce and how to allocate employees' energy between production, building adaptive capacity, and engaging in adaptive work, subject to a limit $\overline{E} > 0$, which represents a homogenous energy endowment for each employee that is the same in each production period. Let $e_{j,n,t}^{i}$ represent the amount of energy that firm n requires employee type j to devote to the production of $i \in \{x, y\}$ in time period t.

$i_{j,n,t} \equiv i(e_{j,n,t}^{i}, v^i)$ represents how energy for production results in output, where $v^i(D_{j,n,t}^{R})$ is the effectiveness of the employee's norms and beliefs for producing i at time t. We assume that $\frac{\partial i_{j,n,t}}{\partial e_{j,n,t}^{i}} > 0$, $\frac{\partial^2 i_{j,n,t}}{\partial e_{j,n,t}^{i}{}^2} < 0$, $\frac{\partial i_{j,n,t}}{\partial v^i} = 1$, and $\frac{\partial^2 i_{j,n,t}}{\partial e_{j,n,t}^{i}\, \partial v^i} = 0$. We represent the norms and beliefs of employee type j in firm n at time t as a vector $\boldsymbol{\beta}_{j,n,t} \in \mathbb{R}^m$. To focus our analysis on the impacts of changed circumstances, we assume that employees' beliefs and norms do not change prior to t^c, i.e., $\boldsymbol{\beta}_{j,n,t} = \boldsymbol{\beta}_{j,n,1}$ for all $t < t^c$. We define $D_{j,n,t}^{R} \equiv \left\| \boldsymbol{\beta}_{j,n,t} - \boldsymbol{\beta}_{R,t} \right\|$ as the distance between the employee's beliefs and reality, $\boldsymbol{\beta}_{R,t} \in \mathbb{R}^m$. The distance function measures how far the employee is from believing and functioning in perfect alignment with reality, so $v^i\left(D_{j,n,t}^{R}\right)$ is decreasing in $D_{j,n,t}^{R}$. For simplicity, we assume $v^{i'} = -1$. Also, at the start of the game the specialist functions more closely in line with reality than does the generalist, i.e., $D_{G,n,1}^{R} > D_{S,n,1}^{R}$. As we describe below, a closer alignment between beliefs and reality results in more effective norms.

$\boldsymbol{\beta}_{R,t}$ changes when customers change from purchasing x to purchasing y, but does not change at any other time in our model. As a result $D_{j,n,t}^{R} = D_{j,n,1}^{R}$ for all $t < t^c$. We denote reality before the change as $\boldsymbol{\beta}_{R,1}$ and reality after the change as $\boldsymbol{\beta}_{R,t^c}$. Firms cannot directly observe reality except at a prohibitively high cost, but can observe indicators regarding the nature of the change. One indicator is the change in customer buying habits. Another is a change in employee productivity -- i.e., the amount of product produced for a given amount of energy devoted to production – if that happens. A third is employees' emotional responses to the change. We discuss the productivity and emotional indicators next.

When customers change from purchasing x to purchasing y, the distance between employees' beliefs and reality changes from $D_{j,n,1}^{R}$ to D_{j,n,t^c}^{R}. We focus on situations where the change is disruptive, so we assume that $D_{j,n,t^c}^{R} > D_{j,n,1}^{R}$. Also, recalling that generalist employees are more adaptable than specialist employees, we assume that $D^R_{S,n,t^c} - D^R_{S,n,1} > D^R_{G,n,t^c} - D^R_{G,n,1}$ for all n. A firm knowing its choice e^y_{j,n,t^c} and the functional forms of $y(e^y_{j,n,t}, \nu^y)$ and $\nu^y(D^R_{j,n,t})$ can deduce $D^R_{j,n,t^c} - D^R_{j,n,1}$. So it knows how the change in reality has affected its employees' alignments, but does not know the location of the new reality in $\mathbb{R}^m$.

