The 'Sandcone' Cumulative Capabilities Model: Testing Its Application in Some Asia-Pacific Countries

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Abstract: A carefully crafted manufacturing strategy that enables a company to develop its key competitive capabilities – quality, delivery, flexibility and cost efficiency – can strongly influence its ability to compete effectively. To date, a number of models have been proposed that provide guidance on how companies should treat these capabilities. Our study focuses on the cumulative 'sandcone' model proposed by Ferdows and De Meyer [1]. This model not only suggests that firms can compete on all four capabilities simultaneously, but also defines how this can be done (a plant should start with quality, followed by delivery, then flexibility and lastly cost efficiency). This model has been widely cited; however its validation has been inadequate. We tested this model with data from 218 manufacturing firms in five Asia Pacific regional countries (Hong Kong, Singapore, Taiwan, Korea and Australia). We found evidence in support of it, although this support was not emphatic. Results suggested that firms develop capabilities in quality, then simultaneously develop capabilities in delivery, flexibility and cost efficiency. The higher level capabilities are indirectly related to each other.

Keywords: manufacturing strategy, quality, delivery, flexibility, cost efficiency.

I. Introduction

Interest in manufacturing strategy has grown significantly in recent years ever since Skinner [2] identified its strategic significance for firms. A well crafted manufacturing strategy can bring numerous competitive benefits to an organization. An effective manufacturing strategy can enhance sales, profits, and return on assets [3]. It also helps to develop organizational goals and objectives, assists in strategic resource allocation, and co-ordinates and integrates complex business organizations [4]. There is general consensus in the literature that the main manufacturing capabilities are cost, quality, flexibility and delivery [5-9], although some researchers have added other capabilities such as innovation [10]. In this paper, we limit our consideration to the four main capabilities (cost, quality, flexibility and delivery).

Since the 1960s, different conceptual models and approaches have been suggested for building up manufacturing capabilities [11-14]. One of the models is that proposed by Ferdows and De Meyer [1]. The cumulative model suggests that long lasting improvements can be achieved if the manufacturing capabilities are built up in a sequential and cumulative manner. Capabilities that are developed following a particular sequence can avoid trade-offs and enhance each other.

Our study attempts to empirically validate the cumulative capabilities model. This is because studies to date have produced mixed results, with some showing support [10, 15], while others do not [12, 16]. Thus, there is no clear empirical conclusion on the validity of the cumulative model. In our study, we used data from companies located in the Asia Pacific region (South Korea, Taiwan, Singapore, Hong Kong and Australia) because country context has been identified as an important factor in explaining differences in how capabilities are developed [12, 16]. Another key aspect of our study is that it is replication research. Validating the cumulative model using Asia-Pacific data will enrich the literature on the understanding and applicability of the cumulative model in a different setting.

Through addressing these objectives, our study makes several important contributions. We provide validation of the cumulative model in a new research setting that is regarded as an emerging global manufacturing and economic powerhouse. Given the strong demand for Asia-Pacific knowledge, we enrich the literature and offer valuable insights to both researchers and practitioners on the manufacturing capability development process of firms operating in the Asia-Pacific.

II. Literature Review

Frameworks for Manufacturing Capability Development

Several conceptual models have been suggested to depict the development of manufacturing capabilities. One of the earliest, the trade-off model, was proposed by Skinner [2]. This formed the basic concept for subsequent studies in the capability development research stream. Skinner called for managers to choose their plants' competitive priorities first before designing and operating the manufacturing systems. This implies that plants should focus on one priority at a time because capabilities require different operational structures and infrastructures for support. Skinner [17] and Hayes and Wheelwright [5] followed with the concept of a 'focused factory' that emphasizes only one capability or at most, a few compatible ones. The corporate strategy as well as the nature of its existing plant should determine the capability that manufacturing focus on.

Several studies have investigated the trade-offs between manufacturing capabilities [7, 11, 18]. Results are mixed on the validity of the trade-off model. Boyer and Lewis [11] argue that the notion of trade-offs may be irrelevant in an environment characterized by advanced manufacturing technologies and global competition. Intense competition has placed pressure on firms to excel on multiple capabilities, and thus to overcome trade-offs and create synergies among various capabilities [19, 20]. Skinner [21] argues that although trade-offs are quite different from those 25 years ago, they still exist in technologically based systems.

