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Empirical investigation of alternate cumulative capability models: A multi-method approach

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Abstract

Quality (Q), delivery (D), flexibility (F) and cost (C) may reinforce each other to form specific models of cumulative capability. Previous empirical studies reveal two dominant models of cumulative capabilities (Q-D-F-C and Q-D-C-F) without testing whether other models could better fit their data. The present study fulfils this gap and conducts a comparative analysis by testing various models of cumulative capabilities based on a survey of 368 Thai manufacturing plants, and concludes that Q-D-C-F is the best-fit model and further extends the models to reveal "simultaneous" cumulative capability. The contributions are threefold. First, multiple methods are applied to robustly search for the best-fit model. Second, direct and indirect links between capabilities are revealed to add insights into the cumulative reinforcement patterns among capabilities. Third, we show that the widely accepted sand-cone model (Q-D-F-C) and Competitive Progression Theory (CPT) are not necessarily the dominant approaches for explaining cumulative capability patterns of manufacturers, especially from an emerging country. The results are also significant for practitioners as they understand how capabilities such as quality and delivery can simultaneously improve the next sequential capability.

Keywords Manufacturing capability; Operations strategy; Cumulative capability; Automotive industry; Food industry; Electronics industry

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1. Introduction

Manufacturing capabilities, namely quality (Q), delivery (D), flexibility (F), and cost (C) are known to trade-off with each other (Skinner, 1974), or reinforce each other to form cumulative capabilities (Ferdows and de Meyer, 1990; Dangayach and Deshmukh, 2001). As shown by two meta-analyses (White, 1996; Rosenzweig and Easton, 2010) most manufacturers apply the cumulative capability models but only a few face trade-off. Cumulative capabilities are even more important for manufacturers from developing countries that have not achieved performance frontier (Rosenzweig and Eaton, 2010). The relationships among capabilities for such manufacturers are stronger and their associations with productivity improvements are also stronger than those from industrialised or developed countries (Schoenherr et al., 2012).

It is argued that cumulative capabilities are built cumulatively in a sequential manner but there is no conclusion as to why and which sequences are used dominantly in different regions. Among others, the most popular cumulative model argues that cumulative capabilities are built from first mastering quality then progressing further to delivery, flexibility and, lastly, to cost (Rosenzweig and Roth, 2004). This Q-D-F-C sequence, or the so-called sand-cone model (Ferdows and de Meyer, 1990), has been found in manufacturing industries from mainly developed countries (Ferdows and de Meyer, 1990; Groβler and Grübner, 2006; Rosenzweig and Roth, 2004) and recently among Spanish manufacturers (Avella et al., 2011). The second most popular model follows the Q-D-C-F sequence. Emphasizing flexibility only after achieving cost-efficiency, delivery and quality capabilities, the Q-D-C-F model has been regarded as "the most comfortable sequence" of cumulative capabilities for manufacturers to make progress (Schmenner and Swink, 1998). This model has been previously found in Japanese (Hall, 1987; Nakane, 1986) and American manufacturing industries (Schemener and Swink, 1998). Furthermore, recent evidence suggests cumulative capabilities do not simply follow a serial "step-by-step" sequence; it is possible to extend the cumulative capability models by examining both direct and indirect effects (Avella et al., 2011; Sum et al., 2012) so that research can inform manufacturers on how to improve multiple capabilities simultaneously.

It is, thus, necessary to discover whether Q-D-F-C or Q-D-C-F is more prevalent or suitable for manufacturers from developed and developing countries (Narasimhan and Schoenherr, 2013) because manufacturers from different countries may apply different models or sequences of cumulative capabilities owing to different competitive environments (Noble, 1995; Flynn and Flynn, 2004). For example, Rosenzweig and Roth (2004) argue that the Q-D-F-C model is suitable for manufacturers competing in high-tech environments. Quality and product introduction speed may form the basis of cumulative capabilities for manufacturers competing in more competitive and rapidly changing industries, where product life cycles are shorter (Flynn and Flynn, 2004). As stated by Schroeder et al. (2011), national contingency factors have not been taken into account by most existing studies because they examine their datasets based on a single cumulative capability model.

