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Artificial Neural Network Evaluating Nonlinear Evolutionary Effect of Cognitive and Risk Complexity in Ambidextrous Strategy Renewal

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ABSTRACT

This research examines the micro-foundations of individual ambidexterity as a managerial dynamic capability for addressing the tension associated with pursuing dual strategies. It empirically investigates the coevolutionary intertwining effects of different levels of integrative complexity (IC) and business complexity to identify the optimal composition of cognition–risk interaction that enhances ambidexterity performance. A multidisciplinary approach was adopted to address dualities and ambidexterity through a managerial cognition lens. The application of artificial neural networks has helped to gain a deeper understanding of the role of the cognitive dimension related to dualities. The results clarify that risk and business complexity can have both negative and positive effects. Specifically, in low-risk settings, high levels of IC are not capable of inducing higher ambidexterity performance, suggesting that risk should stimulate the cognitive complexity of CEOs. Moreover, the findings reveal that a high degree of cognitive complexity cannot be viewed as the sole dominant factor in successful strategy renewal, as it is exogenously fueled. An investigation of different scenarios indicates that, at higher levels of risk, differentiation-dominant IC, encompassing a perceptual decision-making style can enhance ambidexterity despite limited integration. In contrast, in low-risk settings, integration supported by analogical thinking may be more effective.

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1. Introduction

The study of scenario planning and strategic cognition in the domain of strategy-making has been a flourishing area (Molina et al., 2023; Vecchiato, 2019), as cognition has been proven to be a critical determinant of managerial decisions and strategic performance (Grewatsch & Kleindienst, 2017; Ocasio et al., 2018). Cognition is defined as the process of noticing external stimuli, interpreting them, and integrating their meaning with other relevant information in order to make strategic decisions (Vecchiato, 2019). This research stream aligns with the growing interest in the micro-foundations of strategic decisions, which focus on identifying interactions among aggregate variables of different identities that lead to heterogeneity in firms' strategic performance (Helfat & Peteraf, 2014; Karhu, 2017; Molina-Azorín, 2014; Rodrigo-Alarcón et al., 2020; Ruiz-Ortega et al., 2021).

In studies that seek to explain the micro-level foundations of strategic renewal, scholars have increasingly focused on factors that enable ambidexterity, which is commonly understood as an organization's capacity to engage in both exploration and exploitation (O'Reilly & Tushman, 2013; Pertusa-Ortega et al., 2021).

Exploration emphasizes learning that emerges from experimentation and iterative trial and error, while exploitation is associated with activities aimed at preserving stability, maintaining existing capabilities, and solving problems in a systematic and careful manner (Karhu, 2017). The dominant research stream addressing the role of cognition and its potential in the dynamic evolution of strategy processes (Garud et al., 2010; Laamanen et al., 2018), or in balancing dual strategies in ambidexterity, is based on the premise that strategy renewal or successful ambidexterity stems from individuals' underlying mental models and strategic assumptions (Karhu, 2017). This vein of research has been extended to domains such as scenario planning and treating cognition as a dynamic process (Laamanen & Wallin, 2009; Phadnis et al., 2015). Although scenarios have been extensively praised, there remains a scarcity of research on their impact on strategic investment decisions under uncertainty (Vecchiato, 2019). Examining the micro-foundations of dualities in ambidextrous decision-making and identifying antecedents that facilitate or hinder ambidexterity has gained increasing attention in recent years (Molina et al., 2023). Based on this perspective, the present study employs a multidisciplinary approach to examine dualities and ambidexterity by focusing on managerial cognition as the central analytical lens.

Cognitive complexity describes an executive's ability to search for information, distinguish among different cues, and combine them into a coherent understanding. It also involves the capacity to think in abstract terms and to identify, interpret, and appreciate multiple perspectives when making decisions (Karhu, 2017). This concept has been widely used to analyze variations in decision-making styles (Shao et al., 2019; Zhou et al., 2020) and to support research on differential diagnostic processes (Conway & Woodward, 2020; Suedfeld et al., 2005).

Recent studies suggest that cognitive complexity is one of the key capabilities needed to successfully carry out strategic change and to maintain high levels of performance in environments characterized by constant change and uncertainty (Latukha & Panibratov, 2015; Zyung, 2017).

In examining its underlying mechanisms, cognitive complexity has been classified into three main levels: low, medium, and high. Prior research on managerial cognitive complexity has largely assumed that higher levels of cognitive complexity are more beneficial for firms (Ehrensberger-Dow, 2016). However, more recent studies challenge this assumption, arguing that different levels of cognitive complexity, which represent distinct information-processing styles, may exert differential effects on firms' strategies, thereby calling for research that explicitly examines these levels (Zyung, 2017). Moreover, despite the classification of

cognitive complexity, there remains a lack of empirical studies investigating such distinctions in decision-making within SMEs (Molina et al., 2023), where the role of CEOs' responsiveness has been particularly emphasized.

A second research gap addressed in this study concerns the notion that, despite the importance of cognitive complexity as a driver of ambidextrous decision-making, it may be insufficient in highly dynamic environments (Khezri, 2021; Severgnini et al., 2019). Environmental complexity has long been considered a dominant moderator in strategy research (Severgnini et al., 2019). However, the boundaries between organizations and their environments are increasingly fluid, and environmental change cannot be treated as entirely exogenous (Khezri, 2021; Poutanen et al., 2016). Sensing and interpreting critical signals for launching strategic renewal is not primarily about matching the organization to its external environment. Instead, it centers on co-creation, where firms develop agility by actively shaping and making sense of their surroundings through distinctive forms of environmental enactment. In this view, environment and cognition are deeply intertwined (Agarwal & Helfat, 2009; Khezri, 2021; Schmitt et al., 2016).