Questions concerning trade-offs were raised when Nakane [22] posited that Japanese manufacturers followed a rather specific sequence for building manufacturing capabilities. He suggested that a cumulative model with quality enhancements as the foundation for other improvements. He postulated a sequential building up of capabilities from quality to dependability to cost efficiency and finally, to flexibility. Subsequent work arising from his ideas led to the conceptualization of the cumulative model [23-25], culminating in the sandcone model being proposed by Ferdows and De Meyer [1]. They argued that excellence in manufacturing is built sequentially upon a common set of fundamental principles. The model suggests that lasting improvements in performance can only be achieved by building manufacturing capabilities in a sequential manner from quality to dependability, then flexibility, and finally cost. Like constructing a sandcone, capabilities built layer upon layer will cumulatively reinforce each other.

Several empirical validations have been attempted over time. Noble [10] attempted to validate the cumulative model using regression techniques on data collected from manufacturing plants in North America, Europe and Korea. She modified the cumulative model by introducing the innovation capability and separating dependability into speed and delivery. The order (sequence) of the capabilities was also altered. She found positive relationships between quality, dependability and cost. Using meta-analysis, White [26] found some support for the sequence of the cumulative model. Quality was found to be the basic source for improving other capabilities. White [26] also highlighted that improvements in lower tier capabilities can result in improvements to higher tier capabilities. Flynn and Flynn [12] surveyed 165 plants in five countries (Germany, Italy, Japan, England and United States) across three industries to test the pattern of cumulative capabilities. Substantial differences were found in the patterns of cumulative capabilities between countries, but industry differences were not evident. Cumulative capabilities were related to plant performance. However, there was little evidence to support the sequence of the cumulative model. Brown et al. [27] found that the capabilities of high-performing firms are cumulative. Größler and Grübner [15] also showed that manufacturing capabilities are cumulative in nature. Unlike Flynn and Flynn [12], their study found empirical support for the sequence of the cumulative model. Amoako-Gyampah and Meredith [16] validated the applicability of the cumulative model in Ghanaian firms. They postulated that the difference in development sequence between Ghana and developed nations can be attributed to the dissimilar economic conditions. Roth and Miller [20] surveyed 193 firms and found that firms that built up multiple capabilities outperformed those that targeted specific capabilities. They also showed that the top-performing firms performed consistently better than other firms in all capabilities.

III. Model and Hypotheses

The original cumulative model as proposed by Ferdows and De Meyer [1] is conceptual in form. In order to empirically test the model, it was converted to hypothetico-deductive form. This form of the model is shown in Figure 1. This is similar to that proposed by Größler, and Grübner [15]. The sequence of the model in Ferdow and De Meyer [1] was quality, dependability, flexibility and cost efficiency. In our representation of the model, we replaced dependability with a more general delivery capability. The model takes a partially mediated form with direct and indirect relationships. The model shows that improvements in higher level capabilities are directly or indirectly associated with lower level capabilities. By modeling both direct and indirect effects, we provide for greater flexibility and generalizability to our analysis.

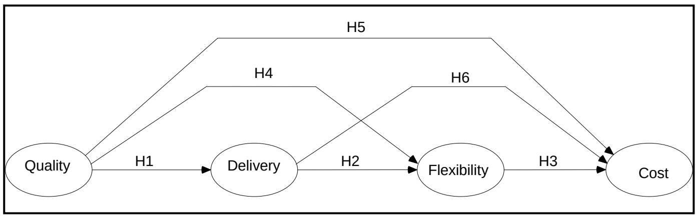

Figure 1: Hypothesized theoretical model representing cumulative model.

Figure 1 shows the hypotheses that test the specific relationships between the capabilities. Other studies have provided extensive literature support to justify these hypotheses [e.g., 12, 14, 15, 27-30]. As such, we do not provide similar exposition in this paper. Instead, we simply present these hypotheses here. The specific hypotheses are:

H_1: *Quality performance leads to delivery performance.*
H_2: *Delivery performance leads to flexibility performance.*
H_3: *Flexibility performance leads to cost performance.*
H_4: *Quality performance leads to flexibility performance.*
H_5: *Quality performance leads to cost performance.*
H_6: *Delivery performance leads to cost performance.*

IV. Research Method

Data Collection Process

Asia-Pacific is a very large geographical region with many countries at different stages of economic development and industrialization. Given the exploratory nature of our study, we decided to select countries that have a relatively large manufacturing presence in their economic base. Countries such as Japan and China that have been studied before in Flynn and Flynn [12] and Zhao et al. [31] were excluded. We decided to include Hong Kong, South Korea, Singapore, Taiwan and Australia in our study. The four Asian tigers (Hong Kong, South Korea, Singapore, Taiwan) are well known for their economic development in Asia-Pacific, with all having large manufacturing sectors. Australia also has a large manufacturing sector, with this sector accounting for one eighth of GDP and total employment.