Let $d^y_{j,n,t}$ represent the amount of energy that firm n requires employee type j to devote to adapting to the production of y in time period t.[24] A firm observing a change in alignment at period t^c can seek to increase $\nu^y(D^R_{j,n,t})$ by choosing $d^y_{j,n,t} > 0$ for $t > t^c$ since it may affect alignment as we describe in the next paragraph. However, expending energy for adaptive learning does not ensure that the learning occurs (Hofmann and Wilson 2010) because learning may involve reshaping values, which some employees hold tightly because it feels wrong to change them (Heifetz 1994), or may require rethinking basic understandings of how things work, which Byers (2014) explains taps into a non-sequential thinking system that may or may not give results. So the effort invested at time t may not result in a change in beliefs and norms. And even if the effort does transform $\boldsymbol{\beta}_{j,n,t}$ to $\boldsymbol{\beta}_{j,n,t+1}$, there is no assurance that $\|\boldsymbol{\beta}_{j,n,t} - \boldsymbol{\beta}_{R,t^c}\| > \|\boldsymbol{\beta}_{j,n,t+1} - \boldsymbol{\beta}_{R,t^c}\|$ because, for example, some of the changed beliefs and norms may move in the wrong direction given the uncertainty of the location of $\boldsymbol{\beta}_{R,t^c}$.[25]

We address this uncertainty in the effects of energy directed to adaptive learning by assuming that $\frac{\partial D^R_{j,n,t}}{\partial d^y_{j,n,t}} < 0$, $\frac{\partial^2 D^R_{j,n,t}}{\partial {d^y_{j,n,t}}^2} > 0$, with probability $\rho^d(A_{n,t^c}) = [0,1]$, which is known to all firms, and is 0 otherwise. $A_{n,t^c} \equiv g(n) \cdot A_{G,n,t^c} +$

[24] We omit the option to engaging in adaptive learning to improve productivity while producing x to focus on the adaptive issues that arise when circumstances change.

[25] It is also possible that the changed beliefs and norms are farther away from reality if mistakes are made in the learning process. We omit this possibility to simplify our analysis.

$(1 - g(n)) \cdot a_{S,n,t^c}$. For simplicity we assume that once a firm observes whether the effect is zero, the effect either stays zero or stays zero or negative for the remaining production periods.

Empirical research has shown that there is the possibility that change may induce emotional flooding. We address this by assuming that if the nature of the change is so emotional that employees flood, there is a drain on equal to $\overline{E}$. The probability of this being true for firm n is $\rho^E(A_{n,t^c}) = [0,1]$, which is known to all firms.

We assume that at time $t^s < t^c$ nature provides a signal regarding when $t = t^c$. A firm observes the signal if $A_{n,t^s} \geq \hat{A}$, but otherwise does not. Absent seeing the signal, each firm believes correctly that t^c will occur at either $\underline{t}^c$ and $\overline{t}^c$, but does not know when. Each firm assigns an equal probability to each such that each firm has an expected value Et^c. Firms that see the signal update their beliefs about $\underline{t}^c$, but the other firms do not. The other firms can observe changes in the observing firms' behaviors, but do not know the reason for the change.[26]

Normalizing exogenously determined wages to zero, we can now express firm n's objective function, namely maximizing

$$\pi_n{}^y \equiv -C_n + \sum_{t=t^c}^{\overline{t}} \delta^{t-t^c} \cdot \phi_{n,t} \cdot y_{n,t} \qquad (2)$$

for periods t^c through $\overline{t}$. This is subject to $\overline{E} \geq e^y_{j,n,t^c} + d^y_{j,n,t^c} - \overline{E} \; \forall \, j \in \{G,S\}$ for $t = t^c$ if flooding occurs, to $\overline{E} \geq e^y_{j,n,t^c} + d^y_{j,n,t^c} \; \forall \, j \in \{G,S\}$ for $t = t^c$ if flooding does not occur, and to $\overline{E} \geq e^y_{j,n,t} + d^y_{j,n,t} \; \forall \, j \in \{G,S\}$ for periods t^c through $\overline{t}$.[27]

[26] We could formally represent this with a random variable that affects firms at time t^s, that is individualized to each firm, and that is unobservable to firms other than the one

[27] At $t = t^c$, the firms observe $\overline{D}$, so its energy cost is known.

A firm that observes the signal at t^s seeks to maximize

$$\pi_n{}^{x(3)} \equiv -T_n + \sum_{t=1}^{Et^c-1} \delta^t \cdot p_{n,t} \cdot x_{n,t} - C_n + \sum_{t=Et^c}^{\bar{t}} \delta^t \cdot \phi_{n,t} \cdot y_{n,t} \qquad (3)$$

for periods 1 to t^s, and

$$\pi_n{}^{x(4)} \equiv \sum_{t=t^s}^{t^c-1} \delta^{t-t^s} \cdot p_{n,t} \cdot x_{n,t} - C_n + \sum_{t=t^c}^{\bar{t}} \delta^t \cdot \phi_{n,t} \cdot y_{n,t} \qquad (4)$$

for periods t^s to t^c. This is subject to $\overline{E} \geq e_{j,n,t}^x + a_{G,n,t} \,\forall\, j \in \{G,S\}$ for $t = [1, t^c)$, $\overline{E} \geq e_{j,n,t^c}^y + d_{j,n,t^c}^y - \rho^D\left(A_{n,t^c}\right) \cdot \overline{E} \,\forall\, j \in \{G,S\}$ for $t = t^c$, and $\overline{E} \geq e_{j,n,t}^y + d_{j,n,t}^y \,\forall\, j \in \{G,S\}$ and $t = \left(t^c, \bar{t}\right]$.

