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Evaluating Innovation Capability in Banking Under Uncertainty

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***Abstract*—The evaluation of innovation capability (IC) plays a key role in an age of keen competition driven by modern technologies, since it enables organizations to review their innovation management process and to adjust their corresponding innovation policies. Moreover, the IC evaluation is, in fact, a multicriteria process with high uncertainty, since the market environments and competitors' performance are both in a dynamic environment. Therefore, the evaluation of IC under uncertainty is vital to organizations. This study proposes a new integrated method for the evaluation of IC in banking organizations by combining the analytic hierarchy process (AHP) and the evidential reasoning (ER) approach in terms of the Dempster–Shafer theory of evidence. Three Vietnamese banks were used as a case study to demonstrate the applicability and validity of the proposed method. Experts in banking-related fields were invited to determine the relative importance weights of critical innovation management practices (CIMPs) and their sub-CIMPs using the AHP and to score the maturity levels of sub-CIMPs at the evaluated banks. The ER approach was then applied to generate aggregated assessments representing the ICs of banks that were finally used for their ranking in terms of IC.**

***Index Terms*—Analytic hierarchy process (AHP), banking, evaluation, evidential reasoning (ER), innovation capability (IC), uncertainty.**

I. Introduction

DURING the industrial revolution 4.0 with the great pressure on changing technologies, global competition, and constantly fluctuating environments, every organization must regularly innovate its products/services to satisfy better customer demands, respond to dynamic markets, strengthen competitiveness, and achieve superior business performance. Abundant evidences suggest that innovation is a crucial driving force to create sustainable competitive advantages [1]–[3]. Not surprisingly, innovation widely occurs in not only manufacturing companies but also service sectors. In addition, the innovation evaluation also plays an important role in innovation management and has recently received considerable attention from the literature. For instance, Dozier and Montgomery [4] conducted an in-depth investigation of the evaluation process utilizing the grounded theory approach for blockchain technology innovation in banking. Wang *et al.* [5] proposed an evaluation method using a two-stage data envelopment analysis model for innovation efficiency of the patent-intensive industry. Koliouska *et al.* [6] developed a multicriteria evaluation model for tourism enterprises in Greece through their websites that not only allows identification of the most successful practices, but also provides suggestions for service improvement or innovation taking advantage of the opportunities arising in the new era of technological innovation in the tourism sector.

In the banking sector, banks have been rapidly improving and diversifying their services by integrating new technologies to accelerate service delivery processes, improve service quality, and bring personalized experiences to their customers. Innovation was found to have a positive impact on service delivery and customer satisfaction in the banking industry of Ghana [7]. It is, thus, helpful for banks to increase their profitability and performance [8], [9]. However, innovation causes multidimensional difficulties because it requires organizations to integrate numerous organizational resources, such as innovation decision, research and development (R&D), marketing, capital, and manufacturing capabilities [10]. To innovate effectively, banks have to enhance their innovation capability (IC) [3] by simultaneously managing, continuously improving, and reasonably investing in various innovation management practices (IMPs) in their innovation processes. The existing literature has presented a great number of IMPs across sectors [11]–[14]. Depending on specific business contexts, managers should adopt suitable IMPs carefully and allocate resources properly to attain their expected innovative performance. According to [15], the identification of innovation activities to be measured and improved helps managers to make sure that their organizations are innovative, become aware of the important factors, and develop an appropriate roadmap to be more innovative. Hence, an IC evaluation method in banking is required to point out the development

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degrees of IMPs in banks, to highlight the most important areas upon which banks should focus on to improve, and thereby to adjust their corresponding innovation strategies to upgrade their IC to increase innovation outcome and business performance.

Although extensive research has been carried out on IC assessment in the manufacturing sectors [10], [16]–[19], very few studies have been devoted to evaluating IC in the service sectors, especially in banking. An amount of research has shed some light on innovation in banking; however, no single study exists that adequately covers the problem of IC evaluation in banking. Drew [20] highlighted some important IMPs in banks and financial service firms in Canada, such as strategic planning, cultural and organizational changes, generation and transfer of ideas, human resources and budgets spending on innovation, R&D, process and product innovation, and joint ventures for innovation. Other existing works on innovation in banking only consider a single facet; for example, on culture and strategic orientation [21], top management [22], technology [23], customer knowledge management [24], teamwork [25], or organizational learning [26]. There remains a lack of a comprehensive research on IC evaluation in banking, and the importance of IMPs in banking is still in question.

Under the above observation, this study aims to contribute to the literature by proposing a new framework to evaluate broadly the innovation management process of many different IMPs in banks and to determine the importance weights of these IMPs in banking innovation. In particular, we first apply Pareto analysis to derive the most common IMPs from the relevant studies that can be used in banking and then propose an IC evaluation method under uncertainty by combining the analytic hierarchy process (AHP) and the evidential reasoning (ER) approach. The AHP, developed by Saaty [27], is a powerful tool and an effective method in multiattribute decision making (MADM); it is employed to set the priorities among the IMPs in banking innovation. In this study, the experts evaluate the IMPs based on a five-point scale from their individual perspectives; however, this potentially leads to conflicts among experts' opinions. For dealing with this problem, the ER approach for multiattribute decision analysis, proposed by Yang and Singh [28], can provide a method for multiattribute aggregation under various uncertainties. Although the ER approach has been widely applied in evaluations of services [29]–[33], this study can be regarded as the first attempt to apply the ER approach in combination with the AHP for IC evaluation. Finally, the utility function introduced by Yang and Xu [34], Huynh *et al.* [35], and Huynh *et al.* [30] is used as a tool for ranking the banks based on the aggregated IC assessments. The findings of this study provide a framework for banks to intensively review their IMPs, explore their strengths and weaknesses, and identify new strategies that could potentially enable banks to enhance their IC and innovation outcomes. For empirical evidence, we collect innovation practices data and compute the corresponding IC in Vietnamese banks, where there is hardly any research on evaluating IC.

The remainder of this article is structured as follows. Section II reviews theories of innovation, IC, IC in bank industry, and typical IC evaluation methods in the literature. Section III presents our proposed process to evaluate the IC of banks in steps. The empirical results of using our IC evaluation method in the case study of three Vietnamese banks are displayed in Section IV. Discussions, implications for theory and practice, limitations, and suggestions for future research are presented in Section V.

II. Literature Review

A. Innovation

Today, references to the concept of "innovation" are common in scientific studies and discussions among practitioners and researchers, though there seems to be some disagreement on its meaning. Damanpour [36] defined innovation as a means of changing a firm to adapt to the changing external environment. Similarly, Rogers [37] argued that innovation is a change in business activities for improving firm performance. Du Plessis [38] stated that innovation is the creation of new ideas and knowledge to improve business processes and create new products/services for facilitating new business outcomes. Additionally, Bigliardi [39] referred to innovation as a process of producing, diffusing, and translating knowledge in developing new or modified products/services, production, or processing techniques. Singh *et al.* [40] focused on the concept of open innovation that includes inbound internalization of new ideas from external sources and outbound commercialization of internally developed ideas to the external environment. Innovation is currently attached to the applications of technologies because of their information processing abilities overcoming human constraints [41], [42]. For instance, Kaur *et al.* [43] explored that cognitive computing technology as an enabler of knowledge integration can support ambidextrous organizations in both exploiting current operations and exploring new business opportunities through collaboration with suitable global strategic partners to become more innovative. Baregheh *et al.* [44] carried out a content analysis of definitions of innovation from different disciplinary literature. They found that three words "new," "change," and "improve," frequently co-occur with innovation. From these definitions of innovation, innovation can be generally defined as the positive changes in an organization based on new ideas that create something new or improved to obtain higher business performance.

Innovation encompasses a wide range of forms, for instance, new products or services, new methods or processes, new organizational structures, new administrative systems, new markets, new technologies, new plans or programs, and new marketing practices [1], [36], [45]–[49]. Based on the level of novelty of an innovation, it can be divided into two categories: incremental and radical [50], [51]. Radical innovation concerns a revolutionary change of complete novelty that breaks with existing practices and leads to considerable challenges and opportunities [36], [52]. In contrast, incremental innovation is an improvement with a low degree of novelty based in current products/services, technologies, processes, and organizations [53]. Whereas a radical innovation can help a firm enter a new product market, incremental innovations on that product decide its ability to remain competitive [54]. As radical innovations require more resources and are riskier compared to incremental innovations [55], the majority of innovations are incremental.

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B. Innovation Capability

Christensen [56] argued that an innovation requires the combination of many types of assets, including process innovative assets, product innovative assets, scientific research assets, and aesthetic design assets. From a similar perspective, Sen and Egelhof [54] asserted that organizations need to utilize a broad array of their resources, assets, and capabilities to implement an innovation successfully. Accordingly, they defined IC as occurring at a wide dispersal of scopes and levels to serve the organizational strategies and response to the external environment's requirements. According to Szeto [57], IC means the continual development of the total abilities and assets in a company to identify and benefit from the creation of new products to meet market demands. Burgelman *et al.* [58] stated that IC includes all characteristics in an organization that facilitate and support the organizational innovation strategy. Wang and Ahmed [59] conceived IC as being capable of using strategic orientation, technological processes, and innovative behaviors to generate new products. Chen and Jaw [60] explained that IC is the ability of a firm to create an innovative process or product based on processes, organizational structure, and systems. Multiple factors must be considered to increase a firm's IC such as top management, knowledge sharing, and organizational support [40], [61]. From the various definitions of IC, the IC of a firm can be defined as a complex construct that includes different IMPs related to strategies, resources, technologies, processes, knowledge, organization, etc., that assist to realize innovative ideas into new or improved products/services. Guan and Ma [62] stated that IC is a special asset of an organization that establishes the base for competitive advantages. If an organization possesses a higher IC, it can quickly adopt new processes to reduce production costs, produce new products/services to attract more customers, increase barriers against imitations by competitors, and thereby obtain a better competitive position [63].

Because of the complicated nature of IC, it is essential to take into account multiple criteria simultaneously when evaluating the IC of a firm to comprehensively capture all of a firm's necessary capabilities to innovate effectively. A large body of literature has revealed that the authors of prior studies mainly used the number of IMPs to assess IC in different sectors. For example, Rejeb *et al.* [64] developed an IC measurement method considering 13 IMPs: collective learning, competence management, creativity, design tasks, integrated strategy, knowledge management, moral support, network management, portfolio management, process improvement, project management, suitable organization, and survey tasks. Wang and Chang [65] developed an innovation value diagnosis system of five modules consisting of strategy innovation, product innovation, organization innovation, process innovation, and resource innovation. Tidd and Thuriaux-Alemán [14] indicated sectors' varying levels of effectiveness by evaluating eight groups of IMPs: innovative strategies, idea management, resources and competence management, technological portfolio management, product portfolio management, development and launch, external business intelligence, and postlaunch.