A total of 218 medium and large sized manufacturing companies participated in the study. These companies were randomly selected from an array of sub-industries (ranging from industrial to consumer products). The broad range of industries provided enabled us to generalize our results.

As the sample frame involved data to be collected from several countries, a research company was engaged to collect the survey data. Firms were randomly selected from the research company's extensive databases, and data was then collected through telephone interviews. Respondents were identified and screened at the start of the telephone interviews. While some job titles varied across countries and firms, all of the respondents in our survey held top managerial responsibilities. This put them in the best position to assess how their manufacturing capabilities compared against their competitors'. Designations of the respondents included General Managers, Assistant Directors and Deputy Managers. Specifically, 31 companies from Hong Kong, 35 from Singapore, 62 from Taiwan, 46 from South Korea and 44 from Australia participated in the study.

Level of Analysis

Flynn et al. [32] suggest that the plant level may be appropriate for production and operations management studies, since many measurable improvement initiatives occur at this level. Following their recommendations, the scope of our survey pertained to only individual plants in the specific countries where the respondents worked.

Respondent Profiles

Due to confidentiality and sensitivity of financial details, almost half of the respondents refused to release information regarding the value of their companies' fixed assets, while 25 percent refused to reveal their annual revenues. However, of the respondents which provided these details, at least 75 percent reported more than US$10 million worth of fixed assets, and about 90 percent reported more than US$10 million of revenue. Of the companies that did not provide financial data, we can still assess their size and scale by examining the number of employees and the number of years for which they have been operating in their respective countries. Ninety five percent of the companies had been operating for 10 or more years, implying that these companies had established a strong presence in their countries. Also, more than 75 percent of the companies had 200 or more employees, which can be considered as being large enterprises. As a whole, most of the companies that took part in this study were large and well established.

Manufacturing Capabilities Measurement Scales

Measurement of capabilities has been a problematic issue in previous manufacturing strategy studies [6]. We attempted to address these issues in several ways. Firstly, we avoided single item indicators. Noble [10] points out that single item indicators are hard to generalize. These single item indicators also fail to capture the richness and complexity of issues that they are attempting to measure. Therefore, we measured the manufacturing capabilities indirectly through constructs of multiple indicator items. Secondly, in order to validate the cumulative model, constructs in the model are represented by items that have been used previously in studies such as Ferdows and De Meyer [1], Roth and Miller [20], Ward et al. [33] and Noble [10]. A total of 13 items were selected. These items are shown in Table 1. For each of the 13 items, the individual respondent was asked to indicate, using a seven-point Likert scale, how his/her plant was performing relative to its competitors. Specifically, "1" on the Likert scale meant that the plant was performing significantly lower than competitors, and "7" meant that the plant was performing significantly higher than its competitors.

Table 1. Constructs and items

Quality (Cronbach's alpha = 0.771)	
V1:	Meet customer design and specifications
V2:	Offer good product design and performance
V3:	Offer durable and reliable products
V4:	Have reliable operations and execution systems
Delivery (Cronbach's alpha = 0.837)	
V5:	Meet delivery due dates
V6:	Offer fast delivery
Flexibility (Cronbach's alpha = 0.827)	
V7:	Respond rapidly to volume changes
V8:	Respond rapidly to changes in product mix
V9:	Customize/modify existing products
V10:	Introduce new products quickly
Cost (Cronbach's alpha = 0.792)	
V11:	Improve capacity utilization
V12:	Increase labour productivity
V13:	Produce at low unit product cost

V. Data Analysis Procedures & Results

Distributional Properties and Missing Data Analysis

The distributional properties (mean and standard deviation) for all 13 items suggested that the items had distributions that did not significantly depart from normality. We performed an analysis of variance test to establish if the responses to each question in the instrument differed with respect to the country location of the plant. This analysis showed that there were no significant differences. Hence we concluded that the plants in the study were unaffected by the country context. This enabled us to conduct all further analysis of the data with one single homogenous sample consisting of 218 firms. The level of missing data ranged between 6.3 and 9.0 percent for the items. These missing data were replaced with values obtained through the 'expectation-maximization' iterative algorithm since this method does not distort the underlying distributions, and is therefore better than other substitution and elimination techniques [34].

