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Vertical Scope, Turbulence, and the Benefits of Commitment and Flexibility

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We address the contested state of theory and the mixed empirical evidence on the relationship between turbulence and vertical scope by studying how turbulence affects the benefits of commitment from integrated development of components and the benefits of flexibility from sourcing components externally. We show that increasing turbulence first increases but then decreases the relative value of vertical integration. Moderate turbulence reduces the value of flexibility by making supplier selection more difficult and increases the value of commitment by mitigating the status quo bias of integrated structures. Both effects improve the value of integration. Higher levels of turbulence undermine the adaptive benefits of commitment, but have a less adverse effect on flexibility, making nonintegration more attractive. We also show how complexity and uneven rates of turbulence moderate the nonmonotonic relationship between turbulence and integration.

Keywords: turbulence; vertical integration; commitment; flexibility; adaptation; NK model
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1. Introduction

Firms face a trade-off between commitment and flexibility in managing environmental and technological uncertainty (Wernerfelt and Karnani 1987, Toh and Kim 2013). The value of commitment comes from specializing in and refining a particular technological option. Conversely, flexibility is valuable because it allows a firm to pursue multiple options in parallel. This trade-off has important implications for the vertical scope of a firm. Vertical integration implies the commitment to a single internal technology supplier, facilitating coordinated technological adaptation (Williamson 1991, Kogut and Zander 1996, Nickerson and Zenger 2004). Market-based nonintegration provides for multiple external suppliers and favors autonomous adaptation (Balakrishnan and Wernerfelt 1986, Geyskens et al. 2006). Choosing one of the two is especially challenging in environments requiring constant adaptation because of technological and environmental uncertainty. Prior work identified two distinct sources of uncertainty: turbulence and complexity (Siggelkow and Rivkin 2005). Turbulence changes the link between technological attributes and performance and thereby often erodes the value of today's superior technological configuration (McCarthy et al. 2010). Complexity contributes to uncertainty because ill-understood interdependencies complicate the development of superior technologies (Levinthal 1997, Rivkin 2000, Sommer and Loch 2004).

The broad contours of how the two sources of technological uncertainty affect the vertical scope of the firm seem straightforward. Turbulence rewards market-based flexibility and the ability to respond quickly to technological changes by switching external suppliers, whereas complexity calls for a commitment to coordinated adaptation and sustained refinement through vertical integration (Walker and Weber 1984, Balakrishnan and Wernerfelt 1986, Heide and John 1990, Folta 1998, Geyskens et al. 2006, Almirall and Casadesus-Masanell 2010). The empirical literature finds strong support for the claim that higher technological complexity leads to vertical integration (David and Han 2004, Geyskens et al. 2006, Lafontaine and Slade 2007, Kapoor and Adner 2012). However, the evidence on turbulence is considerably less clear (David and Han 2004, Carter and Hodgson 2006). Sorenson (2003) showed that increased turbulence in the workstation industry benefitted vertically integrated firms (see Carson et al. 2006 for similar findings on R&D outsourcing). In contrast, Walker and Weber (1984), in the automotive industry, and Balakrishnan and Wernerfelt

(1986), across a sample of industries, found the opposite effect. Indeed, recent metastudies on the performance effects of vertical integration came to opposite conclusions: Geyskens et al. (2006) claimed support for turbulence leading to less integration; Lafontaine and Slade (2007) found the reverse.

The inconclusive empirical evidence reflects the contested state of theory development on the trade-off between flexibility and commitment in turbulent settings. Balakrishnan and Wernerfelt (1986) argued that market-based contracting is superior because firms retain the flexibility to switch suppliers with higher-performing technologies and may adapt quickly to technological changes. They thereby also avoid being locked into a technology that becomes obsolete (Heide and John 1990, Geyskens et al. 2006). By contrast, Williamson (1991, p. 292) claimed that very high levels of technological turbulence undermine market contracting by increasing the value of coordinated adaptation through integration, especially if technologies are complex. Similarly, Sorenson (2003) pointed to the benefits of hierarchical adaptation in turbulent settings because development efforts across technologies can be coordinated, thereby increasing the predictability of changes.

We reconcile these conflicting theoretical perspectives and address the mixed empirical evidence by highlighting two important mechanisms that influence the differential benefits of flexibility and commitment. First, although markets provide for multiple external technological options, these solutions must be identified and evaluated efficiently for rapid adaptation (Sutcliffe and Zaheer 1998, Hoetker 2005). Turbulence degrades the knowledge about the pool of suppliers and their technologies. Yesterday's preferred supplier may not be competitive today. Hence, turbulence lowers the value of flexibility when the identification and evaluation of suppliers is nontrivial. Second, turbulence can increase the benefits of commitment by mitigating the exploitation bias of coordinated adaptation. A drawback of vertical integration is the commitment to the solution provided by the internal component supplier. Turbulence may prevent an integrated firm from lock-in to an inferior solution. To study these two mechanisms, we develop a model based on the NK model that is widely used in the analysis of organizational adaptation (Levinthal 1997, Rivkin 2000, Ethiraj and Levinthal 2004a). The model features two vertical stages of component development that together determine the performance of a focal firm. The model structure allows us to study how turbulence and complexity affect the vertical scope of the firm by considering the relative value of commitment and flexibility. Nonintegration of the two stages corresponds to autonomous adaptation in each component and subsequent selection from multiple external component suppliers. Integration allows for the coordinated adaptation of component development with a single internal supplier. In our model, we do not simply compare the performance of integrated and nonintegrated firms—this would only give us the net effect because moving from integration to nonintegration implies a simultaneous reduction in commitment and an increase in flexibility. Instead, we separate the benefits of commitment and flexibility to isolate the precise mechanisms at play and to derive the intricate effects of turbulence on vertical scope.

Our approach draws on Levinthal and Posen's (2007) distinction of complexity across and within functional departments. They examined variations of coordinated adaptation within a firm (Siggelkow and Levinthal 2003), but did not consider the benefits of flexibility or the influence of turbulence. Marengo et al. (2000), Ethiraj and Levinthal (2004a, b), Frenken (2006), and Brusoni et al. (2007) analyzed the problems of decomposing a complex system into distinct components, whereas Ethiraj et al. (2008) extended the discussion to imitation barriers. We do not consider this problem by assuming that component boundaries are fixed. Sommer and Loch (2004) studied problems of search in complex tasks with unpredictable uncertainty. In our model, firms receive nonnoisy performance signals. Siggelkow and Rivkin (2005) analyzed organization design for both complex and turbulent task environments, but they did not consider the benefits of flexibility and of commitment. Finally, Almirall and Casadesus-Masanell (2010) examined vertical relationships in open innovation processes, but did not distinguish types of complexity and did not consider the impact of turbulence.

Our results show that turbulence has a nonmonotonic effect on vertical scope. Increasing turbulence from an initially stable situation increases the benefit of commitment by diminishing the exploitation bias of vertical integration. Turbulence introduces performance variations that induce the abandonment of inferior solutions and thereby broaden search beyond the immediate neighborhood of the status quo. As turbulence increases further, this benefit loses importance and the disadvantage of being committed to a single supplier comes to dominate. Hence, the benefit of commitment decreases sharply for higher levels of turbulence. Turbulence has a different effect on the benefit of flexibility. Turbulence makes it more difficult to identify and select superior suppliers, thereby reducing the benefit of flexibility, but the effect of a further increase becomes less pronounced the higher the turbulence in the environment. Together, the effects suggest a nonmonotonic relationship between turbulence and vertical scope. Introducing some turbulence to a stable environment makes integration relatively more attractive, whereas for even higher turbulence nonintegration comes to dominate.