This study contributes to the literature in three novel ways:

First, unlike prior research that assumes a linear positive effect of cognitive complexity on ambidexterity, we apply artificial neural networks (ANN) to capture non-linear and co-evolutionary effects between integrative complexity (IC) and risk complexity. Second, while most studies treat environmental risk as an exogenous moderator, we conceptualize it as an endogenous driver that interacts with cognitive differentiation and integration, using a scenario-based approach derived from complexity theory. Third, we empirically test four distinct scenarios of IC–risk interaction in the context of SMEs, an under-researched setting in the ambidexterity literature.

The effects of different types of risk on resource utilization decisions in exploration and exploitation strategies may vary depending on the level of CEOs' integrative complexity and how they perceive risk (Baskarada et al., 2017). In traditional views, managers are assumed to perceive either opportunities or threats in the external environment (Chattopadhyay et al., 2001). However, recent research suggests that CEOs may interpret events as simultaneously presenting both opportunities and threats (Bao et al., 2021; Raffaelli et al., 2020). Therefore, it is essential to investigate how levels of risk and CEOs' integrative complexity interact. Accordingly, this article aims to examine and integrate how risk and CEOs' cognitive processes relate to the development of ambidexterity and strategic decision-making. Previous research on risk and organizational ambidexterity has not clearly connected these concepts, which highlights the need for further investigation (Severgnini et al., 2019).

2- Underpinning Theory and Hypothesis Development

The notion of managerial strategic cognition, complementing rational and intuitional modes of strategy-making as a dominant research area, has integrated the managerial and organizational-level factors in the process of strategy renewal (Cagliano et al., 2017; Kaplan, 2011). The strategic cognition-based orientation to strategy renewal accentuates the hierarchical view of capabilities and considers cognition as the micro-foundation of higher-order dynamic learning capabilities, fostering the functioning of resource reconfiguration capabilities (Helfat et al., 2015). Within this domain, strategic renewal pertains to the co-creation of agility through environmental enactment; in other words, to co-create and maintain systems of shared meaning through intuiting (sensing) and interpreting (sensemaking) relevant signals to initiate strategic action (Khezri, 2021).

The emergence of the enactment view toward the environment, in contrast to the co-alignment view, is due to the boundaries between the organization and the environment being removed, as well as the emergence of a fluid state in which the environment cannot be regarded as exogenously constituted (Agarwal & Helfat, 2009; Schmitt et al., 2016). According to Anderson (2014), defining a strategic goal is less about environmental perception or sensing and more about purpose-driven environmental interpretation or sensemaking. This view aligns with the growing emphasis in neuroscience that sees the brain as an action-oriented system focused on prediction and processing (Clark, 2016). From this perspective, action, cognition, and perception are not separate processes but are continuously formed together through ongoing interaction (Poutanen et al., 2016). Indeed, "business environments are not objective environments, awaiting discovery through the application of formal analytical techniques" (Hodgkinson, 2015). This fact, rooted in complexity theory and highlighted in recent research (Khezri, 2021; Poutanen et al., 2016), necessitates the use of nonlinear machine-learning techniques to discover hidden interactions between agents of change.

Strategy renewal deals with refreshing the attributes of an organization and managing the outcomes and pitfalls of such actions. Ambidexterity pertains to managing the dualities and the tensions coming from them, which has proven to be effective. Dualities can be conceptualized in various ways, and the managerial cognition literature highlights a wide range of mental processes through which organizations recognize, evaluate, and manage these dualities in their efforts to achieve organizational ambidexterity (Kaur et al., 2019). Dualities can emerge as both paradoxes and dilemmas (Birkinshaw et al., 2016). The nature of a duality is shaped by the opposing poles between which the decision-maker moves back and forth. The relationship between the poles can be described, in the case of a dilemma, as "either–or," and, in the case of a paradox, as interrelated "both–and."

Top management teams address the exploration–exploitation paradox through paradoxical cognitive processing. This process reflects their ability to differentiate between exploratory and exploitative demands and then integrate them into a coherent strategic understanding, thereby fostering organizational ambidexterity (Van Neerijnen et al., 2022).

The dualities literature has shown interest in the superiority of paradoxes over dilemmas as a synergistic approach that avoids having to choose one alternative. The tension between exploration and exploitation could turn into "an iterative process of learning," where "periods of incremental adjustment (single-loop learning) are broken by bursts of revolutionary change (double-loop learning)" (Schmitt et al., 2018).

Psychologists have consistently emphasized the key role of the cognitive dimension embedded in dualities, particularly in the case of paradoxes (Karhu & Ritala, 2020). Previous studies illustrate that managers frequently rely on accumulated knowledge and prior learning experiences when making strategic decisions under unfamiliar conditions (Gavetti, 2012). Analogical thinking has been suggested as an appropriate mechanism through which decision-makers integrate prior knowledge with new information when dealing with complex decision-making conditions (Lombrozo, 2024).

In a similar vein, a paradoxical frame, in contrast to a unitary frame, has also been suggested as an underpinning mechanism for managing the tension. In a unitary frame, managers view strategic issues through an "either/or" lens, overlooking the complex connections between opposing elements in order to reduce perceived inconsistencies (Lewis, 2000). By focusing only on one side of a strategic issue and downplaying the other, this frame tends to hide potential linkages between contradictory elements, resulting in limited differentiation and integration and, consequently, a weak ability to manage tension (Bao et al., 2020; Lüscher & Lewis, 2008). In contrast, the paradoxical frame takes into account the trade-off between different aspects of

an issue (Hahn et al., 2014). This orientation toward complexity enables managers to recognize the multiple facets of an event at different levels (Grégoire et al., 2010). A CEO with a paradoxical cognitive frame broadens the scope of attention to a wide range of stimuli, leading to a high degree of cognitive differentiation (Rothman & Melwani, 2017).