A firm that that does not observe the signal at t^s seeks to maximize (3) for periods 1 to t^c if $t^c = \underline{t}^c$. If $t^c = \bar{t}^c$, then the firm that does not observe the signal seeks to maximize (3) for periods 1 to $\underline{t}^c$ and then seeks to maximize

$$\pi_n{}^{x(5)} \equiv \sum_{t=\underline{t}^c}^{t^c-1} \delta^{t-\underline{t}^c-1} \cdot p_{n,t} \cdot x_{n,t} - C_n + \sum_{t=t^c}^{\bar{t}} \delta^t \cdot \phi_{n,t} \cdot y_{n,t} \qquad (5)$$

for periods $\underline{t}^c$ to t^c. This is subject to $\overline{E} \geq e_{j,n,t}^x + a_{G,n,t} \,\forall\, j \in \{G,S\}$ for $t = [1, t^c)$, $\overline{E} \geq e_{j,n,t^c}^y + d_{j,n,t^c}^y - \rho^D\left(A_{n,t^c}\right) \cdot \overline{E} \,\forall\, j \in \{G,S\}$ for $t = t^c$, and $\overline{E} \geq e_{j,n,t}^y + d_{j,n,t}^y \,\forall\, j \in \{G,S\}$ and $t = \left(t^c, \bar{t}\right]$.

Using backwards induction, we now examine decision-making for firms optimizing (2). Because energy has zero opportunity costs outside the model, $\overline{E}$ is always binding. A firm's choice of how to distribute energy is given by

$$\frac{\partial y_{n,t}}{\partial e_{j,n,t}^y} = \frac{-\sum_{\hat{t}=t}^{\bar{t}} \delta^{\hat{t}-t} \cdot \frac{\partial D_{j,n,t}^R}{\partial d_{j,n,t}^y} \cdot \left(\phi_{n,\hat{t}} + \phi_{n,\hat{t}}{}' \cdot y_{n,\hat{t}}\right)}{\phi_{n,t} + \phi_{n,t}{}' \cdot y_{n,t}} - \frac{\partial D_{j,n,t}^R}{\partial d_{j,n,t}^y} \qquad (6)$$

Proof (to be in reviewer notes).

FOCs give $\frac{\partial \pi_{n,t}}{\partial e_{j,n,t}^y} = \phi_{n,t} \cdot \frac{\partial y_{n,t}}{\partial e_{j,n,t}^y} + \phi_{n,t}{}' \cdot \frac{\partial y_{n,t}}{\partial e_{j,n,t}^y} \cdot y_{n,t}$ and $\frac{\partial \pi_{n,t}}{\partial d_{j,n,t}^y} = \phi_{n,t} \cdot \frac{\partial y_{n,t}}{\partial v^y} \cdot \frac{\partial v^y}{\partial D_{j,n,t}^R} \cdot \frac{\partial D_{j,n,t}^R}{\partial d_{j,n,t}^y} + \phi_{n,t}{}' \cdot \frac{\partial y_{n,t}}{\partial v^y} \cdot \frac{\partial v^y}{\partial D_{j,n,t}^R} \cdot \frac{\partial D_{j,n,t}^R}{\partial d_{j,n,t}^y} \cdot y_{n,t} + \sum_{\hat{t}=t}^{\bar{t}} \delta^{\hat{t}-t} \cdot \Bigg(\phi_{n,\hat{t}} \cdot \frac{\partial y_{n,t}}{\partial v^y} \cdot \frac{\partial v^y}{\partial D_{j,n,t}^R} \cdot$