We extend this core result by considering how different forms of complexity and uneven rates of turbulence influence the benefits of commitment and flexibility. Although complexity within components decreases the benefits of commitment and increases those of flexibility (thereby pushing the trade-off toward nonintegration), complexity at the interface between components favors integration because the benefits of commitment increase disproportionally. Finally, we find turbulence in one component (and stability in the other) favors integration compared to a setting in which turbulence affects both components. These results are robust to many alternative assumptions about supplier identification, the internal design of vertical relationships, and selection and survival.

2. Model

2.1. Motivation and Assumptions

There is conflicting empirical evidence on the relationship between turbulence and vertical integration. The mixed evidence reflects a contested state of theory development, with two key mechanisms at play. Williamson (1991) and Sorenson (2003) point to the benefits of coordinated responses in the face of environmental changes, whereas Balakrishnan and Wernerfelt (1986) and Heide and John (1990) highlight the inherent flexibility of multiple options in markets and the increased risk of technological obsolescence of integration. Because we are primarily interested in how the respective benefits of commitment and flexibility affect adaptation in turbulent and complex task environments, we draw on the NK model, which has been widely used in theoretical work on organizational adaptation (Levinthal 1997, Rivkin 2000, Ethiraj and Levinthal 2004a).

The NK model is useful for modeling task environments that differ in both complexity and turbulence. It depicts a task environment with N choice attributes affecting performance. The N attributes may be interdependent in performance outcomes. The degree of interdependency is given by parameter K. If $K = 0$, the performance surface of the task environment is smooth with a single global peak of maximum performance. With higher K, the performance surface becomes more rugged with many local optima (Levinthal 1997). Following Rivkin (2000), we restrict our analysis to interdependencies that are ill-understood in their performance implications and thereby contribute to uncertainty. The benefits of cognitive search (Gavetti and Levinthal 2000) are therefore beyond the scope of our model.

We draw on earlier formulations of how external changes affect the performance landscapes (Levinthal 1997, Ethiraj and Levinthal 2004b, Siggelkow and Rivkin 2005). Turbulence is captured as random changes in the performance contributions of attributes (Siggelkow and Rivkin 2005). This approach lets us gradually tune the degree of turbulence in the task environment. Higher turbulence levels are associated with a greater fraction of redrawn performance values and more substantial changes to the task environment.

The intuition of our setup is as follows. We assume that the performance of a technology rests on the combination of components in two distinct stages of production.[1] For example, the success of a video game depends on the activities of game developers that design and code a video game and on the activities of publishers that coordinate production and marketing mix (Inkpen and Tsang 2007, Gulati et al. 2005). We ask how the benefits of commitment and flexibility change depending on the level of turbulence and complexity and focus on two stylized organizational forms, vertical integration and nonintegration of the two stages.

Integration implies the commitment to joint development with an internal supplier and coordinated adaptation of components. This reduces the number of component providers, but the commitment to tight long-term interactions with a supplier enables coordinated adaptation by enhancing communication (Kogut and Zander 1996, Monteverde 1995) and mitigating coordination (Gulati et al. 2005) and cooperation problems (Williamson 1991, Nickerson and Zenger 2004). Our model focuses on two distinct features of this organizational arrangement. First, the number of technological alternatives in each component is lower than in the case of nonintegration (Balakrishnan and Wernerfelt 1986, Rivkin and Siggelkow 2003). Many firms only have one internal supplier for a component. Second, the development effort in both components is coordinated (Lounamaa and March 1987, Williamson 1991, Gulati et al. 2005). Changes in one component are developed and evaluated in terms of its performance implications for the entire system. Prior literature studies how different internal designs facilitate or stifle joint development across components (Siggelkow and Levinthal 2003, Mihm et al. 2010). We model an internal structure that provides for coordination of development activities across departments and that was studied in prior work (Rivkin and Siggelkow 2003, Levinthal and Posen 2007). Specifically, the two components search for improvements in parallel and evaluate alternatives in terms of overall and not just component performance. This setup also takes up the argument by Sorenson (2003) that vertical integration reduces the endogenous rate of change (since alternatives are discarded if they only improve local performance). In the results section, we report how robust our findings are to variations in internal structure.

At the other end of the spectrum is nonintegration of the two components to reap the benefits of flexibility

[1] The term "component" describes any collection of activities and/or technological choices that contribute to a final product. That is, components could also be modules in a systems product or stages in a vertical value chain.

from selecting among multiple alternatives and their parallel development efforts (Balakrishnan and Wernerfelt 1986, Heide and John 1990, Williamson 1991). Nonintegration forgoes the benefits of coordinated adaptation in long-term interactions with a single supplier, but expands the number of possible options of vertical relationships. Central features of nonintegration therefore are parallel development efforts that generate multiple options and autonomous adaptation—suppliers do not coordinate with specific buyers. We model this by allowing for many component suppliers that evaluate technological improvements locally (i.e., without considering the performance implications for specific combinations of two components). This formulation establishes a crisp difference between integration and nonintegration in terms of their adaptive properties.

We do not cover intermediate organizational forms such as alliances, joint ventures, or relational contracting because we want to understand the mechanisms behind the benefits of commitment and flexibility. Hence, we focus on the stylized types of integration (that maximizes commitment) and nonintegration (that maximizes flexibility). Intermediate forms are subject to the same trade-off between flexibility and commitment and are covered implicitly by our model. For example, a strategic alliance trades off flexibility (by restricting the possible set of suppliers) for increased commitment with the alliance partner.

Figure 1 compares integration and nonintegration in terms of organizing component development.

We assume that the search for improvements in each component is local and restricted to the neighborhood of existing solutions. This follows the behavioral literature (Rivkin 2000, Knudsen and Levinthal 2007, Levinthal and Posen 2007) and reflects empirical work that has documented a status quo bias in organizational search (Hannan and Freeman 1984, Sørensen and Stuart 2000).

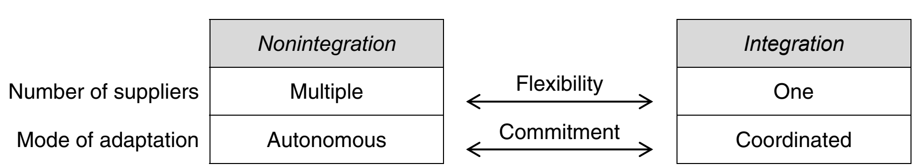
Crucially, we assume that supplier selection is nontrivial because our argument is that turbulence also troubles supplier selection (Jacobides 2005, Hoetker 2005, Li et al. 2008). Prospective buyers face problems in identifying attractive suppliers and assessing their technological capabilities. Indeed, the supply chain literature's concerns with qualification screening (Hwang et al. 2006, Wan et al. 2012) and supplier selection (Hoetker 2005) support our intuition that supplier selection is not straightforward in many settings. We model supplier selection as a sampling process in which buyers evaluate only a subset of potential suppliers. In the results section, we discuss how robust our findings are to variations in the sample size and evaluation rule.

To model components, we create two distinct, but interrelated task environments (Levinthal and Posen 2007). Each task environment represents a component. We define the complexity contained within a particular task environment as *component complexity*. If the interface between components is fully standardized, all interactions are well defined and changes in one component do not influence the performance properties of the other component (Thompson 1967, Brusoni et al. 2001, Levinthal and Posen 2007). Less standardized interfaces imply nontrivial interdependencies, so changes in one component may have performance implications for the other. We denote the residual interdependencies between components as *interface complexity*. Overall system complexity is the combination of component and interface complexity. This lets us analyze how complexity within and between components affect the benefits of commitment and flexibility.