With a paradoxical cognitive frame, individuals can link opposing elements and gradually form a more integrated understanding. The emphasis on managing the tension stemming from dualities has been addressed in a similar vein in studies on ambivalence and its effect on ambidexterity. When CEOs see a strategic issue as having both positive and negative sides, this ambivalence becomes essential for ambidexterity to work. Conventional thought considers threats and opportunities as independent, orthogonal dimensions of a manager's interpretation of a strategic issue. More recent research, however, recognizes the inherent linkage between the polarized cognitive frames of a strategic issue, noting that the perceived threats and opportunities are actually compensatory to each other in shaping strategic actions. CEO ambivalence refers to a CEO's evaluation of a strategic issue as simultaneously positive and negative (Plambeck & Weber, 2010). This concept is rooted in attitudinal and emotional ambivalence in social psychology and reflects a cognitive state that tolerates and accepts the coexistence of contradictory evaluations of an object (Baek, 2010). From this view, CEO ambivalence mirrors a paradoxical cognitive frame, whereas a unitary cognitive frame pushes executives to see an issue in strictly positive or negative terms.

Cognitive complexity, consisting of various levels of differentiation and integration, has been introduced as an effective coping mechanism for tackling the tension coming from dualities. Previous research shows that executives with higher cognitive complexity perform better in strategic planning, as they can adapt to changing environments by continuously processing new information and revisiting goals and strategies (Hambrick et al., 1996). Cognitive abilities (fluid intelligence) are positively linked to strategic decision-making performance (Reverberi et al., 2022). IC is measured on a 7-point scale, where a rating of 1 signifies no differentiation and integration, and a rating of 7 represents high differentiation and integration. Differentiation can range from emergent (2) to stable (3–7), while integration can be absent (1–3), emergent (4), stable (5), emergent at an important level (6), or highly integrated (7). Both components are present at each point and are measured in conjunction.

An ambidextrous strategy requires firms to attain balanced levels of both exploration and exploitation. In doing so, firms sidestep the pitfalls of each action, such as the competency or success trap in excessive exploitation and the failure trap in excessive exploration, and achieve synergy by integrating the benefits of both, leading to higher added value in performance efficiency in exploitation or flexible design in exploration. Based on complexity theory principles and benefiting from the classification of complexity theory, the following four scenarios demonstrate how different levels of cognitive complexity, along with different levels of uncertainty, can determine ambidexterity performance.

Despite the growing body of literature on cognitive complexity, risk, and organizational ambidexterity, existing studies remain fragmented in terms of methodological approaches and conceptual integration. To provide a clearer positioning of the present study within the existing literature, a comparative summary of key prior studies is presented in Table 1.

Table1. Comparative Analysis of Prior Studies and the Present Research

Study	Core Variables	Methodology	Type of Relationship	Context	Position vs. Present Study
Karhu (2017)	Cognitive complexity, Strategic decision-making	Conceptual	Linear	General organizations	Present study applies ANN to capture nonlinear cognitive effects
Samimi et al. (2026)	CEO construal level, Cognitive flexibility, Firm ambidexterity	Two-wave survey	Indirect positive relationship	SMEs	Present study adds risk complexity and uses ANN + scenarios to model more complex relationships
Bao et al. (2020)	CEO Cognition, Ambidexterity	Quantitative (Regression)	U-shaped	Large firms	Present study models complex nonlinear patterns via ANN
Molina et al. (2023)	Cognitive perspective in management	Systematic review	Descriptive	General	Present study provides empirical predictive framework
O'Reilly & Tushman (2013)	Organizational ambidexterity	Conceptual	Linear	General	Present study introduces scenario-based dynamic modeling
Present Study	Cognitive or integrative complexity, Risk complexity, Ambidexterity	Artificial Neural Network (ANN) + Scenario-based	Complex nonlinear	SMEs	Integrates cognition and risk and ambidexterity using ANN under scenarios

As shown in Table 1, prior studies have mainly relied on conceptual or linear approaches and have not simultaneously examined cognitive complexity, risk complexity, and ambidexterity using advanced nonlinear methods. The present study addresses this gap by applying an ANN-based and scenario-driven framework.

2.1 Scenario 1

In Scenario 1, identified with low risk accompanied by a high level of integrative complexity (differentiation & integration), the low level of internal and market uncertainties facilitates decisions on investing resources to carry out new innovations, which is known as an explorative strategy (Junni et al., 2013). In the scenario with a low-risk setting, cognitive differentiation could also lead the CEO to be more certain of the strategic decisions taken and seek exponential market gains through new products and experimentation (Benner & Tushman, 2003; Gupta et al., 2006). Yet, by benefiting from the integration process, which helps identify opportunities for the exploitative strategy to leverage infrastructure and resources associated with the explorative strategy, and vice versa (Smith et al., 2012), the ambidexterity mechanism can function effectively. A high level of integration, along with cognitive differentiation, acts to elicit the linkages for trade-offs between resources so that exploitation strategies can also proceed along with explorative strategies. Therefore, it facilitates identifying synergies between exploitation and exploration, leading to the accomplishment of ambidexterity. Thus, it can be hypothesized that:

H1: Low risk level accompanied with high level of integration and differentiation is positively associated with ambidexterity performance.