Psychometric Properties of Constructs

Face validity. The items assigned to each construct were obtained from literature. As such, there is ample evidence to conclude that the constructs and their associated items have strong grounding in literature and therefore, they possess high levels of face validity.

Multicollinearity. If inter-item correlations are greater than 0.9, the possibility that multicollinearity - two or more items are measuring the same entity - could be existing is high [35]. As none of the correlation coefficients between the 13 items was greater than 0.9, multicollinearity was not present.

Reliability. The Cronbach's alpha reliability coefficients for all four constructs are shown in Table 1. These coefficients range from 0.771 to 0.837. These exceed the minimum threshold level of 0.7 for acceptable reliability [36] for all the constructs. Therefore, the selected items reliably estimated the constructs.

Convergent and discriminant validities. Convergent validity (i.e., items assigned to a construct contribute roughly the same amount to the construct's measurement) and discriminant validity (i.e., items only estimate the construct to which they are assigned to and not any others) were both assessed using a confirmatory factor analysis (CFA) model testing approach. The CFA model is a structural equation model (SEM) where the constructs are all co-varied with each other. We used the AMOS® 5.0 software package for the SEM analysis. The maximum likelihood (ML) estimation technique was used to fit the CFA model to the data because it is a robust algorithm that is widely used [35].

We obtained a number of commonly reported indices for assessing the goodness-of-fit of models with data. For our CFA model, these fit indices are as follows: $\chi^2_{(59)} = 186$ with p-value = 0.000; χ^2/df= 3.158; goodness-of-fit index (GFI) = 0.889; adjusted goodness-of-fit index (AGFI) = 0.829; Tucker-Lewis index (TLI) = 0.883; comparative fit index (CFI) = 0.911; root mean square residual (RMR) = 0.081; and, root mean square error of approximation (RMSEA) = 0.100. To decide how well the model fits with data, the recommendations are that the p-value associated with χ^2 statistic should be greater than 0.05; GFI, AGFI, TLI and CFI should be close to one; and, RMR and RMSEA values should be close to zero. For our CFA model, the χ^2 statistic p-value is 0.000, suggesting poor fit. However, this fit measure has a tendency to produce negative results with sample sizes greater than 200 [35]. Since our sample size was 218, this measure was disregarded. As for other measures of fit, it has been conventional to use 0.95 for indices such as GFI, AGFI, TLI and CFI; and 0.05 for RMR and RMSEA as cut-off values for acceptable fit. Applying these to our CFA model results, we conclude that fit is poor. But these conventional cutoff criteria are considered to be excessively stringent [35, 37-39]. Less stringent cutoff criteria where factors such as model complexity, sample size and number of observed variables are taken into account have been proposed. For example, Sharma et al. [38, pp.941-942] suggest that for datasets with more than 24 items and sample size of around 200, "more liberal" cutoff values (e.g., 0.8) should be used for fit indices such as GFI and TLI. Applying these criteria to our CFA model, we conclude that an 'adequate' level of fit has been obtained. Our results and fit assessment is similar to many studies. For example, Hult et al. [40] declared "moderate but acceptable model fit" [40, p.581] based on CFI = 0.84, AGFI = 0.86 and RMSR = 0.08.

Having concluded that the CFA model has adequate empirical support, we then made an assessment of the convergent and discriminant validities. The convergent validity of the constructs is generally supported; all the factor loadings of items on constructs are significant (at p-values < 0.001), the signs are all positive and all standardized factor loadings are above the conventionally acceptable level of 0.4 [35], with the minimum being +0.618. Further, the squared multiple correlation coefficient values indicate that the variances of the items explained by their constructs are reasonably high (with the average being 55 percent). As for discriminant validity, correlations between the constructs are mostly moderate (i.e., less than 0.9), ranging between 0.715 and 0.855. This suggests that items assigned to one construct were not significantly highly loading on others.