The second major aspect of the two task environments is technological turbulence. Turbulence is the rate of exogenous environmental change that affects the performance implications of choice attributes. For example, for producers and developers of video games, changes in the hardware of personal computers and video consoles have a substantial impact on how games are designed and marketed. For instance, the release of the Wii console triggered a wave of "motion-based" games for family audiences, changing both game design and marketing channels and style. Note that technological turbulence translates into market outcomes. Conceptually, the higher the rate of technological change, the more frequent the changes in the performance implication of a choice attribute. We do not consider the impact of radical, discontinuous change (Tushman and Anderson 1986) and the appropriate responses (Levinthal 1997, Siggelkow and Levinthal 2003). Rather, we analyze a setting in which environmental change is an ongoing challenge. Moreover, we consider settings in which turbulence affects both components equally (in our baseline case) or asymmetrically (in a robustness test).

In the following, we detail the formal building blocks of our model.

Figure 1 Stylized Characteristics of Integration and Nonintegration



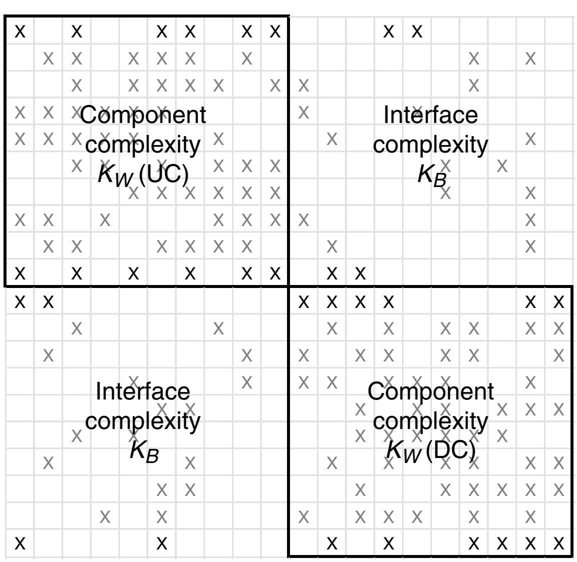
2.2. Technological Complexity

We model a technology consisting of two interdependent stages and follow Levinthal and Posen (2007) in combining two interdependent NK landscapes. The technology design is partitioned into choice attributes of an upstream component, UC, and a downstream component, DC, where $S_{UC} = (s_1, \ldots, s_{N/2})$ and $S_{DC} = (s_{N/2+1}, \ldots, s_N)$ are two equal-sized binary vectors describing the configurations of each individual component. The technology contains N elements and can be fully described by the vector $S = [S_{UC}, S_{DC}]$. Each choice attribute s_i contributes to performance V:

$$V(s_1, \ldots, s_N) = V_{UC} + V_{DC} = \frac{\sum_{i=1}^{N} c_i(s_i; s_{i_1}, \ldots, s_{i_K})}{N}.$$

The performance contribution of each choice attribute $c_i(s_i; s_{i_1}, \ldots, s_{i_K})$ depends on the configuration of the attribute itself and on the state of $K = K_W + K_B$ other elements. These interdependent elements can be located within the same component (K_W) or the other component (K_B). Here, K_W denotes component complexity, i.e., interdependencies among the choice attributes of a particular component. K_B refers to interface complexity, the residual interdependencies across components. In keeping with prior literature (Rivkin and Siggelkow 2003, Ethiraj and Levinthal 2004b, Levinthal and Posen 2007), we assume $K_B \le K_W$. Figure 2 illustrates what these interdependencies may look like: in total there are $N = 20$ choice attributes, 10 associated with the UC and 10 associated with the DC. A configuration depends on the configuration of $K = 7$ other choice attributes, five in the same component and two in the other component. For example, the performance contribution c_1 of element s_1 depends on the configurations of s_3, s_6, s_7, s_9, and s_{10} from the UC and on s_{14} and s_{15} of the DC.

Figure 2 **Example of an Interaction Map** ($N = 20, K_W = 5, K_B = 2$)



Whenever one of the interdependent attributes changes the configuration, the performance contribution of the focal element is redrawn from a uniform distribution [0; 1]. For example, if s_3 changes from 0 to 1, the performance contribution of s_1 changes, but a change in s_2 does not lead to changes in the performance contribution of s_1. Therefore, each attribute's performance contribution can take on 2^{K+1} different values.

The attributes of a configuration may be more or less interdependent. Attributes are interdependent if the value of each of the N individual attributes depends on both the state of that attribute itself and the states of K other attributes. If $K = 0$, attributes are independent. As K increases, more attributes of a configuration become interdependent, with $K = N - 1$ indicating full interdependence among all attributes. Higher values of K imply that there are more local peaks. Here, performance differences among neighboring configurations that differ only in a single choice attribute become relatively more pronounced (Levinthal 1997, Rivkin 2000).

Component complexity K_W and interface complexity K_B regulate how the interdependencies in the value function are distributed for a given K. If $K = K_W$, all complexity resides in the components and there are no residual interdependencies across components, for example because the interface has been designed to be fully modular. In the extreme case of $K = K_B$, the performance effects of combining components are ill understood. Figure 2 shows an intermediate case in which most of the uncertain complexity is located in the individual components ($K_W = 5$), but nontrivial residual interdependencies exist across components ($K_B = 2$). For each simulation run, the specific interaction pattern is randomly determined, with parameters K_W and K_B regulating how interdependencies are distributed within (K_W) and across components (K_B).

2.3. Technological Turbulence

For a static environment, the $N \cdot 2^{K+1}$ performance contributions $c_i(s_i; s_{i_1}, \ldots, s_{i_K})$ are drawn at the beginning of the simulation and remain fixed over the entire simulation run. With technological turbulence, the performance contributions no longer stay stable. The degree of turbulence is adjusted with the parameter τ, which determines the percentage of the performance contributions that are redrawn in each time step of the simulation. In our baseline model, the redraws occur across the entire vector S (even rates of turbulence). In an extension, we compare the baseline model to a scenario where one component remains fully stable and all changes occur on the other component (uneven rates of turbulence). The more performance contributions are redrawn each period, the higher the technological turbulence. This allows for a fine-grained tuning of turbulence. In other studies, turbulence has also been implemented as a redraw of multiples of all 2^{K+1} performance values of a choice (Levinthal 1997), which reflects radical change (Levinthal 1997, Ethiraj and Levinthal 2004b), and as a random walk of performance contributions (Siggelkow and Rivkin 2005).

2.4. Integration and Nonintegration in Organizational Adaptation

Integrated and nonintegrated organizations differ in their search for performance improvements in task environments (Figure 1). Integration enables coordinated adaptation across task environments, whereas nonintegration implies autonomous adaptation and selection among multiple suppliers.

2.4.1. Integration. In an integrated organization, both components are developed with coordinated adaptation. Each agent starts the search for high-performing configurations with a randomly drawn configuration $S = [S_{\mathrm{UC}}, S_{\mathrm{DC}}]$. We model integration as two distinct departments within the same firm (Siggelkow and Levinthal 2003, Siggelkow and Rivkin 2005, Levinthal and Posen 2007). For every time step of the simulation, the departments search in parallel for a higher-performing solution. Each department generates an alternative configuration for their respective component through local search by changing one randomly determined attribute (Levinthal 1997, Levinthal and Posen 2007). They then evaluate how the implementation of the alternative affects overall performance of the firm, assuming that the other component stays fixed (Rivkin and Siggelkow 2003). A new configuration is only adopted if it increases overall performance.

This structure represents coordinated adaptation through aligned incentives (Rivkin and Siggelkow 2003) and coordination across departments (Gulati et al. 2005). Integration considers the residual interdependencies across components in joint development, and aligned incentives and improved coordination conditions reflect the benefits of commitment through integration. However, the firm only has one supplier for each component. We consider alternative specifications of adaptation within firms in the robustness section.