There is some recent evidence suggesting that one should consider cumulative capability models as alternatives to the most popular sand-cone model (Q-D-F-C). Based on a multi-country (e.g., Finland, Germany, Japan, Korea, Sweden, and the United States) cross-sectional dataset, not every manufacturer was found to apply the Q-D-F-C model (Schroeder et al., 2011). Another repeated multi-country (i.e., Hungary, Italy, and Taiwan) cross-sectional study by Narasimhan and Schoenherr (2013) also found that manufactures did not follow the Q-D-F-C model as they progressed. A more recent study by Sum et al. (2012) found no evidence for the Q-D-F-C model among manufacturing firms from five Asia Pacific countries. Amoako-Gyampah and Meredith (2007) discovered that the cost-driven manufacturing and services industries in Ghana, instead, preferred to improve cost after mastering quality. Manufacturers, especially from developing countries, appear to apply cumulative models alternate to the sand-cone or Q-D-F-C model and trade-off model (Singh et al., 2014).

In this vein, the current study presents a comparative analysis for different models of cumulative capabilities and further extends the models to reveal "simultaneous" cumulative behaviours. Specifically, this study empirically tests and extends the applicability of two popular models (Q-D-F-C and Q-D-C-F) that are potentially predominant among Thai manufacturing industries. To achieve the utmost rigour, the study applies multiple methods, including correlations and sequential tests (see Schroeder et al., 2011), followed by structural equation modelling (SEM). SEM is the most appropriate method for replication studies (Rosenzweig and Easton 2010; Narasimhan and Schoenherr, 2013). Using a model fit index, SEM helps to compare the fit between each model with the same dataset. Furthermore, SEM allows us to systematically examine the direct and indirect effects of various capabilities (Schroeder et al., 2011), leading to a more comprehensive understanding of cumulative capabilities in terms of both sequential and simultaneous relationships amongst different capabilities.

This study contributes to the production and operations management (POM) literature in two aspects. First, it advances the theoretical foundation of the cumulative capability by providing new evidence for comparing the different models of sequences and simultaneous progressions using the same dataset, establishes links between cumulative capability and performance frontier, and uncovers new insights into the direct and indirect effects among manufacturing capabilities. This study addresses a key research challenge in the sense of discovering and understanding alternative cumulative capability models, and models other than cumulative and trade-off (Singh et al., 2015). Second, this study analyses a valuable dataset from a developing country using multiple methods for triangulation to achieve conclusions of the utmost rigour. Recent evidence suggests that cumulative capabilities are more powerful resources for manufacturers from less-developed countries compared to those from developed countries (Schoenherr et al., 2012). Thus, more evidence from a developing country is provided to help understand national contingency. The datasets of manufacturers from Thailand represent more recent evidence with larger sample sizes compared to most previous studies. Using different methods to compare different trade-off, cumulative and simultaneous capabilities this study extends the work of Schroeder et al. (2011) by verifying the best-fit cumulative and simultaneous capabilities models for another developing country. The study complements the work of Amoako-Gyampah and Meredith (2007) based on manufacturers in Ghana and Sum et al. (2012) based on manufacturers in Asia Pacific countries by adding new evidence for the model of cumulative capabilities in developing countries.

2. Theoretical background and investigated models

Various studies suggest some dimensions of manufacturing capabilities are crucial for achieving competitiveness (White, 1996). To remain competitive, a firm should focus on manufacturing capabilities that have an external-customer orientation and manifest the relative strength of the firm against its competitors (Koufteros et al., 2002). The production and operations management literature has generally agreed on four dimensions of manufacturing capability: quality (Q), cost (C), flexibility (F) and delivery (D); these are considered as key determinants of a manufacturer's competitive advantage (Hayes and Wheelwright, 1984; Ferdows and De Meyer, 1990; White, 1996; Dangayach and Deshmukh, 2008). Accordingly, manufacturing capabilities in this study are measured based on quality, cost, flexibility and delivery as defined in Table 1.