$\frac{\partial D^R_{j,n,t}}{\partial d^y_{j,n,t}} + \phi_{n,\hat{t}}{}' \cdot \frac{\partial y_{n,t}}{\partial v^y} \cdot \frac{\partial v^y}{\partial D^R_{j,n,t}} \cdot \frac{\partial D^R_{j,n,t}}{\partial d^y_{j,n,t}} \cdot y_{n,\hat{t}} \Big)$, which simplifies to $-\frac{\partial D^R_{j,n,t}}{\partial d^y_{j,n,t}} \cdot \big(\phi_{n,t} + \phi_{n,t}{}' \cdot y_{n,t}\big) - \sum_{\hat{t}=t}^{\bar{t}} \delta^{\hat{t}-t} \cdot \frac{\partial D^R_{j,n,t}}{\partial d^y_{j,n,t}} \cdot \big(\phi_{n,\hat{t}} + \phi_{n,\hat{t}}{}' \cdot y_{n,\hat{t}}\big)$. These FOCs imply $\frac{\partial y_{n,t}}{\partial e^y_{j,n,t}} = \frac{-\sum_{\hat{t}=t}^{\bar{t}} \delta^{\hat{t}-t} \cdot \frac{\partial D^R_{j,n,t}}{\partial d^y_{j,n,t}} \cdot (\phi_{n,\hat{t}} + \phi_{n,\hat{t}}{}' \cdot y_{n,\hat{t}})}{\phi_{n,t} + \phi_{n,t}{}' \cdot y_{n,t}} - \frac{\partial D^R_{j,n,t}}{\partial d^y_{j,n,t}}$. QED

From (6) we can see that a firm optimally engages in adaptive learning for all periods.

[THIS IS WHERE OUR ANALYSIS IS AS OF MARCH 30. WE EXPECT THE FOLLOWING TO HOLD.]

More firms will produce y hold for higher levels of θ^y and $\bar{t}$, and lower levels of t^c, consistent with our findings in the simple model.

Firm can receive negative profits in period t^c as long as the positive profits in periods t^c through $\bar{t}$ compensate by enough to cover fixed costs and the costs of adaptation.

A more specialized firm architecture for producing x results in a higher $C_n{}^*$, making it less likely that a firm will produce y.

A firm will choose to not invest in adaptive work nor in building adaptive capacity for sufficiently few production periods for the new product and for sufficiently high product homogeneity for the new product.

A firm with a more specialized production architecture is less likely to produce the new product than is a firm with a more general architecture, all other things being equal.

The choice between investing energy in production and energy in adaptive work results in the less production in early periods than in each subsequent period because the value of marginal revenues declines as the $\bar{t}$ comes closer.

A firm choosing to produce the new product will appear less x-efficient in the production period than in subsequent periods because its production costs are the same, but its output is lower. However, the firm is minimizing costs.

Firms investing in adaptive capacity produce less x per period than other firms, all other things being equal, because of the tradeoffs between energy used for production and energy used for building adaptive capacity. Therefore, they have smaller market shares in x than they would otherwise.

More specialized firms for producing x produces more x than their rivals, but invests in less adaptive capacity than they do because the marginal costs of doing so are higher. They are also less likely to produce y than are other firms, all other things being equal.

More generalized firms are more likely to produce y because their marginal costs of adaptive work and of building adaptive capacity are lower, all other things being equal. They also produce less x than the other firms. Furthermore, there is a level of θ^x below which generalized firms will not produce x because revenues will not be sufficient to cover fixed costs.

A highly specialized firm will have a larger market share than its rivals in the initial product market, but is less likely to survive a disruptive technology than a more generalized firm, all other things being equal. If it does survive, its market share will be lower than that of the more generalized firms.

A more generalized firm will have a lower market share in the initial product market compared to its more specialized rivals, but is more likely to produce the new product than are its rivals (all other things being equal) and to have a larger market share in the new product market.

In situations where the initial product is highly homogeneous, only more specialized firms will produce the product, but they may not survive the disruptive technology change.

III. Conclusion

We examine how advances in neuro-economics, behavioral economics, psychology and strategic management provide insights into why firms choose to close rather than adapt to a disruptive technology, or at least decline in market share. We show that the key considerations are the limits that mental capacity, mental energy and specialization place on firms' abilities to adapt. We show that these limits lead to situations where firms that are most successful in initial markets are less successful after the disruptive change. We also show that some firms find it optical to invest in adaptive capacity while producing the initial product in order to increase profits in the subsequent market.

We do not explore challenges that firms face if employees adapt at different paces, nor the effects of uncertainty as to whether or when a disruptive technology might be introduced. We also do not explore the effects that government regulations might have on firm adaptation.

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