2.4.2. Nonintegration. With nonintegration, the supplier (UC) and buyer (DC) search their respective task environments autonomously and disregard the residual interdependencies between components (K_B). That is, they evaluate performance improvements locally.[2] Each agent engages in local search by randomly changing one choice attribute and then evaluates the component's performance. A change is implemented if component performance increases.

After engaging in local search, downstream firms and upstream suppliers are matched. The matching process is kept simple and general. In each time step, a buyer takes a sample of S suppliers and then evaluates the performance of the supplier component. The sample includes last period's supplier and a set of randomly determined alternative suppliers. The supplier offering the highest joint performance is then selected as the component supplier in that round.

Two parameters matter for supplier selection. The first is the number of component suppliers, which captures stylized market conditions in the supplier market. For example, concentrated markets with high barriers to entry feature a low number of potential suppliers. The second parameter is sample size. It represents the costs of screening, evaluating, and qualifying potential suppliers. We discuss the robustness of our results to variations of these parameters as well as alternative rules for supplier selection in the robustness section.

2.5. Deriving the Benefits of Commitment and Flexibility

We already identified the advantages of integration and nonintegration: integration benefits from the commitment to joint development, nonintegration benefits from the flexibility of multiple options. We study the relative strength of these forces. Although the performance difference between nonintegration and integration is clearly driven by these benefits, we cannot directly derive their relative strengths from the performance of integration and nonintegration as both effects are present in each of the governance forms. Moving from integration to nonintegration implies lower benefits from commitment but more benefits from flexibility, but not an isolated change of one or the other:

$$V_{\mathrm{Integration}} - V_{\mathrm{Nonintegration}} = V_{\mathrm{Commitment}} - V_{\mathrm{Flexibility}}.$$

To quantify the effects, we introduce a hypothetical third form, *malintegration*. Malintegration is designed so that it benefits neither from commitment nor flexibility. We think of malintegration either as nonintegration with a single supplier (which then lacks the benefits of flexibility) or as integration where vertical stages do not coordinate search (and therefore enjoy no benefits of commitment).[3]

[2] Formally, the entire N-bit string can be thought of as two separate components, UC and DC. Component complexity is contained within each of the components, whereas interface complexity captures interactions across components. In assessing the performance of any change within one component, a nonintegrated agent only considers the average performance over all possible configurations in the other component. This is similar to the approach by Gavetti and Levinthal (2000) to develop coarse cognitive representation. The lower the interface complexity, the more precise is the estimate of the performance implications of a local change in a component.

[3] Our approach of disentangling performance differences between two organizational forms by introducing a hypothetical third form is similar to the approach adopted by Almirall and Casadesus-Masanell (2010).

Using the malintegrated firm, we can isolate the benefits of commitment and flexibility as follows:

$$V_{\text{Commitment}} = V_{\text{Integration}} - V_{\text{Malintegration}},$$
$$V_{\text{Flexibility}} = V_{\text{Nonintegration}} - V_{\text{Malintegration}}.$$

The benefit of flexibility is defined as the difference between nonintegration, which only benefits from flexibility, and malintegration, which benefits neither from flexibility nor from commitment. The benefit of commitment is obtained by subtracting the performance of malintegration from the performance of integration.

2.6. Implementation Details

Regarding our model parameters, we follow Levinthal and Posen (2007) and implement a $N = 20$ landscape, the overall technology, partitioned into two equal-sized components with $N_{\text{UC}} = N_{\text{DC}} = 10$. Unless stated otherwise, component complexity is set to $K_W = 8$ and interface complexity is set to $K_B = 3$, i.e., the payoff of one attribute depends on 11 other design choices. We vary the turbulence parameter τ between 0 and 2%, with robustness tests going up to 50%.

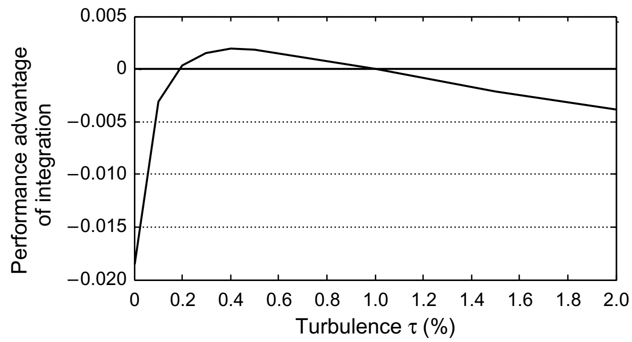
For each simulation run, both integrated and nonintegrated firms are placed on the same landscapes. There is no competitive interaction within a population of integrated and nonintegrated firms. We only consider selection and survival in the robustness section (Levinthal 1997, Levinthal and Posen 2007). We model a population of 100 integrated firms and of 100 nonintegrated firms, which can choose between 100 different suppliers for the baseline case. The number of firms evaluated by each buyer per period is set to four (i.e., the previous supplier and three new ones) unless stated otherwise.

Each simulation runs for 200 time steps and we report long-run performance at $t = 200$. Results are averaged over 10,000 simulation runs. Our outcome variable is defined as the absolute difference in performance between integration and nonintegration at $t = 200$. Positive values imply a relative performance advantage of vertical integration, negative ones for nonintegration.

3. Results

We present our results in four steps. First, we examine how increasing turbulence affects the relative attractiveness of integration and nonintegration. Our results reveal a nonmonotonic relationship between turbulence and vertical scope, and we explain this finding by showing how turbulence has a differential effect on the benefits of commitment and of flexibility. Second, we extend this analysis by considering the main and the moderating effects of component and interface complexity on the relationship between turbulence and vertical scope. Third, we discuss how uneven rates of turbulence influence our results. Finally, we discuss the robustness of our main results.

Figure 3 **Influence of Turbulence on the Relative Performance of Integration** ($N = 20, K_W = 8, K_B = 3, \tau \in [0\%; 2\%]$)



Interpretation. (1) Integration becomes more attractive for moderate levels of turbulence. (2) Integration becomes less attractive for high levels of turbulence.

3.1. How Does Turbulence Affect the Relative Attractiveness of Integration?

To ease exposition, we first examine a setting with turbulence where the performance contributions of each choice attribute are subject to random fluctuations over time, while holding the level of complexity constant. Figure 3 reports the relative performance properties of integration and nonintegration for various levels of environmental turbulence. The turbulence parameter is set from 0 to 2%, going from a completely stable to a turbulent and unstable environment. Turbulence challenges adaptation by changing how choice attributes map onto performance outcomes. This also implies that the speed of adaptation becomes important for performance, because it regulates how rapidly an organization can identify better-performing configurations (Siggelkow and Rivkin 2005).