2.2 Scenario 2

In Scenario 2, signified by high risk along with medium integrative complexity (high differentiation and low integration), labeled as levels 4 and 5 of IC, companies are more likely to allocate resources to exploitation strategies because they possess established knowledge of the activities and processes that contribute to lower operating costs and greater task efficiency (Gibson & Birkinshaw, 2004). In this sense, organizations tend to stick to traditional processes, known activities, and controllable actions (Gupta et al., 2006). Although high risk can determine exploitative strategies, it cannot individually function as the determinant of ambidexterity. In cases where high risk embodies a CEO with highly differentiated cognition and low cognitive integration, the CEO's mind can accumulate so much data as to lose all practical value. Besides, the highly perceived risk in this manner can accelerate the speed of decision-making and direct him onto the wrong track. In fact, excessive exploitation could foster structural inertia, leading the firm to fall into competency or success traps, thereby lowering ambidexterity performance. Thus, we hypothesize that:

H2: High-level risk complexity accompanied with high differentiation and low integration is associated with lower ambidexterity performance.

2.3 Scenario 3

Scenario 3, known with a low level of uncertainty accompanied by a low level of integrative complexity, as labeled levels 2 and 3 with sufficient (low) differentiation and emergent (low) integration (Brodbeck et al., 2022), is likely to cause managers to make decisions intuitively (Malik et al., 2017). Because exploitation activities involve lower risk, fewer potential negative consequences, and reduced complexity, managers can make decisions with less extensive analysis and deliberation (Tahar et al., 2011). Intuition could use analogical thinking and prior knowledge and lead the CEO to come up with an abstract understanding of what the future would look like. In such a scenario, the cognitive structure shifts from a unitary frame to a mixed frame that recognizes fragmented positive elements of a crisis but is asymmetrically dominated by the threat perception of a crisis. Because CEOs with low cognitive complexity are constrained in their cognitive ability to recognize the positive ramifications of a crisis, information cues inconsistent with the dominant threat schema only paint an ambiguous picture of the possible opportunity. In addition, the limited cognitive integration inhibits the identification of structural linkages between the positive and the negative attributes of a crisis. As a result, it is difficult for CEOs to "connect the dots" and perceive a clear, meaningful pattern of opportunity. Therefore, such a scenario is most likely to push managers to fall into failure traps due to excessive exploration, unless there is an ability to identify diverse signals of opportunity. Thus, it is expected that a low-level scenario of decision-making identified with sufficient (low) differentiation and emergent (low) integration, labeled as level 2 or 3 (emergent or stable), could not optimally enhance ambidexterity. Therefore, it can be proposed that:

H3: Low-level risk complexity along with low-level integrative complexity with sufficient (low) differentiation and emergent (low) integration is not associated with high ambidexterity performance.

2.4 Scenario 4

Scenario 4 is developed under high levels of market, technological, and internal uncertainty accompanied by high levels of integrative complexity (high-level differentiation and high-level integration). Through cognitive differentiation, managers can understand the detailed distinctions between strategic domains, distinguish exploitation from exploration, and recognize the unique contributions of each to the overall corporate strategy (Smith et al., 2012). Cognitive differentiation could help CEOs understand where various strategic domains differ in detail, helping to craft dual strategies. In this scenario, a high level of cognitive integration reduces information overload by contracting differentiated models or translating a laundry list of differentiated factors into a critical assessment of essential features. In the presence of a high level of integrative complexity and the ability to establish connections between main features, it is expected that managers avoid high-risk strategies and come up with a balanced array of ambidextrous strategies. Thus, we hypothesize that:

H4: High-level integrative complexity along with high-level risk complexity is associated with ambidexterity performance.

3. Research Method

3.1 Measures and Data

All questionnaires were administered in Persian. To ensure content similarity with original scales, a translation/back translation procedure was used. Two independent bilingual persons translated all the scales into Persian.

To examine the relationship between cognitive complexity, risk complexity, and ambidexterity performance, data were collected from small and medium-sized enterprises in Iran. These companies were active in the manufacturing and service sectors and, according to the common definition of SME in the region, had between 10 and 250 employees. Due to resource constraints, convenience sampling was used, which is particularly appropriate for exploratory research like this study.

In this study, 60 CEOs and senior managers of small and medium-sized companies in Iran participated. They were selected because of their role in strategic decision-making in the company. Data collection was carried out by distributing Persianized questionnaires through industry associations and professional networks within the country. Due to the exploratory nature of the research and the complexity of the neural network analysis, this sample size (60) was considered sufficient for initial modeling, although the generalization of the results to broader areas is limited.

To ensure data quality, incomplete responses were removed, resulting in a final usable sample of 60 responses. The sample included companies from different industries to capture different levels of risk complexity. While this sample provides initial insights into cognitive and risk dynamics in SMEs, its size and non-random selection limit the generalizability of the findings. Future research with larger random samples is recommended to validate these results.

3.2 Cognitive Differentiation and Integration (Integrative Complexity)

Integrative complexity comprises cognitive differentiation and integration and was measured as a higher-order construct (Hair et al., 2014). Cognitive differentiation was measured by a 6-item scale. A sample item is “I believe in the value of dissent.” Cognitive integration was measured by a 5-item scale. A sample item is “I highlight connections between seemingly conflicting perspectives raised by people on an issue” (Zhang et al., 2015). The items were used

to measure the cognitive integration and differentiation levels of the respondents. The scale applied by Oleynick (2015) has been used in the current study. The construct measures the tendency to perceive similarities and see a need for integration, as well as the tendency to perceive differences and see a need for differentiation. In this measurement model, "integration" and "differentiation" are conceptually distinct, unipolar dimensions of personality. This model implies that some individuals are high in both integration and differentiation, and conversely, that some individuals are low in both of these traits.

3.3 Ambidexterity Performance

In previous literature, in order to measure ambidexterity, the process and product innovation orientation of the managers is primarily assessed, and then the higher-order construct of ambidexterity is calculated (Alamsjah & Yunus, 2022; Cao & Jiang, 2022). However, in the present study, in alignment with the purpose of the research measuring ambidexterity performance, the scale is adapted considering the newness, the rate of change, and the diversity of innovation in explorative and exploitative strategies.