<< Insert Table 1 about here >>

2.1 Trade-off versus cumulative capabilities

Before explaining the major models of manufacturing capabilities, there is a need to explain the trade-off versus cumulative perspectives. The trade-off perspective argues that one manufacturing capability can only be improved at the expense of other capabilities (Skinner, 1974). Trade-off means one capability could have negative correlations with other capabilities. Another perspective argues that one capability can enhance another; they become cumulative (Ferdows and De Meyer, 1990), meaning that all capabilities are positively correlated with the others. Ferdows and De Meyer (1990) further argue that manufacturers with cumulative capability are more likely to achieve lasting improvement. Manufacturers such as those from developing countries that have not reached the performance frontier and have made significant progress in acquiring multiple capabilities are expected to apply cumulative capabilities instead of the trade-off perspective (Amoako-Gyampah and Meredith, 2007).

2.2 Q-D-F-C cumulative model

When a manufacturer accumulates capabilities, they first develop one capability and then move on to the next, in a sequence. The first cumulative capabilities model is supported by Competitive Progression Theory (CPT) developed by Rosenzweig and Roth (2004). CPT theory argues that sustainable competitive capabilities can be built cumulatively, starting from quality to delivery to flexibility and to cost (Q-D-F-C). This sequence, also called the sand-cone model (Ferdows and De Meyer, 1990), is supported by two main arguments. First, quality (Q) and delivery (D) are capable of improving the other two capabilities (F and C). Second, this sequence allows manufacturers to develop the fundamental capabilities (Q and D) because lessons learned from these initial efforts are required to develop the other capabilities (F and C), which are more difficult to master (Rosenzweig and Roth, 2004). These two arguments are further explained below.

Quality is essential for ensuring delivery and cost performance because it provides effective quality control to ensure that the production process is more reliable such that it warrants on-time delivery and reduces waste (Ferdows and De Meyer, 1990; Noble, 1995; Fawcett et al., 1997) because they will spend less time and resources to rework or handle rejects (Flynn et al., 1995; Milgate, 2000). Essentially, when quality control becomes effective, the production process will produce less rejects and, therefore, less rework is required, subsequently resulting in lower cost of poor quality (Crosby, 1979; Deming, 1982; Gupta and Campbell, 1995; Flynn et al., 1995). Furthermore, quality management techniques such as the quality deployment function, Taguchi method, and design for manufacturing design are often used to improve the features of a product as well as the costs of production (Taguchi and Clausing, 1990; Lockamy and Khurana, 1995). Several empirical studies confirm that an enhanced quality positively and directly influences improvements in delivery reliability (Flynn and Flynn, 2004; Gröβler and Grübner, 2006; Schroeder et al., 2011).

Quality equates to more reliable production scheduling and, thus, production planners have more room to provide lead-time flexibilities (Corbett and van Wassenhove, 1993). Poor process quality often creates bottlenecks in production; therefore, resources which could provide flexibility are used for managing bottlenecks instead. Also, poor quality adds manufacturing time and reduces speed (Ferdows and De Meyer, 1990), and speed is an essential enabler of volume and lead-time flexibility. Quality also helps to provide variety flexibility. For example, the Yamazaki machine tool factory in the UK was able to offer to the industry four times more models in one third of the time normal, while the quality of their products “matched or beat” the high Japanese standard (Jones et al., 1988).

Delivery capability is another step manufacturers need to achieve to further improve cost and flexibility. As suggested by Sakakibara et al (1997) and Funk

(1995), manufacturing at high speed reduces times in the operations process and helps in reducing costs through higher productivity and lower inventory costs. This is particularly relevant to manufacturers from developing countries as they have progressed from being low-cost manufacturers based on purely low labour costs to being able to achieve cost savings based on conformance quality and JIT supply (Laosirihongthong and Dangayach, 2005). Furthermore, when manufacturers reduce variance in their delivery processes and the predictability of the production and distribution systems (delivery reliability), production (volume) flexibility will be enhanced (Flynn and Flynn, 2004; Rosenzweig and Roth, 2004). In addition, the positive relationship between delivery and cost has been previously reported (Narasimhan and Jayaram, 1998a).