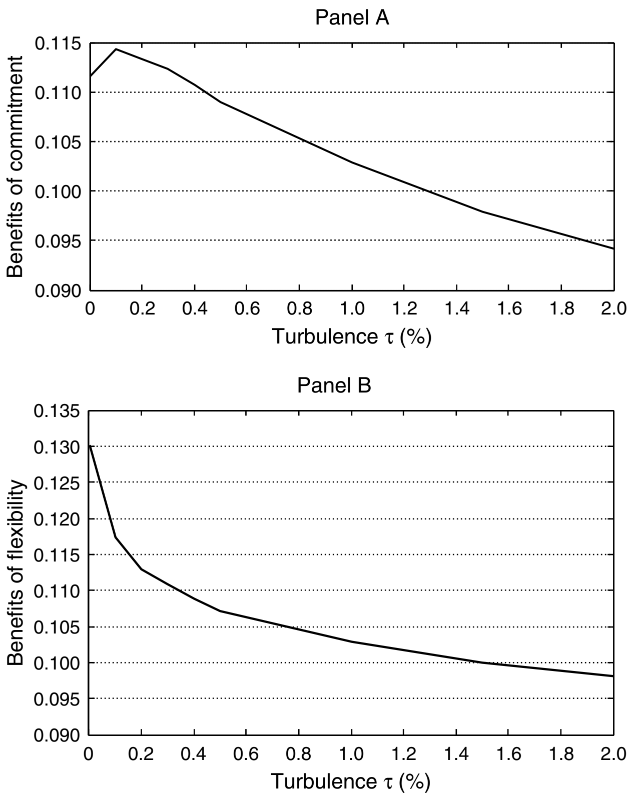
Figure 3 reveals a nonmonotonic relationship between turbulence and the performance advantage of integration. For stable environments, nonintegration clearly dominates. As the environment becomes less stable, integration becomes increasingly more attractive and outperforms nonintegration for moderate levels of turbulence. When turbulence increases even further, the performance advantage of integration deteriorates, and nonintegration again performs best for high levels of turbulence.

It is fairly intuitive that higher levels of turbulence make nonintegration more attractive as a firm can respond quickly to changes by shifting external suppliers. What is less clear is why lower levels of turbulence increase the relative performance of integration.

To understand the drivers behind the nonmonotonic relationship, we disentangle the performance differences between integration and nonintegration into the benefits of commitment and flexibility, as outlined above. Figure 4 reports results for benefits of commitment (panel A) and flexibility (panel B).

First, consider the pattern for the benefits of commitment (panel A). The benefits of commitment first

Figure 4 Drivers of the Performance Advantage of Integration for Different Degrees of Turbulence



Interpretation. (1) For moderate levels of turbulence, increased attractiveness of integration from increased benefits of commitment and reduced benefits of flexibility. (2) For high levels of turbulence, decreased attractiveness of integration from reduced benefits of commitment, even though this effect is partly offset by decreased benefits of flexibility.

increase slightly and then decrease sharply in the level of turbulence. Low (but positive) levels of turbulence increase commitment benefits by offsetting a key weakness of coordinated adaptation, the tendency to remain stuck in low-performing local optima. Integration adapts through local search in each component whereas coordination ensures that only changes improving overall firm performance are adopted. This creates a bias toward local search around the current status quo. Environmental turbulence offsets this bias by creating performance variations that move integrated firms away from inferior local optima and thereby improve the ability of the firm to identify better-performing configurations. Turbulence thus partly compensates for the organizational bias toward exploitation.

However, as turbulence increases further, the relative benefits of coordinated over autonomous adaptation decrease strongly. Strong turbulence makes it harder for coordinated adaptation to keep up with the rate of external changes. Turbulence washes out the structural properties of the rugged landscape since the performance surface depends increasingly on random fluctuations and less on its complexity level. Thus, the decline in commitment benefits does not originate from a greater value of autonomous adaptation, but rather from sharply reduced gains from coordinated actions. Coordinated action leads to slower adaptation (Sorenson 2003), because only alternatives that increase joint performance are implemented, and it has its advantages in managing interface complexity across components—but these matter less when random fluctuations significantly drive performance.

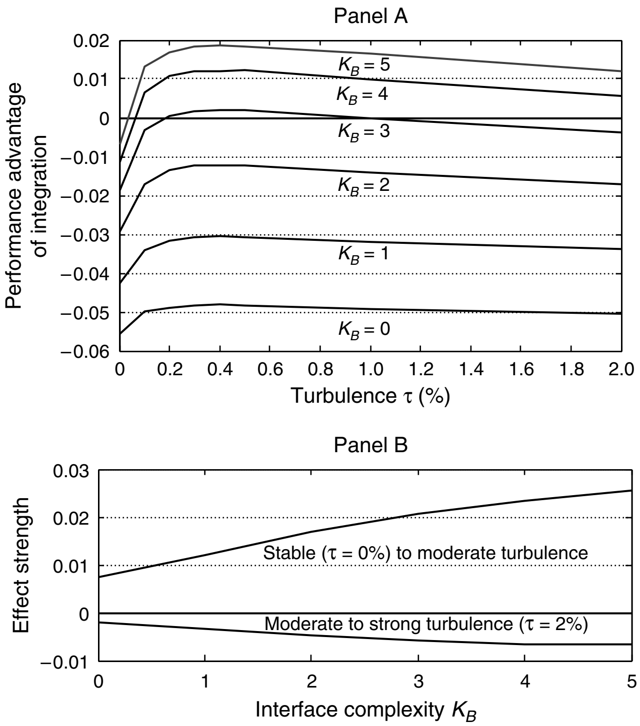
Second, turbulence has a consistent negative effect on the benefits of flexibility because it becomes harder for a firm to identify well-performing suppliers. Yesterday's well-performing supplier may not be a good choice tomorrow owing to technological changes. Importantly, however, this effect levels off and the flexibility benefits suffer increasingly less adverse effects from further increases in environmental turbulence. At higher levels of turbulence, the adaptive advantages of having multiple options to choose from mitigate the problem of supplier identification.

Hence, the combined effect on the benefits of commitment and flexibility explains the nonmonotonic relationship between turbulence and the relative performance advantage of integration. Low levels of turbulence reduce the value of flexibility, while even improving the value of commitment. Higher levels of turbulence sharply reduce the value of commitment, while having a less adverse effect on flexibility. At first sight, Figure 3 suggests that integration only offers modest performance improvements over nonintegration for modest levels of turbulence. However, the relative attractiveness of integration also critically depends on the two sources of complexity, and we discuss their influence on the relationship between turbulence and vertical scope in the following section.

3.2. How Does Complexity Moderate the Effects of Turbulence?

In the next step, we study how interface and component complexity moderate the relationship between turbulence and the value of integration. Interface complexity promotes coordinated adaptation and increases the value of integration because changes in a component also affect the performance of the other component (Williamson 1991, Levitan et al. 2002, Ethiraj and Levinthal 2004a). Hence, the higher the interface complexity, the more pronounced are the benefits of commitment. For low levels of interface complexity, firms may benefit from the multiple options in the external supplier market. The more suppliers, the more likely it is that one identifies the global optimum in a component landscape. Because of low interface complexity, the performance of the supplier component is largely independent of the current configuration of the focal firm and it can easily mix and match components. Thus, the lower the interface complexity, the higher is the value of flexibility.

Figure 5 **The Moderating Effect of Interface Complexity on the Relationship Between Turbulence and the Relative Performance of Integration** ($N = 20$, $K_W = 8$, $K_B \in [0; 5]$, $\tau \in [0\%; 2\%]$)



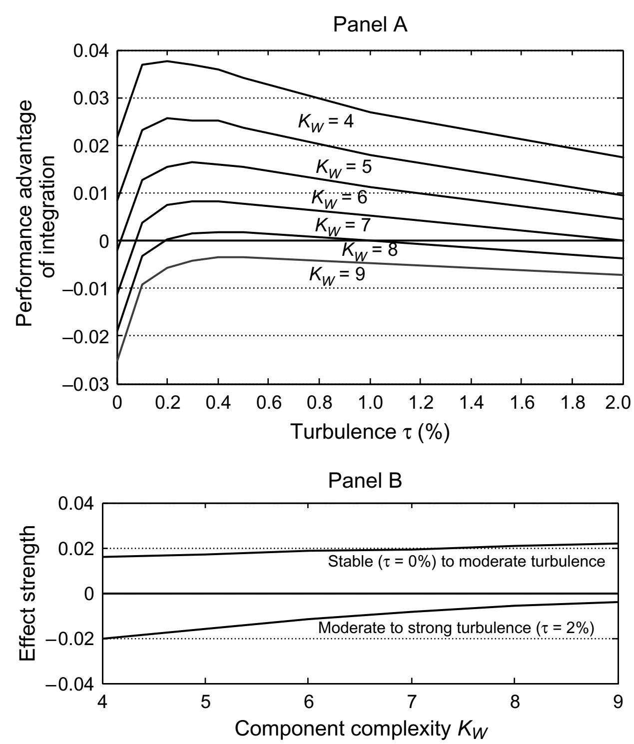
Interpretation. (1) Interface complexity K_B increases the attractiveness of integration. (2) The increases in attractiveness of integration (from introducing some turbulence) are stronger for higher interface complexity. (3) The decreases in attractiveness of integration (for high levels of turbulence) are stronger for higher interface complexity.