Common methods bias. Since all items were measured using seven-point Likert scale and responses were received from a single individual in the organization, there is some possibility that common methods bias could be present. We performed Harmon's one factor test [41] using a confirmatory approach to test for this effect. This involved testing a one-factor congeneric model [42], where all 13 items were loaded onto a single 'common factor' construct. The SEM results of this test indicated that common methods bias was unlikely to be present, with the goodness-of-fit indices for this model indicating poor fit with data.

SEM Results for the Structural Model Representing Sandcone Model

Evaluation of goodness-of-fit indices. As with the CFA model, we used the SEM analysis procedure to assess the hypothesized relationships in Figure 1. The fit indices for the hypothesized model are the same as that for the CFA. This is because the number of parameters in the hypothesized model is exactly the same as that in the CFA, resulting in all fit indices being the same for the two models. Our assessment of fit for this model is the same as for the CFA, the model-data fit is adequate.

Evaluation of parameter estimates. Figure 2 shows the SEM output associated with the structural part of the hypothesized model, with all the parameters presented in standardized form. As Figure 2 shows, three out of the six hypothesized relationships (H1, H4 and H5) were supported, with the rest (H2, H3 and H6) not supported. Also, the squared multiple correlation coefficients associated with the endogenous constructs 'delivery', 'flexibility' and 'cost' were 0.632, 0.673 and 0.758 respectively. This indicates that the exogenous constructs accounted for large proportions of the variances in these endogenous constructs.

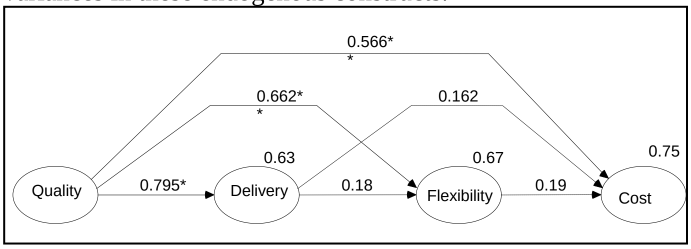

Figure 2: Hypothesized model, showing maximum likelihood estimates of standardized regression coefficients (on lines), and squared multiple correlation coefficients (on constructs).

** p-value < 0.01. ----- Dashed lines indicate statistically insignificant (p-values > 0.01) relationships.

We further analyzed the regression data presented in Figure 2 by examining the standardized effect sizes between the constructs. Effect sizes measure the increase/decrease in the endogenous construct (in standard deviation units) arising from an increase of one standard deviation in the exogenous construct. The standardized direct effects, indirect effects and total effects of all the exogenous constructs on the endogenous construct of the model are shown in Table 2. From this table, an important observation can be made. While three out of the six direct effects are small in magnitude, two of the three indirect effects are of significant magnitude such that when the direct and indirect effects are added together, the total effect sizes in all cases are moderate to strong in magnitude and positive in sign.

Table 2. Estimates of standardized direct, indirect and total effects of the exogenous constructs on the endogenous constructs

Exogenous construct:	Direct effect	Indirect effect	Total effect
	Endogenous construct: Delivery		
Quality	0.795	0.000	0.795
	Endogenous construct: Flexibility		
Quality	0.662	0.150	0.812
Delivery	0.189	0.000	0.189
	Endogenous construct: Cost		
Quality	0.566	0.288	0.855
Delivery	0.162	0.037	0.199
Flexibility	0.196	0.000	0.196

VI. Discussion

Results of our study relating to the fully representative cumulative model in Figure 1 suggest that there is overall empirical evidence to support the cumulative model. However, this support is not straightforward and emphatic. Figure 2 shows that three relationships are supported (H1, H4 and H5), and three are not supported (H2, H3 and H6). Here, we might conclude that there is no interaction between the higher level capabilities of delivery, flexibility and cost, and that capabilities are not accumulating according to the sandcone pattern as suggested by Ferdows and De Meyer [1]. This view, however, is not complete because Table 6 shows that when both direct and indirect effects are taken into consideration, the total effect of lower level capabilities on higher level capabilities is strong and positive. The weaker effects are compensated for by stronger related effects. As such, the results, taken in totality, suggest that firms have cumulative capabilities. Furthermore, the manner in which these capabilities are built up do, to a certain extent, resemble the cumulative model. We therefore conclude that our study does provide empirical support for the cumulative model.