This study also relies on an innovation management process of different IMPs to measure IC in banking. A search was conducted on a wide range of keywords, such as innovation capability, innovation capability evaluation, innovation management practices, innovation practices, innovation management measurement, empirical innovation management, and new product development practices. As a result, 28 articles that are most related to the scope of this study were chosen. A number of IMPs were extracted from these 28 studies. By grouping the relevant IMPs together according to their descriptions in the related works, we categorized them into 24 main IMPs that can be used in the banking sector. They are: 1) strategic management; 2) resource management; 3) organization management; 4) idea management; 5) process improvement; 6) marketing management; 7) R&D; 8) cooperative learning; 9) portfolio management; 10) knowledge management; 11) technology management; 12) network management; 13) product innovation; 14) project management; 15) performance measurement; 16) team management; 17) moral support; 18) commercialization management; 19) business intelligence; 20) survey task; 21) senior management; 22) risk management; 23) management participation; and 24) delegation (see Table I).

C. IC in Bank Industry

According to Tajeddini *et al.* [86], banks must explore new opportunities to be highly innovative for achieving long-term success and stable performance. The investment of innovation strategies and new technologies can help banks to enhance their fragility and growth [87]. Nowadays, the high-tech application can be considered as an important measure of the extent of bank innovation. Abualloush *et al.* [88] found that the use of management information systems (decision support system and executive information systems) positively affects product innovation and process innovation in the Housing Bank in Irbid Governorate. The adoption of modern technologies, such as machine learning and blockchain, helps banks not only serve customers faster and reduce operational costs, but also increase security and transparency [4]. Banks also continue to launch new versions of digital banking, which helps to improve banks' networks in the areas of withdrawals, deposits, and other activities and, therefore, leads to a positive impact on financial inclusion [89], [90]. Concurrently, to better understand customers, banks are racing to collect and process data using artificial intelligence and Big Data from nontraditional channels such as social networks, behavioral psychology, telecommunications, and also through cooperation with FinTech companies. Such collaboration with technical alliances tends to strengthen organizational IC [54]. Particularly, the coordination between banks and FinTech companies helps both parties take advantages of their respective strengths. Whereas the strengths of banks lie in their customer base, ability to predict the growth of the banking industry, and knowledge of laws and regulations in banking operations, FinTech companies can create disruptive innovations based on their advanced technology platforms that are not held back by existing systems [91]. Thus, Palmié *et al.* [92] posited that

TABLE I
LIST OF IMPs IN THE LITERATURE

No	IMPs	Authors
1	Strategic management	[10], [12], [14], [17]–[20], [64]–[81]
2	Resource management	[10]–[12], [14], [17]–[20], [64], [65], [67], [69]–[72], [74], [76]–[78], [80]–[82]
3	Organization management	[11], [12], [17]–[20], [64]–[66], [68], [69], [72], [73], [76]–[78], [80]–[83]
4	Idea management	[14], [18]–[20], [64], [66], [69], [70], [74]–[76], [79], [84]
5	Process improvement	[14], [17], [18], [20], [64], [65], [68], [74], [76], [80], [82], [85]
6	Marketing management	[10], [11], [18], [19], [70], [72], [77], [78], [82]
7	R&D	[10], [11], [18], [20], [70], [72], [77], [78], [81]
8	Cooperative learning	[11], [18], [64], [72], [75], [77], [78], [82]
9	Portfolio management	[12], [14], [18], [64], [71], [73], [74]
10	Knowledge management	[12], [17]–[19], [64], [78], [81]
11	Technology management	[69], [70], [75], [76], [78], [79], [82]
12	Network management	[18], [20], [64], [67], [73], [78]
13	Product innovation	[20], [65], [76], [79], [82]
14	Project management	[12], [18], [64], [76]
15	Performance measurement	[66], [68], [70], [73]
16	Team management	[75], [78], [83]
17	Moral support	[18], [64]
18	Commercialization management	[12], [76]
19	Business intelligence	[14], [69]
20	Survey task	[18], [64]
21	Senior management	[83]
22	Risk management	[78]
23	Management participation	[75]
24	Delegation	[75]

FinTech ecosystems can disrupt the financial service industry to create grand innovative changes in the future.

Besides the many opportunities that the wave of new technologies brings, banks are encountering severe challenges regarding transforming processes, developing infrastructure, recruiting high-quality human resources, and managing risks to adapt to the age of technology. Harle *et al.* [93] claimed that the continuous emerging of technological innovations requires new risk-management techniques to detect, manage, and reduce risks in banking operations. Azarenko *et al.* [94] stated that in the digital transformation of the economy, personnel need to be trained to master professional digital skills and competences in the technology fields. To this end, to innovate successfully, banks should adopt a multiple-dimensional innovation management process to enhance their IC and obtain better innovation performance.

D. Multicriteria Evaluation Approach to IC

Rejeb *et al.* [64] and Boly *et al.* [18] presented an IC measure framework using the multiple criteria approach and value test method. They considered multiple IMPs that are subdivided into multiple directly observable criteria. If a criterion exists, its score equals 1; otherwise, its score equals 0. The problem of evaluating the IC of companies is solved by using two levels of aggregation. In the first aggregation, the development degree of IMP i at a company (p_i) is determined by averaging the values of corresponding criteria: $p_i = \frac{1}{m_i}\sum_{j=1}^{m_i} q_{ij}$, where m_i is the number of criteria related to IMP i; and q_{ij} is the score of criterion j related to IMP i, $q_{ij} \in \{0,1\}$. The second aggregation is to compute the potential innovation index (PII) for a company: PII $= \sum_{i=1}^{n} w_i p_i$ with $\sum_{i=1}^{n} w_i = 1$, where n is the number of IMPs; p_i is the development degree of IMP i at a company, $p_i \in [0;1]$; and w_i is the weight of IMP i, $w_i \in [0;1]$.

The process of classifying all companies into four innovative groups (proactive, preactive, reactive, or passive) based on PII values is iterative until the latter classification is the same as the previous classification. In the initial classification, the same weights are used for all IMPs in all four groups to calculate PII values. For generating the next classifications, a statistical method called a "value test" is employed to redetermine the weight vector for each group, using the previous classification. The value test of an IMP in a group l is computed as follows:

$$v_l(x) = \frac{\bar{x}_l - \bar{x}}{s_l(x)} \quad \text{with} \quad s_l^2(x) = \frac{r - r_l}{r-1}\frac{s^2(x)}{r_l} \tag{1}$$

where $v_l(x)$ is the value test of IMP x in group l; $\bar{x}_l$ and $\bar{x}$ are the average of IMP x in group l and the average of IMP x in the sample, respectively; $s_l(x)$ and $s(x)$ are the standard deviation of IMP x in group l and the standard deviation of IMP x in the sample, respectively; and r_l and r are the number of companies in group l and the number of companies in the sample, respectively. The importance of each IMP in each group is then calculated in proportion to the value test of this practice. Finally, they recalculate PII values for all companies using the weight vector of the proactive group first, then rank all companies in descending order of PII values, and select the well-ranked companies for the proactive group. By performing a similar procedure for the remaining companies using the weight vectors of the three remaining groups in turns, the remaining companies will be classified into the three remaining groups.

E. Uncertain Evaluation Approach to IC

1) *Wang et al.'s method:* Wang *et al.* [10] employed a non-additive measure and fuzzy integral method to evaluate

technological IC based on a hierarchical analytical system of five aspects that include various qualitative and quantitative criteria. For the degrees of IC, quantitative criteria are described by crisp numbers, while qualitative criteria are rated by linguistic variables {very poor, poor, fair, good, very good}, which are turned into triangular fuzzy numbers. The degrees of importance for criteria are expressed as {very low, low, medium, high, very high}, which are also represented by triangular fuzzy numbers.

To get the aggregated fuzzy evaluation for the degree of IC of each criterion, the fuzzy arithmetic to three vertices of triangular fuzzy numbers given by K evaluators is computed by (2). Similarly, the degree of importance of each criterion on the basis of K evaluators' ratings is determined using (3)

$$\bar{x}_{ij} = \left(\frac{1}{K} \sum_{k=1}^{K} L_{x_{ij}^k}, \frac{1}{K} \sum_{k=1}^{K} M_{x_{ij}^k}, \frac{1}{K} \sum_{k=1}^{K} R_{x_{ij}^k} \right) \quad (2)$$

$$\bar{g}_{ij} = \left(\frac{1}{K} \sum_{k=1}^{K} L_{g_{ij}^k}, \frac{1}{K} \sum_{k=1}^{K} M_{g_{ij}^k}, \frac{1}{K} \sum_{k=1}^{K} R_{g_{ij}^k} \right) \quad (3)$$

where $\bar{x}_{ij}$ represents the average rating over K evaluators for the degree of IC of criterion j associated with aspect i; $L_{x_{ij}^k}, M_{x_{ij}^k}$, and $R_{x_{ij}^k}$ are, respectively, the left, middle, and right loci of the triangular fuzzy number for the kth evaluator's rating for the degree of IC of criterion j associated with aspect i, $k = 1, 2, \ldots, K$; $\bar{g}_{ij}$ is the average rating over K evaluators for the degree of importance of criterion j associated with aspect i; $L_{g_{ij}^k}, M_{g_{ij}^k}$, and $R_{g_{ij}^k}$ are the left, middle, and right loci of the triangular fuzzy number for the kth evaluator's rating of the degree of importance of criterion j associated with aspect i, $k = 1, 2, \ldots, K$. The fuzzy numbers $\bar{x}_{ij}$ and $\bar{g}_{ij}$ are then defuzzified into crisp numbers using the method proposed by Chen and Klein [95].