Figure 5 (panel A) reports the results for interface complexity. We find strong support for the proposed direct effect of interface complexity on integration: Nonintegration dominates for low levels of interface complexity, whereas the performance of integration increases in interface complexity. More importantly, we also find a significant moderating effect of interface complexity on the relationship between turbulence and integration. The nonmonotonic effect is stronger for higher levels of interface complexity (panel B).

To further investigate the moderating effect, we computed the performance differences across complexity levels for the increase (stable to moderate, top line) and subsequent decrease (moderate to high, bottom line) in integration attractiveness from the introduction of turbulence (Figure 5, panel B). For different degrees of interface complexity (horizontal axis), the top line in panel B shows the amplitude of the performance increase of integration in the left part of panel A, whereas the bottom line gives the performance decrease once turbulence exceeds the point at which integration is most attractive. We see that for higher interface complexity, the relative value of integration increases strongly when moving from stable to moderate turbulence (top line). This is primarily because higher interface complexity engenders a greater risk of being trapped on local peaks and turbulence is more beneficial for search the higher the interface complexity. Higher interface complexity also leads to a modestly stronger decrease in the attractiveness of integration for high levels of turbulence (bottom line). Again, this is primarily due to turbulence's influence on coordinated adaptation: The higher the complexity, the more sensitive performance is to variations in technological configurations. From this, we conclude that the nonmonotonic relationship between turbulence and the attractiveness of integration is stronger for higher levels of interface complexity—especially the positive (stable to moderate) gradients are steeper for higher interface complexity.

Next, consider component complexity (Figure 6). Component complexity challenges coordinated adaptation because the danger of lock-in to inferior local optima increases. This reduces the value of commitment for increasing component complexity. At the same time, the value of having many external options increases strongly, because the fit between components

Figure 6 **The Moderating Effect of Component Complexity on the Relationship Between Turbulence and the Relative Performance of Integration** ($N = 20$, $K_W \in [4; 9]$, $K_B = 3$, $\tau \in [0\%; 2\%]$)



Interpretation. (1) Component complexity K_W decreases the attractiveness of integration. (2) The increases in attractiveness of integration (from introducing some turbulence) are stronger for higher component complexity. (3) The decreases in attractiveness of integration (for high levels of turbulence) are weaker for higher component complexity.

is not critical for joint performance. This increases the value of flexibility. In sum, the relative attractiveness of integration decreases in component complexity, which is exactly what we find (panel A): For a given level of interface complexity, integration becomes less attractive the higher the component complexity.

For the moderating effect (panel B), the increase in attractiveness of integration for low turbulence (top line) increases only mildly with component complexity. Conversely, component complexity strongly affects the decrease in attractiveness of integration for higher turbulence (bottom line). That is, turbulence increases the value of nonintegration less strongly for higher levels of component complexity. The reason is its impact on the benefits of flexibility. The higher the component complexity, the more component performance is affected by turbulence. This implies that supplier selection becomes more difficult for higher component complexity, especially because the existing supplier's component has a higher probability of being obsolete (low component performance).

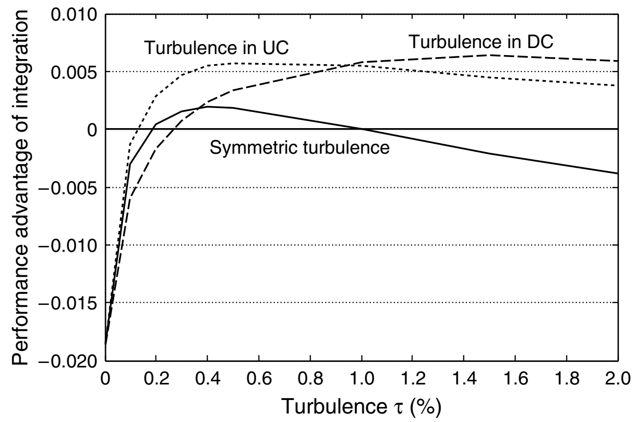
3.3. Do Uneven Rates of Turbulence Make Integration More Attractive?

Because many products build on different technological trajectories, rates of turbulence are often uneven across different components (Brusoni et al. 2001, McCarthy et al. 2010, Furlan et al. 2013). So far, we have only considered even rates of turbulence, i.e., external changes affected the components evenly and we implemented turbulence by redrawing the performance contributions of attributes in each period in randomly determined parts of the two component landscapes. To test for differential effects of uneven rates of turbulence, we now restrict redraws to just one performance landscape, either in the upstream component provided by the supplier (UC) or in the downstream component provided by the buyer (DC).

We report the results in Figure 7. Even though the absolute level of turbulence (i.e., the percentage of changing attributes) is fixed, there are clear differences. If changes are concentrated in just one component, integration remains attractive for much higher levels of turbulence. This resonates with Brusoni et al. (2001) who argued that uneven rates of technology development favor integration. Intriguingly, integration becomes much more valuable for low levels of turbulence if changes are contained within the upstream component.

To understand the drivers of this result, we again decompose the benefits of commitment and flexibility. Figure 8 shows that the benefits of commitment are higher for uneven rates of turbulence than in the symmetric case. Coordination between components becomes easier if one of the components does not change, irrespective of whether the stable component

Figure 7 **Results for Uneven Rates of Turbulence**
($N = 20, K_W = 8, K_B = 3, \tau \in [0\%; 2\%]$)



Interpretation. Uneven rates of turbulence make integration more attractive for higher levels of turbulence.

is upstream or downstream. Further, integration benefits from turbulence by broadening search in one component.

We also find a differential effect of uneven rates of turbulence on the benefits of flexibility (Figure 9). The adverse effect of turbulence on flexibility is much less pronounced when turbulence is restricted to one component. Because adaptation is autonomous and agents do not develop relationship-specific components, they are less affected by turbulence in the other component (given that more variations there tend to cancel each other out to a larger extent). However, the strength of this effect is smaller than the positive impact on the benefits of commitment, thereby shifting the advantage toward integration.

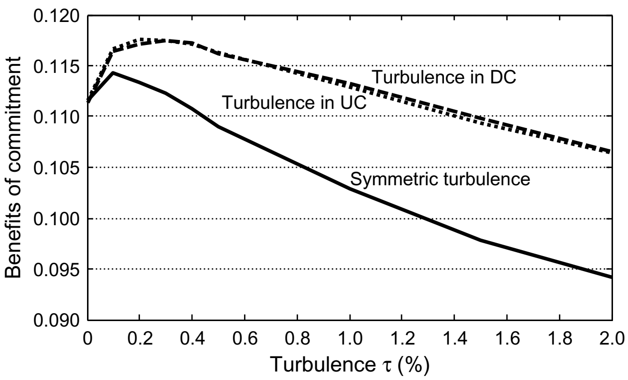
3.4. Robustness Checks

The major result—the nonmonotonic relationship between turbulence and vertical scope—is robust to many changes in key parameters and assumptions of the model.[4]

First, we tested for higher levels of turbulence (up to $\tau = 50\%$) and the result that the attractiveness of integration decreases remains. Second, varying N (the number of component attributes) did not change the reported results. Third, we also considered an alternative specification of turbulence in which individual performance contributions followed a random walk (Siggelkow and Rivkin 2005). Turbulence was captured by the variance of the random draw that changed the payoff contribution. The nonmonotonic relationship also holds for this specification. Next, we considered a wide range of alternative internal designs for integration. We found the nonmonotonic relationship as long

[4] Results from all robustness tests are available from the authors upon request.