3.4 Technology, Market, and Internal Complexity

With regard to the purpose of the current study, which is to elicit respondents' perceptions of technology uncertainty in product development and process development projects, the scale is adopted from the study by Song and Montoya-Weiss (2001) ($\alpha = .87$). In this scale, respondents are asked to assess the level of technology uncertainty associated with innovation projects. The variable measuring market uncertainty, using a five-point Likert scale, captures changes in customer needs, changes in demand, and competitive pressures, and is adopted from previous studies.

In the case of internal uncertainty, risks related to managing resource availability (e.g., employee activities and equipment) and controlling project risks, such as time and cost in new product development, are taken into consideration. The scale is adopted from previous studies on internal uncertainty and its effect on investment decision-making in explorative and exploitative projects (Aslam et al., 2018; Kodama & Shibata, 2014; McGee & Sawyerr, 2003; Yang & Gabrielsson, 2017).

3.5 Validity and Reliability

Cronbach's alpha assumes that the observed variables of each measurement model have equal weights and, in fact, it treats their relative importance as the same. To overcome this limitation, the composite reliability index proposed by Werts et al. (1974) is used. In this index, because the factor loadings of the items are taken into account in the calculation, it provides a more accurate estimate of reliability than Cronbach's alpha. Simulation studies and methodological guidelines (e.g., Hair et al., 2011; Henseler et al., 2009) suggest that the minimum acceptable value of composite reliability should be at least 0.70. According to the results in Table 1, this condition is satisfied. To measure the degree of explanation of the latent variable by the observable variables, this study used an index called convergent validity and the results are presented in Table 2.

Table 2. Reliability and Convergent Validity

Factor	Cronbach Alpha	Composite Reliability	Convergent Validity
Cognitive differentiation	0.956	0.96	0.575
Economic uncertainty	0.856	0.89	0.539
Market uncertainty	0.882	0.907	0.549
Technological uncertainty	0.812	0.864	0.515
Operational uncertainty	0.826	0.884	0.655
Process innovation	0.813	0.877	0.641
Product Innovation	0.887	0.917	0.69
Cognitive Integration	0.96	0.963	0.594

3.6 Complexity Theory and Artificial Neural Network in Strategy Renewal

Complexity theory (CT) and complex adaptive systems (CAS) theory have emerged as the basis for an intriguing new research approach (Mitchell, 2009; Poutanen et al., 2016). It has been argued that complexity theory provides a new theoretical perspective and methodological approach, as well as a new set of concepts that integrate biological, cognitive, and social realms to describe organizations as vibrant, unstable, and complex systems.

The complexity framework encourages researchers to look at the evolution of individuals interacting with elements in their environments. Such a perspective can be highly relevant to innovation research, since innovation often grows out of the interaction of people, technology, and knowledge (Khezri, 2021; Poutanen et al., 2016).

Complexity theory is concerned with the way in which systems are created through the interaction of agents that follow collective rules of behavior (Mitchell, 2009) and with the fact that it provides the analytic tools and concepts with which to study these dynamics. There is an upward trend to study organizations as complex adaptive systems. Complex systems are thus open and adaptive systems consisting of agents, interactions, and an environment. In line with the evolution of complexity theory and advances in neuroscience research, Neural Networks (ANN) offer a fertile perspective, enriching our understanding of CEOs' role in strategic renewal and their potential to solve the tension from duality management labeled ambidexterity (O'Reilly & Tushman, 2008): exploitation vs. exploration (Khezri, 2021).

The literature review of Artificial Neural Networks (ANN) suggests several potential advantages that ANN has over statistical methods. ANN is capable of interpreting non-linear functions by providing algorithmic structures that can interact with the environment, similar to brain mechanisms such as learning from experience and generalizing, which is technically called the training rule. One of the popular algorithms used in many neural network applications is the "back-propagation learning algorithm" based on a "feed-forward" approach, which is used in the current study to evaluate the co-evolutionary effect of CEOs' paradoxical mindset and risk complexity of the business to come up with successful strategy renewal, labeled as ambidexterity performance.

To examine the potential non-linear relationships among the research constructs, an ANN model was developed in Python. In line with the conceptual framework, the model utilizes five input nodes representing the variables detailed in Figure 1.

Ambidexterity performance was specified as the output variable. The ANN was designed as a feed-forward single-hidden-layer network and was trained using a standard back-propagation learning procedure.

For model development and evaluation, the dataset was randomly partitioned into two subsets, with 80% of the observations used for training and the remaining 20% reserved for testing. This split was applied to assess the model's predictive performance on unseen data and to minimize the risk of overfitting. The predictive accuracy was evaluated using Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). All analyses were implemented in Python using standard data science libraries to ensure methodological transparency and reproducibility.