Because all criteria are assumed not to be absolutely independent, the authors applied the Choquet integral, which is considered as a nonadditive fuzzy integral to derive the aggregated assessment for each aspect as well as generate the overall assessment of technological IC for each company in the same way. The Choquet integral of p with respect to g is determined by

$$(C) \int p \mathrm{d}g = p(x_1).g(\mathcal{H}_1) + p(x_2).[g(\mathcal{H}_2) - g(\mathcal{H}_1)] + \ldots + p(x_N).[g(\mathcal{H}_N) - g(\mathcal{H}_{N-1})] \quad (4)$$

where $p(.)$ represents the IC performance of a criterion related to an aspect, such that $p(x_1) \geq p(x_2) \geq \ldots \geq p(x_N)$; $g(.)$ is the degree of subjective importance of a finite set of criteria: $\mathcal{H}_1 = \{x_1\}, \mathcal{H}_2 = \{x_1, x_2\}, \ldots, \mathcal{H}_N = \{x_1, x_2, \ldots, x_N\}$. The computation of $g(\mathcal{H}_n)$ with $n = 1, 2, \ldots, N$ is as follows:

$$g(\mathcal{H}_n) = g_\lambda(x_1, x_2, \ldots, x_n) = \frac{1}{\lambda} \left| \prod_{z=1}^{n} (1 + \lambda \ . \ g_z) - 1 \right| \quad (5)$$

where the parameter λ of a λ-fuzzy measure [96] is determined based on the following equation: $\lambda + 1 = \prod_{z=1}^{N} (1 + \lambda \ . \ g_z)$; g_z is the degree of importance of each criterion.

2) *Cheng and Lin's method:* Cheng and Lin [16] developed a fuzzy expansion of the Technique of Order Preference Similarity to the Ideal Solution (TOPSIS) to evaluate the performance of various technological IC criteria under uncertainty. Similarly to Wang *et al.* [10], fuzzy set theory was employed to express the vagueness in the subjective judgment of evaluators on the technological IC performance and the importance of qualitative criteria mathematically, using trapezoidal fuzzy numbers. The ideas of TOPSIS introduced by Hwang and Yoon [97] is to select the most optimal alternative that is nearest to the positive ideal solution including all of the best values for criteria and farthest from the negative ideal solution consisting of all of the worth values for criteria.

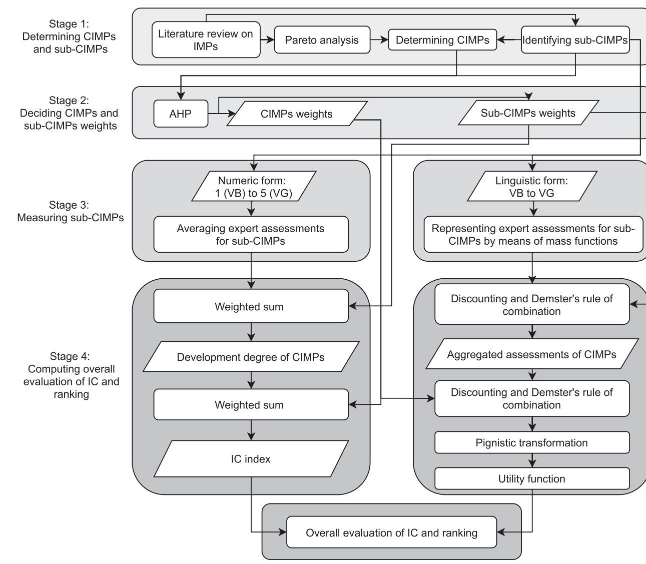

Fig. 1. Proposed IC evaluation process in banking.

III. Methodology

IC is an abstract term, so an IC evaluation is required to deal with multiple pieces of qualitative information. This study takes into account subjective evaluations for the IC of banks from various perspectives by banking experts in different areas who have relevant knowledge about banking innovation. Each expert has a unique point of view and personal opinions that might potentially conflict with those of other experts. We aim to handle such conflicts by proposing a method for IC evaluation under uncertainty. Our proposed process for evaluating IC in banking includes the four stages shown in Fig. 1. In Stage 1, Pareto analysis is applied to explore critical IMPs (CIMPs) that can be applied in banking based on a review of the literature. Measurement items (sub-CIMPs) for the CIMPs are then adapted from the related research. In Stage 2, the AHP is employed to identify the importance weights of the CIMPs and the sub-CIMPs in banking innovation. In Stage 3, data on the maturity level of the sub-CIMPs at the evaluated banks are collected via a questionnaire assessed by a group of different experts in banking-related fields. The collected data are formulated in both numeric and linguistic forms. Finally, the overall evaluations of the IC of the banks are computed and used for ranking them based on their IC in Stage 4.

A. Determining CIMPs and Sub-CIMPs

CIMPs are defined as crucial constructs to which management should pay special attention. If these constructs are accomplished properly, it helps ensure the success of innovation, increase business outcomes, and strengthen competitive advantages. To identify CIMPs, we use Pareto analysis to select the tasks or aspects that can generate a major impact [98]. This statistical technique aids in distinguishing the "vital few" and the "trivial many," a valuable insight when choices are made by management with regards to prioritization of issues. The Pareto analysis begins with a review on a large body of related studies to identify all IMPs by searching for relevant keywords: innovation capability, innovation capability evaluation, innovation management practices, innovation practices, innovation management measurement, empirical innovation management, and new product development practices (see Table I). We then total the number of times the IMPs occur in the literature and rank them from highest to lowest. We can next calculate the percentage of occurrences for each IMP and the cumulative percentage of occurrences. In accordance with the Pareto principle, the "vital few" items in this study, the CIMPs will comprise the majority (80%) of the cumulative percentage of occurrences and the "trivial many" items will make up the other 20%. The Pareto analysis results are typically displayed in a table that presents, in order, the IMPs, occurrences (highest to lowest), occurrences percentages, and cumulative occurrences percentages. To determine the degree to which the CIMPs have developed, the respective sub-CIMPs were taken from the extant literature to confirm validity and reliability.

B. Deciding the CIMPs and the Sub-CIMPs Weights

Our goal is to select the most innovative bank from those evaluated based on its IC as assessed by the CIMPs and the sub-CIMPs identified in Stage 1. Therefore, AHP methodology is employed to solve this problem. The AHP is a powerful and effective tool that is commonly applied to make decisions using multiple criteria. It offers an efficient means to conceptualize a complicated problem as a series of smaller problems using a hierarchical tree with various stages for the elements of decision making. At the top of the hierarchy is the target; in this case, to choose the bank that displays the best IC or to order the banks in terms of their IC. The decision criteria (CIMPs) and subcriteria (sub-CIMPs) form the intermediate stages. The alternatives, which are the evaluated banks, comprise the lowest stage. The AHP first adopts pairwise comparisons to explore the relative importance of decision elements in the lower stage in terms of the higher stage element based on the Saaty scale, as shown in Table II [99]. A group of different experts in banking-related fields, such as bank managers, auditors in banking, lecturers of banking and finance, and professional researchers in banking, is selected to perform the comparison process because such experts can provide convincing opinions about banking innovation. For each pair comparison, the opinions of all experts are averaged. These averages are then used to create the pairwise comparison matrix, which is standardized using the sum of each column. By averaging the values of each row, we obtain a set of weights of elements in a stage in terms of the element at the higher stage. Finally, we compute the consistency ratio (CR) by using (6) to see the degree to which the expert opinions are relative to large samples of completely random opinions

TABLE II
SAATY SCALE OF RELATIVE IMPORTANCE

Intensity of relative importance	Definition
1	Equally important
3	Moderately important
5	Strongly important
7	Very strongly important
9	Extremely important
2, 4, 6, 8	For terms between the above

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{6}$$

where CI [the consistency index, determined by (7)] shows the consistency of the expert opinions in a pairwise comparison matrix and RI (the random index, displayed in Table III) is CI of a pairwise comparison matrix made at random. Basically, a CR of 0.1 or below means that the judgments are trustworthy

$$\mathrm{CI} = \frac{\lambda_{\max} - e}{e - 1} \tag{7}$$

where $\lambda_{\max}$ is the highest eigenvalue of the pairwise comparison matrix and e is the number of compared elements.

C. Measuring the Sub-CIMPs

In practice, the decision makers may find it easier to directly evaluate basic attributes of alternatives on a five- or seven-point scale, possibly with uncertainty and imprecision [35], [100]. We invite experts in banking-related fields to provide judgments about the maturity level of each sub-CIMP for each bank separately via a questionnaire using a set of five evaluation grades: very bad (VB), bad (B), average (A), good (G), and very good (VG). These experts must have a strong understanding of all of the evaluated banks and work independently of these banks to avoid potential bias. In the following, for the purpose of comparison, two approaches for formulation of the collected data will be considered.

1) Data Formulation 1: The set of five evaluation grades is expressed in the numeric form of a five-point scale from 1 (VB)

TABLE III
VALUES OF THE RANDOM INDEX

e	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

to 5 (VG). The score of each sub-CIMP is then computed by using the following equation for averaging the assessments of all experts:

$$s_{ij} = \frac{1}{K}\sum_{k=1}^{K} s_{ij}^{k} \quad (8)$$

where s_{ij} is the score of sub-CIMP j related to CIMP i of a bank, s_{ij} ∈[1,5]; K is the number of experts participating in the evaluation; and s_{ij}^{k} is the score that the kth expert assesses sub-CIMP j related to CIMP i of a bank, $s_{ij}^{k} \in \{1, 2, 3, 4, 5\}$, $k = 1, 2, \ldots, K$.

2) Data Formulation 2: The qualitative features expressing the IC of the banks could be subjectively evaluated in linguistic terms with uncertainty and imprecision. In our case, the questionnaire of IC evaluation is judged by K experts separately, which may result in differences in subjective assessments among them. For these reasons, the following set of linguistic evaluation grades is used to assess the sub-CIMPs of a bank:

$$\mathcal{H} = \{H_1, \ldots, H_n, \ldots, H_N\}$$

where H_n, $n = 1, 2, \ldots, N$, is a linguistic evaluation grade, according to which a sub-CIMP of a bank may be assessed. In this study, a five-point scale ($N = 5$) is used as an assessment instrument, i.e.,

$$\mathcal{H} = \{H_1(VB), H_2(B), H_3(A), H_4(G), H_5(VG)\}.$$

The different assessments of K experts for sub-CIMP j of CIMP i of a bank can then be represented by means of the following distribution:

$$\{(H_n, \beta_{n,ij})|n = 1, 2, \ldots, N\} \cup \{(\mathcal{H}, \beta_{\mathcal{H},ij})\} \quad (9)$$

where $\beta_{n,ij}$ denotes the probability that sub-CIMP j associated with CIMP i at a bank is assessed according to the grade H_n over K assessments, satisfying $\beta_{n,ij} \geq 0$, $\sum_{n=1}^{N} \beta_{n,ij} \leq 1$, and $\beta_{\mathcal{H},ij} = 1 - \sum_{n=1}^{N} \beta_{n,ij}$. Basically, this method of formulating data can reflect an uncertain assessment of sub-CIMP j of CIMP i at a bank in terms of evaluation grades in $\mathcal{H}$. Based on the distributed assessment on each sub-CIMP, we can recognize the weaknesses as well as strengths for each bank.