Figure 8 Benefits of Commitment for Uneven Rates of Turbulence

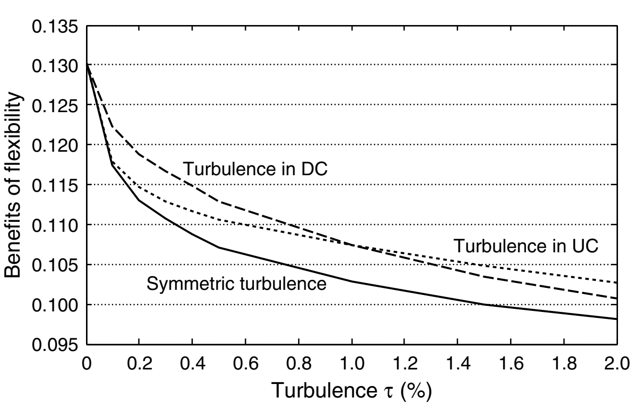


Interpretation. Uneven rates of turbulence lead to higher benefits of commitment.

as the internal structure provided for some coordination of search across components. Our results do not hold when organizations do not coordinate across departments (cf. the decentralized structure in Siggelkow and Levinthal 2003), because these organizations tend to overexplore and adding turbulence exacerbates this exploration bias. They also performed worse than structures that rely on coordinated adaptation and thereby provide for the benefits of commitment.

Fifth, we tested a different specification of supplier selection in which buyers are imperfectly informed about the joint performance of components before choosing a supplier from their sample. Predictably, this reduces the value of flexibility and thereby the attractiveness of nonintegration. Likewise, increasing the number of potential suppliers and the sample size has the straightforward effect of increased benefits of flexibility. However, the nonmonotonic relationship still holds as long as there are some meaningful frictions in supplier identification. Sixth, we considered cumulative performance, which is informative about how agents navigate changes in the landscapes. Our results also hold for this alternative performance measure.

Figure 9 Benefits of Flexibility for Uneven Rates of Turbulence



Interpretation. Uneven rates of turbulence lead to higher benefits of flexibility.

Finally, we tested for selection pressures (Levinthal and Posen 2007). Stronger selection pressure decreases the attractiveness of integration. Nonintegration tends to improve performance faster, thereby giving it a short-term competitive advantage over integration. However, the nonmonotonic relationship between turbulence and vertical scope still holds.

4. Discussion

Our study was motivated by the mixed empirical evidence on how turbulence affects vertical scope and the corresponding conflicting theoretical arguments explaining these findings. Prior literature advanced two distinct mechanisms that speak for and against tighter integration, respectively, as a response to turbulence. Turbulence increases the value of coordinated adaptation across components, entailing a commitment to a single supplier (e.g., Williamson 1991, Brusoni et al. 2001, Sorenson 2003). However, turbulence also increases the value of flexibility provided by many external supplier options (Balakrishnan and Wernerfelt 1986, Heide and John 1990, Geyskens et al. 2006). We address and combine these opposing views by detailing the two core mechanisms at play. Turbulence increases the value of commitment to a single supplier by alleviating the status quo bias of coordinated adaptation. At the same time, turbulence degrades the value of flexibility by exacerbating problems of supplier identification. We analyzed these ideas with the help of an NK model. Our results indicated a strong and robust nonmonotonic relationship between turbulence and the value of integration. The relationship is moderated positively by interface complexity and negatively by component complexity. We also found that uneven rates of turbulence favor integration.

4.1. Theoretical Implications

Our core result is how turbulence affects the value of integration and nonintegration in organizational adaptation. Turbulence has a nonmonotonic influence on the benefits of commitment. Unsurprisingly, extreme levels of turbulence render the benefits of coordinated adaptation through commitment to a single option unattractive. However, moderate levels of turbulence actually increase the benefits of commitment by mitigating the exploitation bias of coordinated adaptation (Stuart and Podolny 1996). A potential disadvantage of commitment is the lock-in to an inferior alternative (Levinthal 1997, Posen and Levinthal 2012). Turbulence triggers performance variations that force organizations to broaden their search beyond the neighborhood of existing alternatives. Posen and Levinthal (2012) reported a similar finding, but suggest a different, complementary mechanism. They show that increasing turbulence calls for less exploration because turbulence erodes the rewards to exploratory efforts at accumulating new knowledge. The mechanism we identify is that a turbulent environment creates performance variations that prompt broader exploration of the solution space and at least partially offset the status quo bias of tightly integrated systems such as vertically integrated firms.

The advantage of integration in a setting with moderate turbulence is reinforced by the negative impact of turbulence on the benefits of flexibility. Although nonintegration offers multiple external options, a problem for rapid adaptation is still the identification and integration of external solutions. If supplier selection is challenging due to restricted information about potential suppliers and the performance implications of their solutions (Hoetker 2005), turbulence reduces the value of flexibility, because identifying an adequate supplier becomes harder for more turbulent contexts.

Both effects—increased benefits of commitment and decreased benefits of flexibility—favor integration for moderate turbulence. In highly turbulent environments, turbulence offsets the adaptive benefits of integration, which engenders a decisive shift toward more autonomous structures that explore multiple options in parallel. More generally, although an episode of abrupt, radical change places tightly coupled organizations at a disadvantage (Levinthal 1997), organizations prosper under conditions of ongoing moderate turbulence (Tushman and Anderson 1986). We summarize these effects and mechanisms in Table 1.

Our second set of results revolves around moderating factors, specifically the second primary source of technological uncertainty, complexity, and the nature of turbulence. Following prior work (Baldwin and Clark 2000, Ethiraj and Levinthal 2004a), we distinguished interface and component complexity. The first-order effects were intuitive: interface complexity increases the value of integration whereas component complexity has the opposite effect (e.g., Argyres and Bigelow 2010, Baldwin and Clark 2000, Almirall and Casadesus-Masanell 2010). These results support the internal and external validity of our model. More importantly, both sources of complexity moderate the relationship between turbulence and integration. The nonmonotonic effect of turbulence on vertical scope is stronger for higher interface complexity and lower component complexity. These findings suggest that more work should study how complexity and turbulence interact in processes of organizational adaptation and selection. Save for a few exceptions (e.g., Siggelkow and Rivkin 2005), most work focuses on either complexity (Levinthal 1997) or turbulence (Posen and Levinthal 2012).