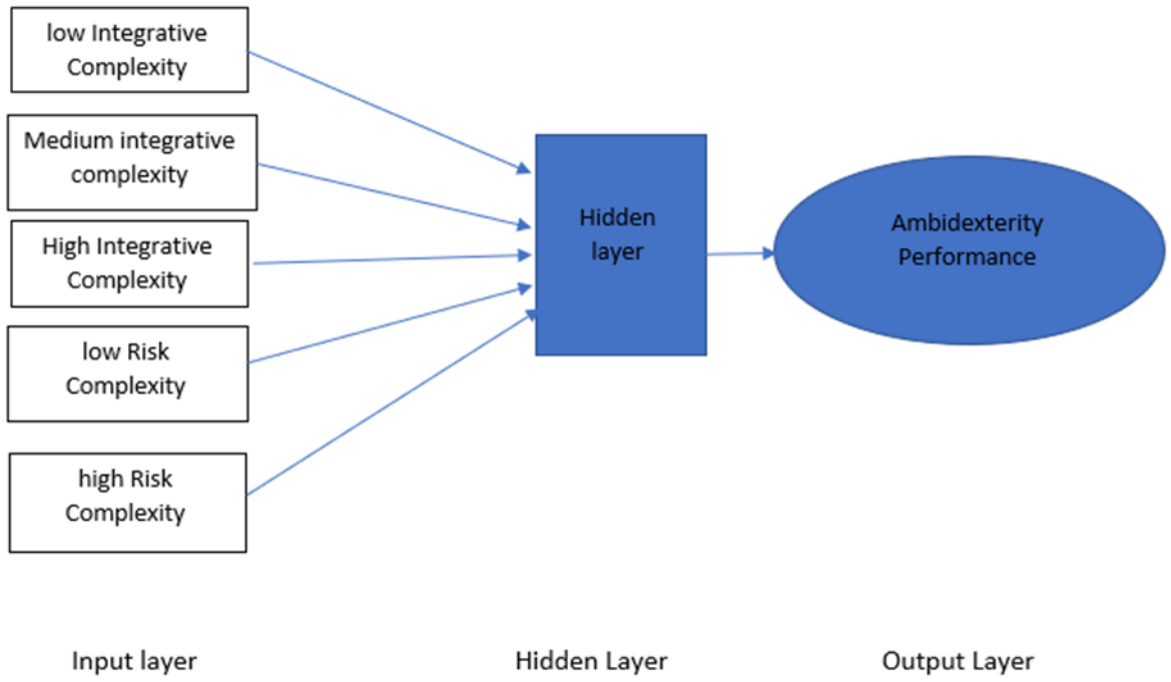

Figure 1. Neural Network based on Conceptual Model

In mathematical terms, we may describe the neural k by writing the pair of equation.

$$u_k = \sum_{\{j=1\}_{\{kj\}x_j}^{\{m\}w}} \quad (1)$$

$$y_k = \varphi(u_k + b_k) \quad (2)$$

where x1, x2…. xm are the input signals, wk1, wk2…. wkm are the respective synaptic weights of neural k, yk signifies the output signal of the neuron, uk represents the linear combiner output, bk denotes the bias, □ stands for the activation function

as

$$yk = uk + bk \quad (3)$$

We may formulate the combination of Equations (1) to (3) as follows:

$$v_k = \sum_{\{j=0\}_{\{k\,j\}x_j}^{\{m\}w}} \quad (4)$$

3.7 Network Generalizability

Generalization refers to the ability of a trained artificial neural network to respond correctly to input not used during the training process. Therefore, we train our model with one partition of the data set and test with another partition not used during the training. Network generalizability is related to the concepts of underfitting, overfitting, and smoothing in polynomial curve fitting. Underlearning and overlearning in neural networks are analogous to underfitting and overfitting, respectively, in polynomial models. Underlearning may occur when the complexity of the neural network, measured by factors such as the number of hidden nodes and connection weights, is insufficient to capture the complexity of the phenomenon being modeled.

Overfitting is the opposite and can occur when network complexity exceeds the complexity of the phenomenon being modeled. Thus, complexity in neural networks is analogous to the flexibility that can be achieved by changing the power of the polynomial in line fitting. Study of the statistical properties of network generalization error led to valuable insight regarding methods and strategies for attacking the generalization problem in neural networks.

In statistics, the mean squared error (MSE) of an estimator is one of many ways to quantify the difference between values implied by an estimator and the true values of the quantity being estimated. MSE is a risk function corresponding to the expected value of the squared error loss or quadratic loss. MSE measures the average of the squares of the "errors." The error is the amount by which the value implied by the estimator differs from the quantity to be estimated. The difference occurs because of randomness or because the estimator does not account for information that could produce a more accurate estimate. The MSE is the second moment of the error, and thus incorporates both the variance of the estimator and its bias. For an unbiased estimator, the MSE is the variance. Like the variance, MSE has the same units of measurement as the square of the quantity being estimated. In an analogy to standard deviation, taking the square root of MSE yields the root mean square error or root mean square deviation (RMSE or RMSD), which has the same units as the quantity being estimated; for an unbiased estimator, the RMSE is the square root of the variance, known as the standard deviation. The MSE of an estimator with respect to the estimated parameter θ is defined as:

$$\text{MSE}(\theta) = \text{E}[(\theta - \theta)\,2] \quad (5)$$

The MSE is equal to the sum of the variance and the squared bias of the estimator

$$\text{MSE}(\theta) = \text{Var}(\theta) + [\text{Bias}(\theta, \theta)]\,2 \quad (6)$$

Variance in this case represents the network's sensitivity to the particular data set used in the training process. Conversely, the bias of the network represents the difference between the target (actual) output of the network t, given a set of input, and the average output of the network over all possible data sets. Increasing the generalizability of a given network involves reducing variance and bias. Network complexity, as a function of the number of weights and hidden nodes in the network's structure, affects both variance and bias. Bias is negatively related to network complexity, but variance is positively related to complexity. Therefore, to achieve good generalizability in a network, we seek the optimal network complexity that minimizes the trade-off between variance and bias.

4. Result and Discussion

In constructing the network and evaluating the quantitative measurement of the amount of network, training error indicators (RMSE, MAE) have been applied to determine the amount of network learning. This index reflects how close the network is to producing correct answers. Often, the allocation of data to these two sets is done in one of the ratios of 90%-10%, 20%-80%, or 70%-30%.