The second argument for the Q-D-F-C model suggests that moving up from Q to D to F and C requires more learning than in the earlier steps (Rosenzweig and Roth, 2004). This argument is supported by Competitive Progression Theory (Rosenzweig and Roth, 2004). Accordingly, learning to "do the right things" and reduce waste (quality capability) makes delivery more reliable and, therefore, learning to provide mix and volume flexibility less difficult. It is premature to build up cost capability before flexibility capability because speed (a dimension of flexibility) is required to save cost (Ferdows and de Meyer, 1990). The Q-D-F-C model is further supported by evidence from many developed countries including Spain (Ferdows and de Meyer, 1990; Groβler and Grübner, 2006; Rosenzweig and Roth, 2004; Avella et al., 2011). However, recent evidence confirms that not all manufacturers have applied the Q-D-F-C model (Schroeder et al., 2011; Narasimhan and Schoenherr, 2013).

2.3 Q-D-C-F cumulative model

Q-D-C-F is another popular model of cumulative capabilities. This model has been regarded as "the most comfortable sequence" of cumulative capabilities for manufacturers to achieve (Schmenner and Swink, 1998). It applies the same arguments put forward earlier for the Q-D-F-C model, that is, the need to first develop quality (Q) and then delivery (D). However, instead of cost (C), flexibility (F) is the next capability to be developed after quality (Q) and delivery (D). Proponents of this model (Hall, 1987; Nakane, 1986; Schemener and Swink, 1998) argue that both quality (Q) and delivery (D) can directly improve cost (C). Furthermore, this model may be suitable for manufacturers from developing countries because emphasizing low-cost could drive them to put more effort into cost efficiency before developing flexibility capability (Amoako-Gyampah and Meredith, 2007). It is, therefore, no surprise to find such manufacturers developing flexibility only after achieving cost-efficiency capability (Q-D-C-F model).

However, there are, so far, less empirical studies of the Q-D-C-F model, compared to the Q-D-F-C model. To this point, the Q-D-F-C model has been found in Japanese (Hall, 1987; Nakane, 1986) and American manufacturing industries (Schemener and Swink, 1998); nevertheless, there seems to be a lack of more recent study, as well as evidence from developing countries. By adding environmental protection (E) as a mediating variable into the path between C and F, Avella et al. (2011) show that Spanish manufacturers followed a Q-D-F-E-C model which, instead, more represents the Q-D-F-C sequence. Sum et al. (2012) found that manufacturing firms from five Asia Pacific countries did not apply the Q-D-F-C model but neither did they test if their data fit with the Q-D-C-F model.

2.4 Cumulative models in Thailand

Thailand is a developing country, and its economy is heavily export-dependent, with exports accounting for more than two-thirds of its gross domestic product (GDP). The industrial sector is the main portion in the Thai gross domestic product, with the former accounting for 32% of GDP (Office of the National Economics and Social Development Board, 2015). Most of the manufacturing industries in Thailand have been dominated by Foreign Direct Investment (FDI). These foreign firms mainly focus on production activities. These FDIs may be prepared to transfer only hardware, automation systems, computer-based control technology, production systems, and experts to support the manufacturing process control. Design information, and engineering data are transferred with very limited knowledge. Thus, most manufacturers in Thailand have a need for improvement before achieving the performance frontier (Schemener and Swink, 1998) and are likely to experience cumulative capability instead of trade-off (Rosenzweig and Easton, 2010). Automotive, electronics, and the food industries are major industries in Thailand.

Though still being considered low-cost producers, Thai manufacturers have to offer high quality products and use process-based quality (Laosirihongthong and Dangayach, 2005; Phusavat and Kanchana, 2007) to ensure reliable delivery because they compete with other low-cost countries such as China, Indonesia and Vietnam with relatively cheaper labour costs. Most Thai manufacturers, therefore, initially place a lot of effort in programmes such as total quality management (TQM) and ISO certification followed by JIT or similar programmes to improve delivery performance (Phusavat and Kanchana, 2007; Laosirihongthong and Dangayach, 2005).