With such a data formulation, the IC assessment problem is regarded as a multiple attribute evaluation problem with uncertainty. In particular, the uncertainty is expressed by means of so-called mass functions in Dempster–Shafer theory of evidence [101]. The next problem is how to aggregate these mass functions to obtain an overall assessment of the IC of each bank that is then used to rank the banks. The ER approach introduced in [28] and [34] (see also [35]) provides a rational method using Dempster's rule of combination to derive an aggregated assessment based on multiple attribute evaluation.

D. Computing the Overall Evaluation of IC and Ranking

1) Based on Data Formulation 1: After determining the weights of all sub-CIMPs, the development degree of a CIMP at a bank can be computed using

$$c_i = \sum_{j=1}^{J} w_{ij} s_{ij} \text{ with } \sum_{j=1}^{J} w_{ij} = 1 \quad (10)$$

where c_i is the development degree of CIMP i at a bank, $c_i \in [1, 5]$; s_{ij} is the score of sub-CIMP j related to CIMP i at a bank, $s_{ij} \in [1, 5]$; J is the number of sub-CIMPs related to CIMP i; and w_{ij} is the weight of sub-CIMP j related to CIMP i, $w_{ij} \in [0, 1]$.

To rank the banks in terms of their IC, a number of CIMPs are considered to compose the IC evaluation. The IC of a bank is conveyed using a composite index known as the innovation capability index (ICI), which is determined using

$$\text{ICI} = \sum_{i=1}^{I} W_i c_i \text{ with } \sum_{i=1}^{I} W_i = 1 \quad (11)$$

where ICI is the innovation capability index of a bank, ICI ∈ $[1, 5]$; I is the number of CIMPs; c_i is the development degree of CIMP i at a bank, $c_i \in [1, 5]$; and W_i is the importance weight of CIMP i; $W_i \in [0; 1]$.

A ranking of the banks in a sample can then be created based on their IC. The bank with the highest ICI is ranked as the most innovative bank, and the bank with the lowest ICI is the least innovative bank.

2) Based on Data Formulation 2: With the assessments of J sub-CIMPs associated with CIMP i, we have J mass functions as defined by (9), for $j = 1, 2, \ldots, J$. By combining these J mass functions, we can get an aggregated assessment for each CIMP i, for $i = 1, \ldots, I$ represented by a mass function of $\{(H_n, \beta_{n,i})|n = 1, \ldots, N\} \cup \{(\mathcal{H}, \beta_{\mathcal{H},i})\}$. The assessments of I CIMPs are next aggregated to obtain an overall assessment of the IC for each bank represented by a mass function $\{(H_n, \beta_n)|n = 1, \ldots, N\} \cup \{(\mathcal{H}, \beta_{\mathcal{H}})\}$. In the ER approach, these aggregated assessments can be computed by means of discounting operation and Dempster's rule of combination.

The discounting operation is first applied to J mass functions: $\{(H_n, \beta_{n,ij})|n = 1, \ldots, N\} \cup \{(\mathcal{H}, \beta_{\mathcal{H},ij})\}$, for $j = 1, \ldots, J$. $m_{n,ij}$ denotes a basic probability mass showing the likelihood that sub-CIMP j of CIMP i satisfies the hypothesis that CIMP i is evaluated to the grade of H_n. $m_{\mathcal{H},ij}$ denotes the remaining probability mass that is unassigned to any evaluation grades after all of the N evaluation grades have been taken into account for evaluating CIMP i. $m_{n,ij}$ and $m_{\mathcal{H},ij}$ for $j = 1, \ldots, J$ are computed by (12) and (13), respectively:

$$m_{n,ij} = w_{ij}\beta_{n,ij}, \qquad \text{for } n = 1, \ldots, N \quad (12)$$

$$m_{\mathcal{H},ij} = 1 - \sum_{n=1}^{N} m_{n,ij} = 1 - w_{ij} \sum_{n=1}^{N} \beta_{n,ij}. \quad (13)$$

$S(j)$ denotes the subset of the first j sub-CIMPs of CIMP i. $m_{n,S(j)}$ is a probability mass showing the likelihood that all of the sub-CIMPs in $S(j)$ satisfy the hypothesis that CIMP i is evaluated to the grade of H_n. $m_{H,S(j)}$ is the remaining probability mass that is unassigned to any grades after evaluating all of the sub-CIMPs in $S(j)$. When combining the probability masses $m_{n,ix}$ and $m_{\mathcal{H},ix}$, for all $n = 1,\ldots,N$ and $x = 1,\ldots,j$, we obtain $m_{n,S(j)}$ and $m_{\mathcal{H},S(j)}$.

Dempster's rule of combination can then be used to generate an aggregated mass for assessing CIMP i. In the ER algorithm, the key step is to inductively compute $m_{n,S(j+1)}$ and $m_{\mathcal{H},S(j+1)}$ as follows:

$$\begin{aligned} m_{n,S(j+1)} = \; & K_{S(j+1)}(m_{n,S(j)}m_{n,i(j+1)} \\ & + m_{n,S(j)}m_{\mathcal{H},i(j+1)} + m_{\mathcal{H},S(j)}m_{n,i(j+1)}) \end{aligned} \quad (14)$$

$$m_{\mathcal{H},S(j+1)} = K_{S(j+1)}(m_{\mathcal{H},S(j)}m_{\mathcal{H},i(j+1)}) \quad (15)$$

for $n = 1,\ldots,N$, $j = 1,\ldots,J-1$, and $K_{S(j+1)}$ is a normalizing factor determined by

$$K_{S(j+1)} = \left[1 - \sum_{t=1}^{N} \sum_{h=1,t\neq h}^{N} m_{t,S(j)}m_{h,i(j+1)}\right]^{-1}. \quad (16)$$

As a result, we have

$$\begin{aligned} \beta_{n,i} &= m_{n,S(J)}, \quad \text{for } n = 1,\ldots,N \\ \beta_{\mathcal{H},i} &= m_{\mathcal{H},S(J)} = 1 - \textstyle\sum_{n=1}^{N} \beta_{n,i}. \end{aligned} \quad (17)$$

In the same manner, the discounting operation is applied to the assessments for I CIMPs of each bank with the discounting rates of W_i, for $i = 1,\ldots,I$. These discounted assessments are then combined based on Dempster's rule to get the overall evaluation of the IC (β_n, for $n = 1,\ldots,N$ and $\beta_{\mathcal{H}}$) for each bank.

Finally, pignistic transformation is employed to drive the approximate distribution for the overall evaluation of the IC of each bank (see [102]). Namely:

$$\beta_{n'} = \beta_n + \frac{1}{N}\beta_{\mathcal{H}}, \quad \text{for } n = 1,\ldots,N. \quad (18)$$

For the purpose of ranking the alternatives in decision making under uncertainty, we need to generate a numerical value from the distributed overall evaluation of the IC of each bank. Such a value can be defined in terms of an expected utility function $u' : \mathcal{H} \to [0,1]$ introduced by Yang and Xu [34] as follows:

$$\begin{aligned} & u'(VB) = 0, \quad u'(B) = 0.35 \; u'(A) = 0.55 \\ & u'(G) = 0.85, \; u'(VG) = 1. \end{aligned}$$

The expected performance of a bank on IC is then obtained by

$$u(IC) = \sum_{n=1}^{N} \beta'_n u'(H_n) = \sum_{n=1}^{N} \left(\beta_n + \frac{1}{N}\beta_{\mathcal{H}}\right) u'(H_n). \quad (19)$$

IV. Empirical Results

A. Determining CIMPs and Sub-CIMPs

Table IV describes the results of the Pareto analysis. First, 24 IMPs extracted from 28 related articles (see Table I) were ranked from highest to lowest according to their frequencies of occurrences in the chosen studies. The percentage of occurrences for each IMP was then calculated along with the cumulative percentage of occurrences. In keeping with the Pareto principle, the "vital few" items (CIMPs in this research) account for the majority (80%) of the cumulative percentage of occurrences, while the "trivial many" items comprise the other 20%. Consequently, 11 IMPs (see Table IV) were selected as the CIMPs and represent 80.347% of the cumulative percentage of occurrences. These CIMPs include: 1) strategic management (STR); 2) resource management (RES); 3) organization management (ORG); 4) idea management (IDE); 5) process improvement (PRO); 6) marketing management (MAR); 7) R&D (RAD); 8) cooperative learning (COO); 9) portfolio management (POR); 10) knowledge management (KNO); and 11) technology management (TEC). Table V represents 44 measurement items (sub-CIMPs) adapted from the previous studies to measure the 11 CIMPs.

B. Deciding the CIMP and the Sub-CIMP Weights

Our IC evaluation problem can be divided into the three-level hierarchy tree shown in Fig. 2. The first stage of the hierarchy shows the aim of choosing the most innovative bank of three Vietnamese banks in our case study based on their IC levels as evaluated by multiple criteria and subcriteria. The intermediate stage contains 11 criteria/CIMPs plus 44 subcriteria/sub-CIMPs. At the lowest level are the three alternative banks, anonymously named Bank A, Bank B, and Bank C.