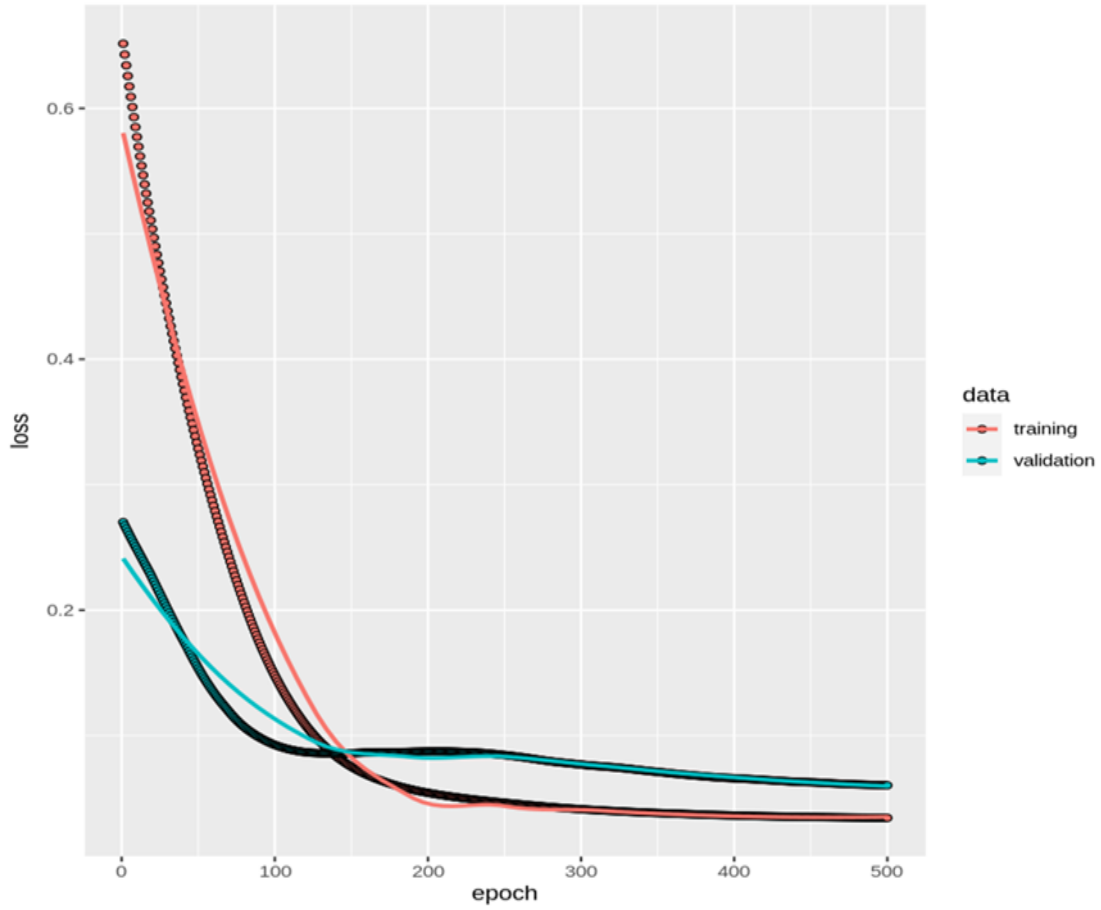

Figure 2

According to the above figure, we can see that the network is well trained during the set repetitions. From the table below, we have the MAE and RMSE loss function values for the training data of the network

Table 3

MAE	RMSE
0.147	0.186

In this research, ambidexterity performance was modeled using single-layer neural networks, and 4 scenarios were defined. The results were analyzed using the output of the network model.

Table 4. Scenarios of Interaction between levels of IC & RC

Scenario	Risk (Uncertainty)	Integration	Differentiation
1	Low	High	high
2	High	Low	high
3	Low	Low	low
4	High	High	high

The threshold of each of the above scenarios is obtained by the quartiles of these indicators. In this way, the first quartile is considered as the low level and the third quartile as the high level, the results of which are summarized in table below.

Table 5

Indictors	Quartile 1	Quartile 3
differentiation	-0.6955	0.7915
integration	-0.9255	0.81875
Risk(uncertainty)	-0.865	0.8525

The table below shows the output of the network under the above 4 scenarios:

Table 6.

Scenario 1	Scenario 2	Scenario 3	Scenario 4
0.659	0.754	0.546	0.752

Evaluating the predicting power of scenarios of intervention between cognitive complexity of CEOs and risk complexity through artificial neural network has proven the first hypothesis in scenario 1 not being fully supported. In scenario 1, with low level of risk, even high level of differentiation and integration cannot lead to highest level of ambidexterity performance.

This finding is in line with the notion that certain degree of risk is the perquisite driver to trigger ambidexterity optimal functioning (Harrison, 2022; Malhotra & Samimi et al., 2026; Severgnini et al., 2019; Yu et al., 2023). Recent studies also indicate that cognitive complexity is less effective in stable environments where environmental signals are weak and managerial sensemaking is under-activated.

The finding from current study refuses the second hypothesis, predicting the occurrence of low ambidexterity performance for scenario 2 (High Risk accompanied with Medium IC, labeled by High differentiation with Low integration). This finding indicates the inefficacy of lower levels of integrative complexity (Carter, 2015), and sheds new light on studies finding a negative effect of cognitive complexity on strategic change (Kiss et al., 2021). The current study narrows down studies proposing the positive effect of cognitive flexibility (Becker & Klarner, 2021). These results also extend prior work on cognitive complexity and strategic change by challenging linear assumptions and supporting more contingent and context-dependent effects. While earlier studies proposed curvilinear or inconsistent relationships between cognitive complexity and organizational outcomes (Bao et al., 2020), more recent research suggests that

boundary conditions, such as environmental uncertainty, significantly reshape these relationships rather than merely moderating their strength (Malhotra & Harrison, 2022).