While it is clear Thai manufacturers first emphasize quality then delivery, it is less certain whether they improve cost (Q-D-C-F) or flexibility (Q-D-F-C) next. Many manufacturing firms in Thailand need to compete with a low cost advantage in their operations over their competitors in developed countries. This could be explained by the fact that most firms in Thailand have been dominated by multinational companies that use offshore manufacturing as their business strategy. To achieve low cost advantage, some Thai manufacturers cannot rely on only cheap labour they need to save costs using process-based quality and reliable delivery. To achieve high levels of efficiency such manufacturers might maintain an adequate level of flexibility but pay more attention to cost efficiency. Thus, it is likely to find the Q-D-C-F model dominating Thai manufacturers.

Instead, some Thai manufacturers may need to emphasize flexibility before cost by adopting the sand-cone model (Q-D-F-C). They need to master the use of Surface Mount Technology (SMT) or a Flexible Production System (FPS) to achieve, especially, variety flexibility so that they are then able to produce a high variety of new products more frequently at a relatively shorter lead time (Bennett et al., 1992; Lambert et al., 2006) High-tech electronics and fresh-produce food manufacturers may need to place more effort in improving flexibility and later save costs owing to the nature of their cost structure and customer requirements (Narasimhan and Jayaram, 1998b; Monden, 2012). In addition, Thai industries still need to conform to global quality standards in order to gain their rightful place in the global manufacturing industry. Such Thai manufacturers use quality as a foundation for formulating other manufacturing strategies. Then, they develop delivery and flexibility capabilities in order to reduce production costs (Rahman et al, 2010).

Depending on the dominant profiles of Thai manufacturing industries, it is possible to find either Q-D-C-F or Q-D-F-C models.

2.5 Extended cumulative models in Thailand

A number of recent studies have argued both the existing cumulative models are, perhaps, being over-simplified (Avella et al., 2011; Sum et al., 2012). As argued earlier, quality (Q) and delivery (D) capabilities can positively influence cost (C) and flexibility (F) capabilities. Taking this argument into account, the studies of Schroeder et al. (2011), Avella et al. (2011) and Sum et al. (2012) demonstrate some of these direct effects do exist and, therefore, reveal that quality and delivery may have direct and indirect effects on the other capabilities. As previous literature suggests, quality can have a positive effect on other manufacturing capabilities. Quality improvement stabilizes production processes, eliminating reworks and improving lead time reduction. A reduction in lead times not only reduces inventories but also shortens internal product transport time, eliminating the need for repeat consignments due to reliable delivery, which also saves energy and reduces costs. Considering the Thai manufacturing sector has a need for further improvement before reaching the performance frontier, it is likely to find direct and indirect effects of quality on delivery, cost and flexibility. Proving these direct and indirect effects helps to extend the “sequential” Q-D-F-C and Q-D-C-F models to a more “divergent” and complete model of cumulative capabilities. By discovering the possible indirect effects via mediating variables, it is then possible to differentiate the roles of different capabilities in building the models of cumulative capabilities.

3. Methodology

3.1 Sampling and data collection

The survey instrument was developed in three stages. In the first stage, all the measurement items were identified from the literature review. An English version of the questionnaire was developed and tested to determine content validity. In the second stage, the questionnaire was translated into the Thai language. A bilingual Thai native proofread the English version and corrected ambiguities that could cause confusion in translation. Next, the questionnaire was reviewed by several Thai practitioners such as directors and production and supply chain managers as well as academics with expertise in operations strategy in Thai industry. They examined the questionnaire for clarity and to ensure that it conveyed the adequate meaning of each item. They suggested some clarification of the instructions and refinement of item wording. No other problems were detected. Finally, the questionnaire was pre-tested by manufacturing industry representatives and academics familiar with competitive capability and operations strategy to ensure the items were clear, providing face validity for the construct examined. Subsequently, minor amendment was made and the instrument was then sent out for data collection.