Each innovation practice plays a specific role in banking innovation; therefore, the AHP was applied to obtain the importance weights of the 11 CIMPs and the 44 sub-CIMPs based on pairwise comparisons using the Saaty scale. These comparisons were completed by five experts in banking-related fields, who have a strong understanding of the banking system in Vietnam: two lecturers at the Banking University of Ho Chi Minh City, two vice directors of banks, and one banking auditor. By following the AHP procedure, the importance weights of the CIMPs (STR, RES, ORG, IDE, PRO, MAR, RAD, COO, POR, KNO, TEC) in terms of IC were then determined to be 0.28, 0.19, 0.05, 0.05, 0.02, 0.06, 0.08, 0.05, 0.02, 0.09, and 0.10, respectively, as shown in Table VI. Hence, in IC evaluation of banking innovation, strategic management (STR) is the most important practice; resource management (RES) is second; and technology management (TEC) is third. Similarly, the importance weights of the sub-CIMPs with respect to each CIMP were determined. For STR1, STR2, STR3, and STR4, their weights were, in sequence, 0.45, 0.09, 0.14, and 0.32. The weights of RES1, RES2, RES3, and RES4 were 0.36, 0.09, 0.34, and 0.20, respectively. The weights of ORG1, ORG2, ORG3, and ORG4 were 0.35, 0.32, 0.11, and 0.22, respectively. With respect to IDE, the weights of IDE1, IDE2, IDE3, and IDE4 were 0.43, 0.15, 0.07, and

TABLE IV
PARETO ANALYSIS FOR IMPs IN THE LITERATURE

No	IMPs	Occurrences	Occurrences percentage (%)	Cumulative occurrences percentage (%)
1	Strategic management (STR)	25	14.451	14.451
2	Resource management (RES)	22	12.717	27.168
3	Organization management (ORG)	20	11.561	38.728
4	Idea management (IDE)	13	7.514	46.243
5	Process improvement (PRO)	12	6.936	53.179
6	Marketing management (MAR)	9	5.202	58.382
7	R&D (RAD)	9	5.202	63.584
8	Cooperative learning (COO)	8	4.624	68.208
9	Portfolio management (POR)	7	4.046	72.254
10	Knowledge management (KNO)	7	4.046	76.301
11	Technology management (TEC)	7	4.046	80.347
	The remaining 13 IMPs	34	19.653	100
	Total	173	100	100

TABLE V
CIMPs AND SUB-CIMPs

No	CIMPs	Sub-CIMPs	Sources
1	STR	STR1: Determine apparently innovation objectives in strategic plans STR2: Innovation strategies are commonly understood in the bank STR3: Top management is dedicated to encouragement of innovation practices STR4: Adopt decision aid techniques such as SWOT to devise the bank strategies	[18], [64]–[66], [71], [74]
2	RES	RES1: Offer appropriate innovation resources RES2: Have adaptable and varied capital sources RES3: Focus on hiring capable staffs RES4: Plan regular training courses for comprehension needed for future product creation	[11], [18], [65], [77], [103]
3	ORG	ORG1: Organizational culture and ambiance support innovation ORG2: Incentivize staffs for innovation ORG3: Allow for failures in innovation ORG4: Adopt an accessible communication system in the bank	[18], [64], [65], [74], [83]
4	IDE	IDE1: Have a validated process to gather ideas from various divisions in the bank IDE2: Collaborate with outside organizations for idea development IDE3: Have a quick procedure to evaluate new ideas IDE4: Use a test markets prior to initiating new products	[18], [66], [74]
5	PRO	PRO1: Use a planned innovation procedure PRO2: Involve facilitators in innovation procedure PRO3: Hold meetings to examine innovation undertakings PRO4: Top management frequently appraises progress of innovation projects	[18], [64], [68]
6	MAR	MAR1: Maintain good relationships with customers MAR2: Have proficient sales personnel MAR3: Measure degree of customer satisfaction after using banking services MAR4: Uphold a strong brand image in customers' minds	[18], [72], [77]
7	RAD	RAD1: Have a structured R&D program RAD2: Enhance budget for R&D activities on an ongoing basis RAD3: Use teamwork and collaboration across functions RAD4: Organize regularly sessions to program research topics	[14], [18]
8	COO	COO1: Adopt cooperative learning practices such as inter-service gatherings COO2: Some managers are accountable for cooperative learning activities COO3: Organize evaluation meetings at the conclusion of projects COO4: Communicate lessons acquired from past experiences throughout the bank	[11], [18], [81]
9	POR	POR1: Make the bank strategies align with investment portfolios POR2: Utilize multi-criteria analysis to manage all continuing projects POR3: Have routine reports about resource distribution into multi-projects POR4: Weigh up long- and short-term, high- and low-risk, etc. projects	[14], [18], [71]
10	KNO	KNO1: Detect and develop the knowledge of employees to match job requirements KNO2: Foster knowledge sharing and exchange KNO3: Categorize and keep knowledge accessible for staffs KNO4: Use knowledge distribution methods	[18], [81]
11	TEC	TEC1: Consider technology development and application as a crucial success factor TEC2: Have practices such as scenario planning to forecast precisely new technology trends TEC3: Know the core technology capability of competitors TEC4: Third party technology acquisition matches the bank's infrastructure systems and operations	[11], [75], [78]

This article has been accepted for inclusion in a future issue of this journal. Content is final as presented, with the exception of pagination.

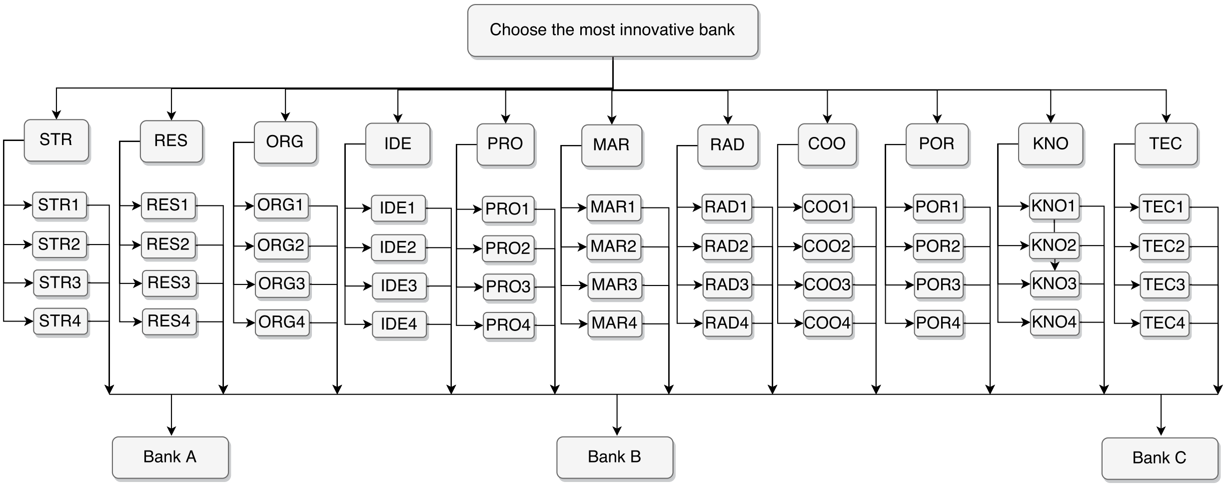

Fig. 2. Hierarchical structure for IC evaluation problem.

TABLE VI
PAIRWISE COMPARISONS OF CIMPS IN TERMS OF IC

CIMPs	STR	RES	ORG	IDE	PRO	MAR	RAD	COO	POR	KNO	TEC	Weight
STR	1	3	5	5	7	5	5	5	7	5	4	0.28
RES	1/3	1	5	4	6	3	4	4	5	4	4	0.19
ORG	1/5	1/5	1	2	3	1/3	1/2	1/2	4	1/3	1/4	0.05
IDE	1/5	1/4	1/2	1	4	1	1/2	1	4	1/2	1	0.05
PRO	1/7	1/6	1/3	1/4	1	1/4	1/4	1/3	2	1/4	1/5	0.02
MAR	1/5	1/3	3	1	4	1	1/2	2	4	1/3	1/2	0.06
RAD	1/5	1/4	2	2	4	2	1	3	5	1	1/2	0.08
COO	1/5	1/4	2	1	3	1/2	1/3	1	3	1/2	1/2	0.05
POR	1/7	1/5	1/4	1/4	1/2	1/4	1/5	1/3	1	1/6	1/6	0.02
KNO	1/5	1/4	3	2	4	3	1	2	6	1	1/2	0.09
TEC	1/4	1/4	4	1	5	2	2	2	6	2	1	0.10

0.35, respectively. For PRO1, PRO2, PRO3, and PRP4, their weights were 0.44, 0.29, 0.12, and 0.16, respectively. With respect to MAR, the weights of MAR1, MAR2, MAR3, and MAR4 were 0.17, 0.39, 0.24, and 0.21, respectively. The weights of RAD1, RAD2, RAD3, and RAD4 were determined to be 0.39, 0.10, 0.37, and 0.15, respectively. The weights of COO1, COO2, COO3, and COO4 were 0.11, 0.40, 0.17, and 0.32, respectively. The weights of POR1, POR2, POR3, and POR4 were identified to be 0.12, 0.45, 0.26, and 0.17, respectively. The weights of KNO1, KNO2, KNO3, and KNO4 were 0.35, 0.32, 0.11, and 0.22, respectively. The weights of TEC1, TEC2, TEC3, and TEC4 were determined to be 0.08, 0.50, 0.27, and 0.14, respectively. Because all of the CR values were below 0.1, the judgments of the experts in this stage are considered reliable.

C. Measuring the Sub-CIMPs

1) Data Formulation 1: A questionnaire for IMP assessment was sent to the same five experts consulted in Stage 2. The questionnaire is comprised of 44 questions (44 sub-CIMPs) to be assessed using a five-point scale from 1 (VB) to 5 (VG). As the five experts were unable to meet together to discuss the questionnaire, we conducted the questionnaire with them individually and computed the average of their assessment scores to obtain the final score for each sub-CIMP at each bank, using (8). Table VII shows the average scores of the 44 sub-CIMPs at the three banks.

2) Data Formulation 2: The assessments for the sub-CIMPs at the three banks are expressed in terms of five linguistic evaluation grades: $\mathcal{H} = \{H_1(VB), H_2(B), H_3(A), H_4(G), H_5(VG)\}$. In the data collected via the questionnaire, the five experts expressed different judgments on the sub-CIMPs of each bank. Therefore, the data formulated by means of the distribution defined by (9) appear to be an effective way to resolve the conflicts among the experts. Table VIII shows the distributions for the assessments of the five experts regarding the sub-CIMPs at the three banks.

D. Computing the Overall Evaluation of IC and Ranking

1) Based on Data Formulation 1: Table IX shows the results of calculating the development degrees of the 11 CIMPs for each bank using (10). Equation (11) was then used to compute the ICIs of the three banks. Consequently, the ICIs of Bank A, Bank B, and Bank C were 3.800, 4.230, and 4.035, respectively (see Table X).