Finally, we explored our two key mechanisms further by studying how uneven rates of turbulence influence the benefits of commitment and flexibility. Brusoni et al. (2001) posit that uneven rates engender a shift toward more integration. Our results support their claim and show that this shift primarily originates from the increased benefits of commitment. At the same time, the benefits of flexibility are less adversely affected from uneven rates, highlighting a distinct advantage of autonomous adaptation in dealing with turbulence: as suppliers do not develop solutions for a specific buyer, variations in one component tend to cancel each other out, which stabilizes the basis for performance improvements by suppliers. Thus, uneven rates of turbulence matter precisely because the adaptive properties of integration and nonintegration differ. This also points to differential value of who integrates whom. One of the vexing questions in the theory of the firm has been the question

Table 1 Summary of Results for Increasing Turbulence

	Low turbulence	High turbulence
Implications for search problem	*Changes mapping of choice attributes onto performance outcomes.* Prior high-performing configuration can be rendered worthless.	
Effect on benefits of *commitment*	*Increase* Coordinated adaptation in integrated firms more prone to get stuck on local peaks. Low turbulence as a mechanism to get off local peaks. Integrated firms can still readjust to changed environment.	*Strong decrease* Coordinated adaptation in integrated firms unable to keep up with high levels of turbulence.
Effect on benefits of *flexibility*	*Strong decrease* Harder to identify well-performing suppliers.	*Decrease* Harder to identify well-performing suppliers. Rapidly changing environment puts a premium on speedy adaption provided by autonomous adaptation of nonintegrated firms.
Performance implication (commitment–flexibility)	Both effects drive increased relative performance of *integration*.	Counteracting effects, but dominance of the commitment effect leads to increased relative performance of *nonintegration*.

of direction, i.e., whether firm A should integrate firm B, or vice versa. The dominant answer in the incomplete contracting literature (Hart 1995) is that the party with the highest investment incentives integrates. Complexity and turbulence affect these incentives. Thus, a supplier may be less inclined to forward integrate into a turbulent component (because it forgoes the advantage of autonomous adaptation), whereas a buyer has a stronger incentive to integrate (to realize the benefits of commitment).

4.2. Empirical Implications

To get empirical traction for our theory, consider a setting in which a stable, vertically disintegrated industry experienced an increase in environmental turbulence. Given our results, our prediction is that firms react by becoming more vertically integrated. The Cacciatori and Jacobides (2005) study of the British construction industry closely resembles this pattern. The industry was vertically disintegrated in the 1970s. Toward the end of that decade, a "shift in demand increased the emphasis on time and cost management over the aesthetic aspects of buildings and accountability" (p. 1862). Moreover, the state as a client became less important, while the industry as a whole experienced strong growth throughout the 1980s. The demand shifts put considerable strain on the disintegrated structure because they made identifying capable suppliers difficult (p. 1861) and thus reduced the benefits of flexibility that characterized the traditional division of labor in the industry. At the same time, higher turbulence broadened the incumbent's search beyond existing solutions. Indeed, "firms respond[ed] by trying to provide new services" (p. 1867). Larger, more integrated building contractors became less inert and moved into financing and maintenance (pp. 1862, 1867–1868). Turbulence increased the benefits of commitment especially for large, more inert firms and triggered a wave of reintegration and the growth of integrated players in terms of size and market shares (p. 1859). Thus, reintegration was shaped by reduced benefits of flexibility and higher benefits of commitment. This is consistent with our predictions, and our framework provides a useful lens to interpret the industry's evolution.

Of course, the qualitative correspondence of the empirical case described and the results of our model do not constitute a formal test of the nonmonotonic relationship between turbulence and vertical scope. Indeed, existing studies were not designed to test for the relationship derived in this paper and can therefore offer only partial confirmation of our findings. Hence, next, we outline a set of conditions that empirical studies would have to fulfill to constitute a meaningful test of the nonmonotonic effect we found. Specifically, we would like to identify a causal effect of turbulence on the relative performance of integration, either measured by performance variations between integrated and nonintegrated firms in similar settings or by observing different vertical scope decisions in settings with varying degrees of turbulence.

Three of the main empirical challenges in this context relate to the functional form, the variance, and the exogeneity of turbulence, the key independent variable. First and most straightforward, testing for a nonmonotonic relationship between turbulence and integration requires an appropriate functional form of the turbulence measure. One could test for an inverted U-shape either with a linear and a quadratic term of the turbulence measure or with a set of dummy variables for different ranges of turbulence. Second, we need an empirical setting capturing a sufficiently wide range of turbulence to identify both performance increases of integration as turbulence goes up to moderate levels and then decreasing performance as it increases further to high levels. This excludes settings where an industry experiences only one shock in the degree of turbulence. Finally, turbulence must be exogenous. In many industries, turbulence stems from technological innovations brought about by market players, which are not exogenous to the industry and may therefore confound cause (turbulence) and effect (integration) and true mechanisms at play. For example, when game console manufacturers release a new platform they typically produce a large share of games in-house. This may be due less to the mechanisms we propose than to the empirical reality that a console manufacturer has to provide a sufficient variety of games and will only release a console if it can provide enough games itself. In other words, integration is a prerequisite for turbulence, not the other way round.

Even if these requirements are met, identifying the causal effect might still be difficult because confounding factors may be at play. Consider the microchip industry: even if a reduction from moderate to low turbulence would be a plausible explanation for the recent disintegration between chip designers and producers, this industry also experiences increasing complexity in the design and manufacturing processes (component complexity) and reduced interface complexity between these two domains. As we have seen in the model, all these changes would predict changes to more nonintegration, complicating the identification of the influence of turbulence. This is exemplary for many other industries in which one market and one technology provide all the variation for empirical testing.

We therefore need empirical settings that let us isolate the effect of turbulence from confounding factors. Two possible roads to identification could be the exploitation of cross-market or cross-product heterogeneity. Cross-market variation could, for example, be observed in a setting where different markets with varying degrees of turbulence are covered through franchises (nonintegration) or own outlets (integration). By contrast, with cross-product variation, turbulence affects products in different stages of their life cycles. For video games, for example, variation in turbulence could stem from differences in market segments or genres that are subject to fluctuations in consumer preferences.

Finally, our results highlighted not only the importance of considering the main effects of confounding factors like interface or component complexity, but also their moderating effects. We can expect to observe stronger nonlinear effects for settings with high interface and low component complexity.

5. Concluding Remarks

Our model abstracts from many interesting aspects to focus on clearly understanding two particular mechanisms, namely how turbulence and complexity influence the benefits of commitment and flexibility. One important limitation is that the trade-off between commitment and flexibility is hard-coded and cannot be changed by the economic agents. Prior work demonstrated that internal organization design influences how a firm adapts to a complex task environment (Rivkin and Siggelkow 2003, Knudsen and Levinthal 2007, Gulati et al. 2005, Levinthal and Posen 2007, Kretschmer and Puranam 2008). This implies that firms may influence the benefits of commitment and flexibility through internal design, for example, by providing for better alignment between departments or by having multiple project teams approach the same problem from different angles. A sizable literature has studied how the organization of supplier networks may provide a firm both with benefits of long-term interaction and of the flexibility of alternative suppliers (Dyer 1997). Softening the trade-off between commitment and flexibility gives firms advantages of adaptability and performance. We did not consider this issue. Crucially, although these initiatives may alleviate the trade-off, they cannot eliminate it as long as scarce resources limit the pursuit of parallel options.

Our model substantiates the commitment-flexibility trade-off in the general context of vertical stages of production. Yet, the model neglects other important drivers of firm boundaries and we do not take a conceptual stand on how boundaries should be defined (Alchian and Demsetz 1972, Hart 1995, Santos and Eisenhardt 2005). For example, we do not consider how ownership influences investment incentives (Hart 1995) or mitigates contractual hazards (Williamson 1985). These issues are beyond the scope of our study. The model structure is also limited by the assumption of two stages of production. Their boundaries are taken as given and cannot be changed by the economic agents. The problem of how to design near-modular systems has been studied elsewhere (Ethiraj and Levinthal 2004a, Frenken 2006). An interesting avenue for further research is to consider how multiple stages of production in an industry impact the coordination of distributed search and how coordinated adaptation complements or substitutes for autonomous adaptation.

However, despite the inevitable limitations of a stylized model we still believe that the intricate trade-off between the benefits of commitment and flexibility affecting the attractiveness of integration and nonintegration have significant theoretical and empirical appeal.

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