Data for this research were obtained from a survey distributed across three major industries: automotive, electronics, and food in Thailand because they are highly diverse and heterogeneous spanning manufacturers of structural characteristics and maturity. The level and degree of technology, sophistication and innovation in productive processes, the capital investment compared to manpower use, the size of the investment, the total number of workers, and the scale capacity of operations are distinctive characteristics of the industries. In addition, these three industries are likely to influence 19% of Thailand's gross domestic product (GDP) (Yusuf and Nuh, 2015). The mailing lists were obtained from three sources: (1) the Directory of the Society of Automotive Engineering of Thailand, (2) the Thailand Industry Directory, and (3) the Export-Import Bank of Thailand. Respondents included plant managers, CEOs, presidents, vice presidents, and directors. Potential respondents were contacted first by telephone to confirm contact information for mail delivery.

<< Insert Table 2 about here >>

The survey was sent to 1,708 potential respondents from the automotive, electronics and food industries. The final number of completed and usable responses was 368 usable responses (21.54% response rate). This response rate meets the recommended minimum of 20% for empirical studies in operations management (Malhotra and Grover, 1998). Table 2 summarizes the respondent profile. The non-respondent bias was further assessed by comparing the responses of early and late respondents to test for their significant difference (Armstrong and Overton, 1977).

The first 75% of the responses were classified as “early respondents”. The last 25% were classified as “late respondents” and they were considered as manufacturers that did not respond to the survey for each industry. At a 0.05 significance level, analysis of variance (ANOVA) tests indicated no differences between the early and late respondents across the key characteristics including number of employees, respondent’s position, and number of years in business. Along with the demographic variables, ten items from all constructs (i.e., quality, delivery, flexibility, and cost) were also included in this analysis. The results indicate no significant difference on any criteria for all industries, suggesting that non-response bias was not a problem with regard to data collection.

We also separately assessed common method bias by incorporating a Harman’s one-factor test (Podsakoff and Organ, 1986) that is widely followed by the extant operations management literature (e.g., Craighead et al., 2011) to determine the extent of common method variances (CMV). Using an un-rotated principal components factor analysis identifies factors with eigenvalues greater than 1.0 and these factors explain greater than 70% of the total variance, identifying several factors, as opposed to one single factor. No single factor was found to account for a majority of the variance in data. In addition, in the design of the questionnaire, we separated the variables into sections to overcome the shortcomings of common method variance. Thus, common method bias was not considered a problem for further analysis.

3.2 Construct measures

We adopt the measures used in this study from a well-established instrument in the operations management field. For most items, a five-point Likert scale was used for all the constructs; a higher value indicates a better performance. In the following paragraphs we make extra effort to clearly define the domain of each construct in terms of which item will be included, even though all measures in this research were adopted from previous literature.

Quality: Quality capability is measured using indicators from both process-based and market-based quality, following Flynn and Flynn (2004), Dangayach and Deshmukh (2006) and Amoako-Gyampah and Meredith (2007). Process-based quality focuses on achieving the conformance of specification (Flynn and Flynn, 2004) with an emphasis on low defects. Market-based quality is visible to customers so it is essential to fulfil customer needs (Koufteros et al., 2002). It ensures that the products are “fit for use” (Tracey et al., 1999). It is measured based on functionality, features, durability, aesthetics, and serviceability, reliability, and perceived product quality that meet customer needs (Dangayach and Deshmukh, 2006; Gröβler and Grübner, 2006; Avella et al., 2011; Schroeder et al., 2011; Sum et al., 2012).

Delivery: Delivery capability is often related to time-based performance such as delivery speed (Li, 2000; Thun et al., 2000; Dangayach and Deshmukh, 2006) and reduction of production lead time (Vickery et al., 1997; Jayaram et al., 1999), for both current and new products (Wacker, 1996; Li, 2000). It is measured in terms of speed or short lead time, on-time and short customer order taking time (Gröβler and Grübner, 2006; Avella et al., 2011; Schroeder et al., 2011; Sum et al., 2012). Some argue delivery capability should include the reliability or dependability of delivery (Wacker, 1996; Dangayach and Deshmukh, 2006) to ensure delivery on-time according to promise (Fawcett et al., 1997) and a high level of customer service (Ward and Duray, 2000). Therefore, delivery capability is further measured in terms of correct quantity, correct products and reliable delivery.