TABLE VII
AVERAGE SCORES OF SUB-CIMPS AT THREE VIETNAMESE BANKS

Sub-CIMPs	Bank A	Bank B	Bank C	Sub-CIMPs	Bank A	Bank B	Bank C
STR1	4.4	4.6	4.0	MAR3	3.6	4.2	3.8
STR2	4.2	4.4	4.0	MAR4	3.8	4.4	4.2
STR3	3.8	4.4	4.8	RAD1	3.6	4.4	4.0
STR4	4.0	4.4	4.4	RAD2	3.8	4.0	3.8
RES1	3.4	4.0	4.0	RAD3	3.6	4.4	3.6
RES2	4.2	4.0	4.8	RAD4	3.6	4.2	3.6
RES3	4.0	4.6	4.4	COO1	4.0	4.0	4.2
RES4	3.4	4.2	4.2	COO2	3.4	4.0	4.2
ORG1	3.8	4.4	3.4	COO3	3.6	4.2	4.2
ORG2	4.0	4.0	4.2	COO4	3.2	4.0	4.0
ORG3	3.6	3.6	3.4	POR1	4.2	4.4	4.4
ORG4	3.4	4.2	4.0	POR2	3.4	4.2	4.4
IDE1	3.2	3.8	4.2	POR3	3.8	4.2	4.0
IDE2	3.4	4.0	3.6	POR4	3.8	4.0	4.2
IDE3	3.2	3.8	3.8	KNO1	4.6	4.0	4.2
IDE4	3.4	4.2	3.6	KNO2	3.8	4.2	4.2
PRO1	3.4	4.2	4.2	KNO3	3.8	4.0	4.0
PRO2	3.8	4.2	4.0	KNO4	4.6	4.0	3.8
PRO3	3.8	4.2	4.0	TEC1	4.4	4.2	3.8
PRO4	3.6	4.2	3.8	TEC2	3.6	4.2	3.8
MAR1	4.0	4.6	4.4	TEC3	3.8	4.4	3.8
MAR2	3.8	4.2	3.6	TEC4	3.4	4.2	4.2

2) Based on Data Formulation 2: By coding a MATLAB program to automatically calculate the discounting and combination operations using a bottom-up approach along the hierarchical tree (see Fig. 2), the overall assessments regarding the IC of the three banks could be obtained.

In the case of Bank A, the assessments for the sub-CIMPs were discounted using the discounting operation with the discounting rates of their corresponding weights. For example, Table XI shows the discounted masses of STR1, STR2, STR3, and STR4 with the corresponding discounting rates of 0.45, 0.09, 0.14, and 0.32, respectively.

The assessments for the remaining sub-CIMPs at Bank A were then discounted in the same manner. The discounted assessments for the four sub-CIMPs of each CIMP were next combined using Dempster's rule to obtain the aggregated assessment of each CIMP. As a result, Table XII reveals the aggregated assessments for the 11 CIMPs of Bank A.

In the same manner, the discounting operation was applied to the assessments for STR, RES, ORG, IDE, PRO, MAR, RAD, COO, POR, KNO, and TEC with the discounting rates of 0.28, 0.19, 0.05, 0.05, 0.02, 0.06, 0.08, 0.05, 0.02, 0.09, and 0.10, respectively. These 11 discounted assessments were then combined using Dempster's rule to get the overall assessment of IC. Table XIII describes the discounted masses for the 11 CIMPs of Bank A. By performing the same computations for Bank B and Bank C, we obtained the aggregated assessments on the IC of all three banks, as shown in Table XIV.

Finally, the pignistic transformation and utility function were applied to obtain the ranking of the banks based on their IC levels. The three distributions of the aggregated assessments on the IC of the three banks and their approximations via pignistic transformation are represented in Fig. 3. The expected performances of Bank A, Bank B, and Bank C on IC were then determined to be 0.413, 0.518, and 0.464, respectively. In the final result, Bank B is better than Bank C, while Bank A is ranked last, which is interestingly consistent with the result obtained based on data formulation 1.

It is worth noting here that, although both approaches to data formulation yield the same final ranking of banks based on their IC levels, they are very different in operation and, therefore, provide different analytical insights of the banks' IC. While the first approach quantitatively treats the collected data as numerical data and applies a simple computation process by making use of the weighted sum for criteria aggregation to get the final results for IC level, it could not be able to capture the interindividual variance in experts' evaluations of innovation practices, which are mostly qualitative by nature. Therefore, it does not give bank managers any insight into the detailed analysis for the strengths and weaknesses of the CIMPs that significantly contribute to a bank's IC level. Such limitations are overcome in the second approach, which treats the qualitative five-point scale as a linguistic scale and views multiexpert assessments as uncertain judgments modeled by mass functions in the Dempster–Shafer theory to represent the uncertainty in experts' evaluations of innovation practices. Based on the data formulated in this way, bank managers can look into specific criteria to detect which ones are strong or weak, and thereby propose suitable policies to improve each specific criterion. In particular, when experts' evaluations on the same criterion at the same bank are inconsistent, bank managers may need to reconsider issues related to this criterion so as to improve the evaluation process.

V. DISCUSSION AND CONCLUSION

The evaluation of IC in banking is necessary so that bank managers can review their innovation management activities and understand the current IC status of their banks as well

TABLE VIII
ASSESSMENT MATRIX OF SUB-CIMPS AT THREE VIETNAMESE BANKS

CIMPs		Sub-CIMPs	Banks		
			Bank A	Bank B	Bank C
Goal	STR (0.28)	STR1 (0.45)	{(A,0.2),(G,0.2),(VG,0.6)}	{(G,0.4),(VG,0.6)}	{(A,0.2),(G,0.6),(VG,0.2)}
		STR2 (0.09)	{(A,0.2),(G,0.4),(VG,0.4)}	{(G,0.6),(VG,0.4)}	{(A,0.2),(G,0.6),(VG,0.2)}
		STR3 (0.14)	{(A,0.2),(G,0.8)}	{(G,0.6),(VG,0.4)}	{(G,0.2),(VG,0.8)}
		STR4 (0.32)	{(A,0.4),(G,0.2),(VG,0.4)}	{(G,0.6),(VG,0.4)}	{(G,0.6),(VG,0.4)}
	RES (0.19)	RES1 (0.36)	{(A,0.6),(G,0.4)}	{(G,1.0)}	{(G,1.0)}
		RES2 (0.09)	{(A,0.2),(G,0.4),(VG,0.4)}	{(A,0.2),(G,0.6),(VG,0.2)}	{(G,0.2),(VG,0.8)}
		RES3 (0.34)	{(A,0.4),(G,0.2),(VG,0.4)}	{(G,0.4),(VG,0.6)}	{(A,0.2),(G,0.2),(VG,0.6)}
		RES4 (0.20)	{(B,0.4),(G,0.4),(VG,0.2)}	{(A,0.2),(G,0.4),(VG,0.4)}	{(G,0.8),(VG,0.2)}
	ORG (0.05)	ORG1 (0.35)	{(A,0.4),(G,0.4),(VG,0.2)}	{(G,0.6),(VG,0.4)}	{(A,0.6),(G,0.4)}
		ORG2 (0.32)	{(A,0.4),(G,0.2),(VG,0.4)}	{(G,1.0)}	{(G,0.8),(VG,0.2)}
		ORG3 (0.11)	{(A,0.4),(G,0.6)}	{(A,0.4),(G,0.6)}	{(A,0.8),(VG,0.2)}
		ORG4 (0.22)	{(A,0.8),(VG,0.2)}	{(G,0.8),(VG,0.2)}	{(A,0.2),(G,0.6),(VG,0.2)}
	IDE (0.05)	IDE1 (0.43)	{(A,0.8),(G,0.2)}	{(A,0.4),(G,0.4),(VG,0.2)}	{(A,0.2),(G,0.4),(VG,0.4)}
		IDE2 (0.15)	{(A,0.8),(VG,0.2)}	{(A,0.2),(G,0.6),(VG,0.2)}	{(B,0.2),(A,0.2),(G,0.4),(VG,0.2)}
		IDE3 (0.07)	{(A,0.8),(G,0.2)}	{(A,0.4),(G,0.4),(VG,0.2)}	{(A,0.6),(VG,0.4)}
		IDE4 (0.35)	{(A,0.6),(G,0.4)}	{(G,0.8),(VG,0.2)}	{(B,0.2),(A,0.4),(VG,0.4)}
	PRO (0.02)	PRO1 (0.44)	{(A,0.6),(G,0.4)}	{(G,0.8),(VG,0.2)}	{(A,0.2),(G,0.4),(VG,0.4)}
		PRO2 (0.29)	{(A,0.4),(G,0.4),(VG,0.2)}	{(G,0.8),(VG,0.2)}	{(A,0.2),(G,0.6),(VG,0.2)}
		PRO3 (0.12)	{(A,0.4),(G,0.4),(VG,0.2)}	{(G,0.8),(VG,0.2)}	{(A,0.4),(G,0.2),(VG,0.4)}
		PRO4 (0.16)	{(A,0.6),(G,0.2),(VG,0.2)}	{(G,0.8),(VG,0.2)}	{(B,0.2),(A,0.2),(G,0.2),(VG,0.4)}
	MAR (0.06)	MAR1 (0.17)	{(A,0.4),(G,0.2),(VG,0.4)}	{(G,0.4),(VG,0.6)}	{(A,0.2),(G,0.2),(VG,0.6)}
		MAR2 (0.39)	{(A,0.4),(G,0.4),(VG,0.2)}	{(G,0.8),(VG,0.2)}	{(A,0.4),(G,0.6)}
		MAR3 (0.24)	{(A,0.4),(G,0.6)}	{(G,0.8),(VG,0.2)}	{(A,0.4),(G,0.4),(VG,0.2)}
		MAR4 (0.21)	{(A,0.4),(G,0.4),(VG,0.2)}	{(G,0.6),(VG,0.4)}	{(G,0.8),(VG,0.2)}
	RAD (0.08)	RAD1 (0.39)	{(A,0.4),(G,0.6)}	{(G,0.6),(VG,0.4)}	{(A,0.2),(G,0.6),(VG,0.2)}
		RAD2 (0.10)	{(A,0.4),(G,0.4),(VG,0.2)}	{(G,1.0)}	{(A,0.4),(G,0.4),(VG,0.2)}
		RAD3 (0.37)	{(A,0.6),(G,0.2),(VG,0.2)}	{(G,0.6),(VG,0.4)}	{(A,0.4),(G,0.6)}
		RAD4 (0.15)	{(A,0.6),(G,0.2),(VG,0.2)}	{(G,0.8),(VG,0.2)}	{(B,0.2),(G,0.8)}
	COO (0.05)	COO1 (0.11)	{(G,1.0)}	{(G,1.0)}	{(G,0.8),(VG,0.2)}
		COO2 (0.40)	{(B,0.4),(G,0.4),(VG,0.2)}	{(G,1.0)}	{(A,0.2),(G,0.4),(VG,0.4)}
		COO3 (0.17)	{(A,0.4),(G,0.6)}	{(G,0.8),(VG,0.2)}	{(G,0.8),(VG,0.2)}
		COO4 (0.32)	{(B,0.4),(G,0.6)}	{(G,1.0)}	{(A,0.2),(G,0.6),(VG,0.2)}
	POR (0.02)	POR1 (0.12)	{(G,0.8),(VG,0.2)}	{(G,0.6),(VG,0.4)}	{(G,0.6),(VG,0.4)}
		POR2 (0.45)	{(B,0.4),(G,0.4),(VG,0.2)}	{(G,0.8),(VG,0.2)}	{(G,0.6),(VG,0.4)}
		POR3 (0.26)	{(A,0.4),(G,0.4),(VG,0.2)}	{(G,0.8),(VG,0.2)}	{(G,1.0)}
		POR4 (0.17)	{(A,0.4),(G,0.4),(VG,0.2)}	{(G,1.0)}	{(G,0.8),(VG,0.2)}
	KNO (0.09)	KNO1 (0.35)	{(G,0.4),(VG,0.6)}	{(G,1.0)}	{(G,0.8),(VG,0.2)}
		KNO2 (0.32)	{(A,0.4),(G,0.4),(VG,0.2)}	{(G,0.8),(VG,0.2)}	{(G,0.8),(VG,0.2)}
		KNO3 (0.11)	{(A,0.4),(G,0.4),(VG,0.2)}	{(G,1.0)}	{(A,0.2),(G,0.6),(VG,0.2)}
		KNO4 (0.22)	{(G,0.4),(VG,0.6)}	{(G,1.0)}	{(A,0.2),(G,0.8)}
	TEC (0.10)	TEC1 (0.08)	{(G,0.6),(VG,0.4)}	{(G,0.8),(VG,0.2)}	{(A,0.4),(G,0.4),(VG,0.2)}
		TEC2 (0.50)	{(A,0.6),(G,0.2),(VG,0.2)}	{(G,0.8),(VG,0.2)}	{(A,0.6),(VG,0.4)}
		TEC3 (0.27)	{(A,0.4),(G,0.4),(VG,0.2)}	{(G,0.6),(VG,0.4)}	{(A,0.6),(VG,0.4)}
		TEC4 (0.14)	{(A,0.8),(VG,0.2)}	{(G,0.8),(VG,0.2)}	{(A,0.2),(G,0.4),(VG,0.4)}