The new insight in current study could be explained from two perspectives. First, this result can be justified by referencing the importance of perceptual mental activities that encompass differentiation—a key cognitive capability. Perceptual mental activity refers to the brain's process of combining sensory data from the environment with "knowledge and expectations to make reasonably informed guesses" about what is present in the environment. Previous studies investigating on response speed of experienced people have shown the importance of pattern recognition in being responsive to both opportunities and threats. This could justify the association between scenario 2 and high ambidexterity performance, as in many cases, the differentiation capability could work out as long as it is fueled by high level of risk. Additional paradox theory research also supports that differentiation without full integration does not necessarily suppress ambidexterity when environmental complexity is high (van Neerijnen et al., 2022).

The result supports hypothesis in Scenario 3, proposing inability of Low IC along with low-Risk complexity in determining high ambidexterity performance. The result could be justified by referring to a lack of paradoxical cognitive frames nesting differentiation and integration, and the presence of Unitary cognitive frame and its inefficacy in dual recognition of attributes of an issue. In case of the Unitary cognitive frame of CEOs, embodied with little differentiation and integration, CEOs are prone to narrowing down a strategic issue to threats incapable of comprehending different attributes of an issue. CEOs with a univalent frame are prone to engage in a focused search for a narrow range of solutions and consider linkages to analogous issues evaluated in similar contexts (Plambeck & Weber, 2010).

Constrained in their ability to identify novel linkages, CEOs tend to retreat to the existing business model and follow a routine that resembles minor product adjustments, rather than exploring new product-markets which leads to a low level of ambidexterity. Recent evidence further confirms that low cognitive complexity reduces the capacity for paradoxical thinking and limits exploratory search behavior (Samimi et al., 2026)

The result supports hypothesis 4. In Scenario 4, where high environmental risk coincides with high levels of cognitive differentiation and integration, ambidexterity performance reaches its highest level. Unlike low-risk contexts, in which cognitive complexity may remain underutilized, high environmental risk increases the salience of competing strategic cues and requires executives to engage in greater cognitive integration and deeper sensemaking (Wilms et al., 2019). CEOs with high differentiation are able to recognize both threats and opportunities embedded in uncertainty, while high integration enables them to connect these elements into a coherent strategic understanding, preventing fragmentation and facilitating the simultaneous pursuit of exploration and exploitation (Wilms et al., 2019). Accordingly, this finding suggests that cognitive complexity exerts its strongest positive effect on ambidexterity when executives are able to accommodate paradoxical strategic demands under conditions of heightened risk (Tarba et al., 2020; van Neerijnen et al., 2022). Recent empirical evidence also supports that CEO's cognitive flexibility is most impactful on ambidexterity under high environmental dynamism and uncertainty (Malhotra & Harrison, 2022).

5. Conclusion

The question remains in the strategy renewal literature how continuous strategic renewal can be embedded as an integral facet of organizational life while minimizing the need for inevitably disruptive structural reorganization (O'Reilly & Tushman, 2016) and avoiding falling into

success and failure traps. There have been early efforts to define ambidexterity as executives' ability to balance deliberate and emergent strategies, highlighting the role of CEOs' strategic assumptions as a key driver of strategy renewal practices (Bodwell & Chermack, 2010). This research stream has advanced by investigating how scenario planning, taken not as a tool to foresee the future, but rather to encourage managers to explore strategic responses beyond the scope of their previous experiences and their established search processes, can apply a perceptual style of thinking. This approach contributes to cognitive dynamics and strategic investment decisions in a changing environment (Vecchiato, 2019).

The result from this study, in support of both positive and negative effects of risk, is in line with studies conducted by Severgnini et al. (2019), Yu et al. (2023), and Gilbert (2005), arguing that the threat framing of environmental change intensifies routine rigidity but promotes flexibility of resource commitment; however, the opportunity framing relaxes the routine rigidity while failing to elicit adequate resource commitment. Therefore, risk interacting with cognitive frames of differentiation and integration is interpreted as both negative and positive, which is likely to accommodate CEOs to take balanced array of exploitative and explorative strategic actions.

Moreover, the findings shed light on the superiority of perceptual thinking against analogical thinking in SMEs facing risk complexity.

The results obtained in this study are also consistent with the real world. In conditions where the level of risk and uncertainty is high, managers tend to make decisions as quickly as possible because top-level managers demand making decisions faster. Accordingly, they do not conduct long or comprehensive analyses and instead adopt a quick and general view. This explains the findings of this study which state that high risk combined with high cognitive complexity leads to increased ambidexterity performance.

In contrast, in environments where risk is low and there is a certain level of stability, and cognitive complexity is also high, the outcome is not necessarily high performance. This is because, due to environmental conditions, there is not much need for continuous interpretation or rapid response. Therefore, it can be said that the results of this study reflect a real pattern in the business world, in such a way that ambidexterity is not merely the result of a high level of cognitive complexity, but rather the outcome of the alignment between managers' way of thinking and environmental conditions (level of risk).

5.1 Theoretical and Managerial Implications

The findings of this study suggest that cognitive complexity is not inherently beneficial for ambidexterity performance. Its value depends on whether it is aligned with the level of environmental risk. In low-risk settings, even high cognitive complexity does not necessarily improve ambidexterity, whereas in high-risk contexts, cognitive differentiation becomes more effective in helping CEOs recognize both threats and opportunities.

From a theoretical perspective, these findings support a context dependent view of ambidexterity and extend prior research on the nonlinear effects of executive cognition (Bao et al., 2020; Fong, 2006). They highlight that cognitive resources create value when they fit the level of environmental uncertainty, rather than through their absolute level. Practically, it implies that CEOs should not apply a fixed decision-making style across all situations, but should adapt their cognitive approach to the level of turbulence they face.

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