From our results in Figure 2 and Table 2, a couple of key observations can be made. Firstly, quality is the base capability upon which all other capabilities are built upon. This view of quality being the bedrock capability is shared by many others [e.g., 1, 11, 15, 16, 28]. Secondly, the lack of support for the relationships between delivery, flexibility and cost (H2 and H3) suggests that these capabilities could be independent of each other. Organizations can develop the quality capability, then seemingly move on to develop capabilities in delivery, flexibility and cost efficiency. These higher order capabilities could exist in relative isolation from each other. This supports the notion that capabilities can co-exist simultaneously. Although the lack of support for the direct relationships between delivery, flexibility and cost capabilities is somewhat compensated through other indirect effects, the relationships between these high order capabilities are not clear-cut and straight-forward as suggested by the cumulative model. There are two possible explanations for why the higher order capabilities are not related as hypothesised: (1) unlike quality and cost, the other two capabilities (delivery and flexibility) are not all that well understand in terms of how they are interrelated; and (2) these three capabilities are so different in nature to each other that they do not logically relate to each other as expected. For example, Größler and Grübner [15] hypothesized and found a negative relationship between flexibility and cost. As Ferdows and De Meyer [1, p.169] state: “New insights about the relationship between other capabilities [delivery and flexibility] are more scarce.”

How do our results compare with previous studies? There are a handful of studies which are similar to ours that make direct comparisons possible [12, 15, 16]. Our results are similar to those in Größler and Grübner [15]. Similar to us, they also found general support for the cumulative model, although results relating to some of the specific hypothesized relationships were different from ours. Similarly, Amoako-Gyampah and Meredith [16] found partial support for the cumulative model in Ghanaian manufacturing firms; these firms appeared to focus on cost and quality capabilities, and not delivery and flexibility. In contrast to our results, Flynn and Flynn [12] concluded that their data did not support the cumulative model of capabilities development.

In terms of contingent effect of country location, our analysis indicates that the five countries (Korea, Singapore, Taiwan, Hong Kong and Australia) in which our firms were located did not contribute to any differences to the measures of the four capabilities. There appears to be more similarity than differences in the measures with respect to the countries involved in our study. Generalizing our sample to the broader population of firms, our study suggests that firms in the Asia Pacific region possess cumulative capabilities, though the pattern of capability development is not exactly as specified in the cumulative model of Ferdows and De Meyer [1]. A commonality among Asia-Pacific firms is that their development of delivery, flexibility and cost capabilities is founded on quality. This is somewhat unique, as a similar pattern of capabilities development has not been presented in the literature. This could be a point of distinction for Asia Pacific firms that have developed their competitive capabilities and attained such industrial success in a relatively short period of time.

VII. Conclusion

Our study has provided partial empirical support for the cumulative model. Further, we found that quality is a base capability upon which higher order capabilities such as delivery, flexibility and cost efficiency are built. The high order capabilities do not accumulate in the exact manner described in Ferdows and De Meyer [1]. Instead the accumulation is more indirect in nature. The higher order capabilities seem to exist independently and so it would appear that these capabilities can be effected simultaneously. It appears that Asia Pacific firms have used a fairly novel approach to cumulative capabilities development. This could be a potential insight and explanation, along with many others, for the rapid and successful industrial development of countries represented in this study.

Whilst our study is systematic and rigorous, it does have limitations that could represent opportunities for future research. The first limitation relates to single-respondent data.

We relied on the information provided by the sole respondent from each firm. This may have resulted in some judgment bias. Since the survey was targeted at managers who are well informed, we minimized these potential biases and errors inherent in the survey process. Another limitation relates to the dispersed locations of the firms. As participating firms came from five different countries, we faced challenges during data collection. Although our analysis suggested that there were no significant differences between the firms due to country location thus enabling us to analyze the region as a whole, if a large sample was available, we could have performed cross country comparisons. Lastly, as an exploratory study, we have focused on five countries that have not been studied extensively before. Given the growing prominence of the manufacturing sectors in other developing countries such as India, Thailand, Malaysia and Vietnam, there will be increased demand for knowledge of these countries. As such, these countries can serve as research settings in future research.

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