Note: Values in parentheses following the CIMPs and the sub-CIMPs are their corresponding weights.

TABLE IX
DEVELOPMENT DEGREES OF CIMPS AT THREE VIETNAMESE BANKS

CIMPs	STR	RES	ORG	IDE	PRO	MAR	RAD	COO	POR	KNO	TEC
Bank A	4.170	3.642	3.754	3.300	3.630	3.824	3.656	3.436	3.668	4.256	3.654
Bank B	4.490	4.204	4.140	3.970	4.242	4.352	4.374	4.034	4.190	4.064	4.212
Bank C	4.240	4.208	3.788	3.872	4.096	3.946	3.812	4.136	4.262	4.090	3.818

TABLE X
ICIS AND RANKING OF THREE VIETNAMESE BANKS

Rank	ICI	Bank
1	4.230	Bank B
2	4.035	Bank C
3	3.800	Bank A

TABLE XI
DISCOUNTED ASSESSMENTS FOR STR1, STR2, STR3, AND STR4 OF BANK A

Sub-criteria	Discounted mass
STR1	{(A,0.090),(G,0.090),(VG,0.270),($\mathcal{H}$,0.550)}
STR2	{(A,0.018),(G,0.036),(VG,0.036),($\mathcal{H}$,0.910)}
STR3	{(A,0.028),(G,0.112),($\mathcal{H}$,0.860)}
STR4	{(A,0.128),(G,0.064),(VG,0.128),($\mathcal{H}$,0.680)}

as the strengths and weaknesses in their innovation process. Based on such IC evaluation, bank managers may propose breakthrough strategic plans to enhance the IC of their banks. Our study contributes an integrated approach based on several methods to solve the IC evaluation problem in the banking sector. Particularly, the Pareto analysis was first applied to identify the relevant CIMPs, including strategic management, resource management, organization management, idea management, process improvement, marketing management, R&D, cooperative

TABLE XII
AGGREGATED ASSESSMENTS FOR CIMPS OF BANK A

CIMP	Aggregated mass
STR	{(A,0.177),(G,0.187),(VG,0.314),($\mathcal{H}$,0.322)}
RES	{(B,0.057),(A,0.254),(G,0.231),(VG,0.137),($\mathcal{H}$,0.321)}
ORG	{(A,0.369),(G,0.171),(VG,0.156),($\mathcal{H}$,0.304)}
IDE	{(A,0.547),(G,0.156),(VG,0.012),($\mathcal{H}$,0.286)}
PRO	{(A,0.38),(G,0.249),(VG,0.063),($\mathcal{H}$,0.308)}
MAR	{(A,0.326),(G,0.351),(VG,0.125),($\mathcal{H}$,0.199)}
RAD	{(A,0.374),(G,0.25),(VG,0.076),($\mathcal{H}$,0.301)}
COO	{(B,0.244),(A,0.049),(G,0.508),(VG,0.049),($\mathcal{H}$,0.151)}
POR	{(B,0.122),(A,0.165),(G,0.383),(VG,0.162),($\mathcal{H}$,0.167)}
KNO	{(A,0.099),(G,0.285),(VG,0.309),($\mathcal{H}$,0.306)}
TEC	{(A,0.494),(G,0.205),(VG,0.173),($\mathcal{H}$,0.128)}

TABLE XIII
DISCOUNTED ASSESSMENTS FOR CIMPS OF BANK A

Main criteria	Discounted mass
STR	{(A,0.049),(G,0.053),(VG,0.088),($\mathcal{H}$,0.810)}
RES	{(B,0.011),(A,0.048),(G,0.044),(VG,0.026),($\mathcal{H}$,0.871)}
ORG	{(A,0.019),(G,0.009),(VG,0.008),($\mathcal{H}$,0.965)}
IDE	{(A,0.027),(G,0.008),(VG,0.001),($\mathcal{H}$,0.964)}
PRO	{(A,0.008),(G,0.005),(VG,0.001),($\mathcal{H}$,0.986)}
MAR	{(A,0.02),(G,0.021),(VG,0.008),($\mathcal{H}$,0.952)}
RAD	{(A,0.03),(G,0.02),(VG,0.006),($\mathcal{H}$,0.944)}
COO	{(B,0.012),(A,0.002),(G,0.025),(VG,0.002),($\mathcal{H}$,0.958)}
POR	{(B,0.002),(A,0.003),(G,0.008),(VG,0.003),($\mathcal{H}$,0.983)}
KNO	{(A,0.009),(G,0.026),(VG,0.028),($\mathcal{H}$,0.938)}
TEC	{(A,0.049),(G,0.021),(VG,0.017),($\mathcal{H}$,0.913)}

TABLE XIV
AGGREGATED ASSESSMENTS ON IC FOR THREE VIETNAMESE BANKS

Bank	Overall assessment on IC
A	{(B,0.017),(A,0.205),(G,0.183),(VG,0.139),($\mathcal{H}$,0.456)}
B	{(A,0.009),(G,0.436),(VG,0.142),($\mathcal{H}$,0.413)}
C	{(B,0.003),(A,0.100),(G,0.314),(VG,0.140),($\mathcal{H}$,0.443)}

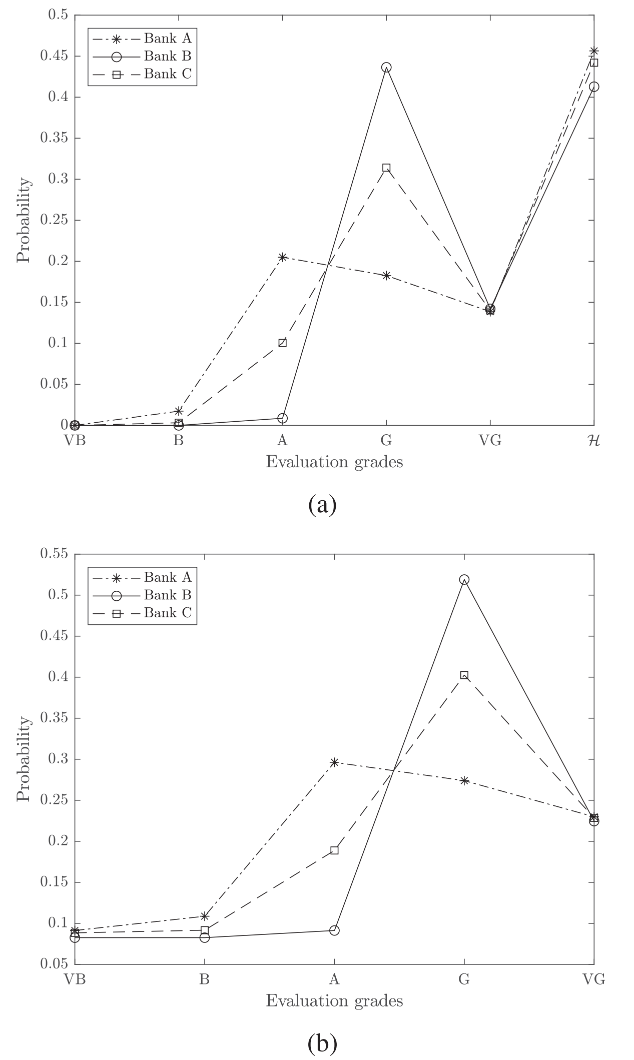

Fig. 3. Overall evaluations of IC for three Vietnamese banks. (a) Aggregated assessments. (b) Approximate assessments by pignistic transformation.

learning, portfolio management, knowledge management, and technology management from the literature. The AHP was then employed to decide the importance weights of CIMPs and their measurement items (with strategic management, resource management, and technology management being the most important practices for banking innovation). Strategies are regarded as the guidance for all activities of a bank, which leads to a thorough and synchronous development and generates innovation breakthroughs for the bank. Thus, according to Geschka [104], the innovation process should begin with building an innovation strategy for setting up strategic orientations, overall objectives, and specific guidance for the development of a company. In addition, strategic leadership plays a crucial role in facilitating exploration and exploitation of new products/processes [105]. Furthermore, resource management is required to allocate the needed resources, such as personnel, capital funding, and infrastructure to implement the innovation activities. Resource management is the second important dimension in the innovation value diagnosis system model of Wang and Chang [65] after process innovation. Their research was performed in the high-tech industry, which may have particular interest in techniques for improving the process of producing and delivering new or improved products with reduced production costs and delivery time, and improved quality and efficiency. In line with our findings, Matroushi *et al.* [106] also found, by applying an AHP technique, that the key requirements that foster innovation in the United Arab Emirates' small- and medium-sized enterprises are innovation policy, opportunity recognition, and finance. Finally, the weighted sum method was used to aggregate the collected data in numeric form, and the ER approach was used to aggregate the data in linguistic form. Specifically, we found the ER approach introduced by Yang and Singh [28] to be an effective method to deal with situations in which the assessments of different experts are subjective and inconsistent. It provides a useful aggregation scheme to drive the aggregated assessments on IC of banks under uncertainty and imprecision.

We also applied this framework to evaluate the IC of three Vietnamese banks as well as to infer valuable managerial lessons in innovation management in banking. Applying two methods of processing the collected data formatted in the numeric and linguistic forms obtained the final results that reach the same conclusion on the ranking of the three banks. Consequently,

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both determined that Bank B is the most innovative bank, Bank C is in second place, and Bank A is the least innovative bank. With minor adjustments, our proposed method can be adopted for various evaluations of IC in other sectors.

A. Implications for Theory

This research presents several contributions to advance theories related to IC as follows: First, this study conducts a deep review on the large body of the related literature on innovation management across sectors to identify the most common IMPs and their corresponding measurement items, which provides a comprehensive theoretical foundation for researchers in the innovation research area. Second, this study shines new light on the innovation management problem in the banking sector, an area in which there is currently little IC-related research, by clarifying the importance roles of IMPs in the previously undiscovered context - banking innovation. Third, from a methodological perspective, this study combines several methods to build a new integrated framework for the evaluation of IC in banking under uncertainty. Our main contribution is the ER-based multicriteria evaluation approach to the IC with an application to the banks in Vietnam. To the best of our knowledge, this research could be the first one that applies ER approach in combination with AHP in IC evaluation.

As mentioned in Section II-D and II-E, most of the previous studies use a multiple-criteria approach for IC evaluation, but data collection and aggregation techniques used by particular authors are different. Boly *et al.* [18] and Rejeb *et al.* [64] presented an IC measure framework considering multiple IMPs measured by multiple observable criteria scored 1 if present or 0 if absent. The limitation of this approach is that it only reflects the presence of an innovation practice but does not provide any information about the efficiency level with which this practice is achieved. The values of the criteria are then averaged to obtain the value for the corresponding IMP. Processing data in this way cannot handle uncertainty and imprecision in the IC evaluation process. In addition, such calculation of the value for an IMP does not consider the different importance weights among the criteria. Finally, a value test is applied to derive the typical weight vectors of the IMPs for four innovative groups, which are then used to compute IC indexes of companies. We notice that the computation of the value test requires at least one company in a group. Consequently, this method is not applicable in the case of a small research sample. Wang *et al.* [10] developed a combined method of nonadditive measure and the Choquet integral to evaluate technological IC based on five aspects consisting of multiple criteria. Qualitative criteria are evaluated by linguistic variables represented by triangular fuzzy numbers. The final rating of each criterion assessed by numerous experts is obtained using the fuzzy averaging technique and a defuzzification method. A nonadditive Choquet integral is then employed to determine the final aggregated IC performance of firms. Although their method based on nonadditive Choquet integral does not require the assumption of mutual independence among criteria, it is a significant challenge to identify the nonadditive measure taking appropriately dependence between criteria into account, while the computational complexity of this task is exponential in the number of criteria making it difficult to be applied in practice. The use of varied linguistic models with different fuzzy numbers also requires the evaluators to have the professional ability to discriminate the differences in qualitative terms. It is also worth emphasizing here that in the case of additive weights, the Choquet integral becomes the weighted sum that is actually used in (11) for computing the ICI of banks based on data formulation 1 formulated above. Cheng and Lin [16] measured the performance of innovation with the goal of choosing the best supplier based on various fuzzy technological IC criteria using a combined method of fuzzy set and a MADM technique—TOPSIS. The application of TOPIS still faces many problems, such as different normalization and distance measurement techniques used leading to different final results [107]. In comparison with existing studies, this study illustrates a novel integrated method to evaluate IC in banking under uncertainty by combining the AHP and the ER approach in terms of the Dempster–Shafer theory of evidence. Data of IMPs can be simply obtained from different evaluators based on the five-point linguistic scale (from very bad to very good), which helps to capture the maturity level of IMPs in the evaluated banks from different perspectives. In data formulation, data represented by means of mass functions in Dempster–Shafer theory of evidence can properly show the nature of uncertainty in the evaluation process of qualitative criteria, which gives more insights about the evaluation criteria than representing the data in crisp or fuzzy numbers. By applying the AHP, we consider both the different importance weights of subcriteria with respect to criteria and the different importance weights of criteria with respect to goal. Furthermore, our proposed method can be applied in any sample size.

B. Implications for Practice

In the current business environment, where innovation is a top priority in all sectors, banks must actively innovate their services by continuously upgrading their IC. There are several crucial managerial implications that can be inferred from our research for application in banking innovation.

First, IC evaluation in banking must simultaneously consider multiple dimensions. IC is not related to single aspect such as new ideas or technologies, but needs to be considered as a combination of various innovation activities. Our proposed framework can provide bank managers a tool to capture an overall picture of CIMPs in their banks, systematically review and evaluate these practices, and thereby improve innovation strategies accordingly to upgrade their IC levels to sustain their competitive advantages.

Second, it is suggested that banks focus on the most important CIMPs for banking innovation, such as strategic management, resource management, and technology management. It is clear that the most innovative bank (Bank B) has the best strategic management practices among the three banks, with a score of 4.490 (in Table IX). Bank B also has the most developed technology management practices, with a score of 4.212. Although the resource management practices of Bank B (4.204) are slightly

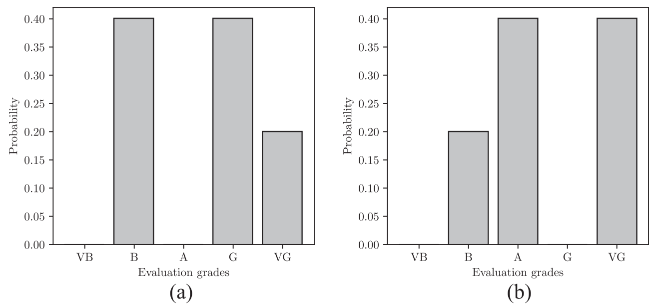

Fig. 4. Inconsistencies among expert assessments. (a) Assessment for RES4 at Bank A. (b) Assessment for IDE4 at Bank C.

weaker than those of Bank C (4.208), they are stronger than those of Bank A (3.642). This analysis demonstrates that the more innovative banks prioritize the development of the more important CIMPs, which results in their higher IC levels and better business performance.

Third, by considering the mass functions representing the experts' assessments regarding the sub-CIMPs at each bank (see Table VIII), managers are able to identify which sub-CIMPs have conflicting assessments among the experts. Because experts with different backgrounds and experiences have different opinions and personal views, their judgments on the same sub-CIMPs at a bank may be inconsistent. Once such sub-CIMPs are identified, the banks need to review their innovation management process to improve those innovation activities. For example, for RES4 at Bank A and IDE4 at Bank C, there were clear inconsistencies among the assessments of the five experts, as graphically depicted in Fig. 4. Therefore, Banks A and C may consult with the experts who assessed B for these sub-CIMPs to determine the points where they perform badly in order to perfect these practices at their banks and achieve more consistent recognition from all experts.

Finally, the result for the IC evaluation is indicative only and is subject to change over time. The development degree of CIMPs and their importance for IC enhancement in banking may be expected to change continuously along with the increasingly shifting business environments. Furthermore, attention should be paid to new emerging IMPs to keep pace with more recent trends. Thus, banks should conduct IC evaluations periodically and adjust their innovation strategies accordingly to keep their IC status up to date.

To sum up, for innovation management in banking, bank managers should take into account multiple IMPs together to have a comprehensive view of their innovation process. They should also periodically evaluate the development degrees of these IMPs, consider the importance of these IMPs according to the changing business environment, and then adjust innovation strategies toward paying more effort to the most important IMPs to boost their IC. Furthermore, they need to keep an eye on emerging IMPs so that their banks can be leading in the increasingly fierce innovation race. Because IC is inherently abstract and uncertain, it is difficult to assess accurately. Each evaluator may have different opinions on the same IMP at a bank; therefore, bank managers should seek advice from different experts to improve their innovation management process based on a variety of perspectives.

C. Limitations and Suggestions for Future Research

Inevitably, this research has some limitations. First, we adopted the IMPs identified in previous research, so there may be new IMPs or unique IMPs in the banking context that have not been included in this study. For future research, more in-depth interviews with experts in fields of banking innovation should be conducted to explore updated IMPs that align with the banking innovation context. Second, it would be inconvenient to use traditional weighting methods such as AHP to derive the importance weights of IMPs in case IMPs change quickly. Further consideration should be placed on developing a new weighting method based on the collected data of IMPs. Third, by using the AHP, we assumed that the weights of IMPs and sub-IMPs are additive and crisp; however, in practical situations, weight information can also be uncertain represented by probability distributions [108]. Therefore, further research is required to extend the proposed approach to be able to handle uncertainty and imprecision in weight information. Fourth, due to the qualitative nature of sub-IMPs and subjectivity in experts' judgment, it is sometimes difficult for experts to express their assessment exactly by making a single choice over multiple options when responding to a question of the questionnaire used for data collection; it would be worth of investigating new methods capable of appropriately capturing uncertainty and vagueness in such subjective judgments as experts use multiple linguistic terms to express their assessments regarding qualitative sub-IMPs. Finally, making complex decisions based solely on the judgments of experts may not be enough. In organizational decision making, Shollo *et al.* [109], [110] proposed to rely on quantitative evidence and use intuitive judgments as a means of involving other aspects to substitute, supplement, interpret, and reframe the available evidence. Based on this observation, in the future work, we suggest considering not only experts' judgments but also quantitative evidence, context analysis, and other information sources such as through networks and forums to reach an ultimate decision about ranking banks and reduce controversy about the ranks.

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