Flexibility: Production flexibility is the ability of a manufacturing system to cope with environmental uncertainties (Narasimhan and Das, 1999), manage production resources and uncertainty to meet various customer requests (Zhang et al., 2003), or respond to changes and to accommodate the unique needs of each customer. Production flexibility is measured based on the ability to rapidly change production volume, make rapid product mix changes, produce customized products features, and produce broad product specifications within the same facility.

Cost: Many scholars (Noble, 1995; Gröβler and Grübner, 2006; Avella et al., 2011; Schroeder et al., 2011) suggest that cost-efficiency is associated with a low-cost product, low work-in-process inventories, production flow, reduced overheads, and so forth. Therefore, this study measures production costs in terms of low cost in production, inventory and overhead. It is also necessary to consider the cost borne by customers compared with other competitors. Swink and Hegarty (1998) suggest including “transfer cost”, which consists of costs to make and deliver products plus costs of return or replacement if necessary into production cost. Thus, production cost is further measured in terms of low price offering compared with other competitors.

3.3 Scale assessment

In order to test the measurement model, confirmatory factor analysis (CFA) using AMOS 18.0 is used as a robust method for establishing unidimensionality and testing the measurement model (Li et al., 2005). CFA involves an estimation of a measurement model, wherein the observed variables are mapped onto the latent construct. We assessed the convergent and discriminant validity of the scales using the method suggested by Fornell and Larcker (1981). Convergent validity measures the similarity or convergence between individual items measuring the same construct; it can be tested by examining whether each individual item's standardized coefficient from the measurement model is significant, that is, greater than twice its standard error (Anderson and Gerbing, 1988). Additionally, the larger the t-values or the standardized coefficients become, the stronger the evidence that the individual items represent the underlying factor.

Table 3 shows that the coefficients for all items greatly exceed twice their standard error. In addition, coefficients for all variables are large and significant, providing evidence of convergent validity. Referring to Table 3, the confirmatory factor analysis (CFA) results also indicate that all items were significantly loaded to their constructs ($\beta > 0.6$) with a significance level of 0.01 or lower ($p \leq 0.01$). In addition, our analysis results indicate that the construct (composite) reliability ranged from 0.75 to 0.90, and the average variance extracted (AVE) ranged from 0.51 to 0.72. To indicate good convergent validity, the value of composite reliability should exceed 0.70, and the variance extracted should exceed 0.50. Furthermore, the standardized coefficients for all items were more than twice their standard errors. Therefore, all items were significantly related to their underlying theoretical constructs.

<< Insert Table 3 here >>

Discriminant validity can be evaluated by fixing the correlation between any pair of related constructs at 1.0, prior to re-estimating the modified model. A significant difference in Chi-square values for the fixed and free solutions indicates the distinctiveness of the two constructs (Bagozzi et al., 1991; DeVellis, 1991). In this research, discriminant validity is established using CFA. The results confirm the discriminant validity among constructs because all three Chi-square differences between the fixed and free solutions in Chi-square are statistically significant at $p < 0.01$ level. Thus, the above results support the overall reliability and validity of the scale items used to measure the various capabilities constructs.

4. Results and analyses

4.1 The model comparison

We compared the different competing models using a two-stage approach. First, we examined the correlations between the manufacturing capabilities (Table 4) and simultaneously compared the number of plants exhibiting different sequences (Tables 5 and 6), following the sequential test utilized by Schroeder et al. (2011) and Narasimhan and Schoenherr (2013). As shown in Table 4, positive correlations also indicate that there is no trade-off, only cumulative relationships. Quality has the highest mean value, followed by delivery, flexibility and cost. The correlation efficient between quality and delivery was the highest, followed by the coefficients for quality-flexibility and quality-cost. These results indicate the likelihood of a Q-D-F-C sequence over other sequences. However, the results cannot reject other cumulative capability models because each manufacturing capability is significantly correlated with all the other capabilities at $p < 0.01$.

<< Insert Table 4 here >>

Table 5 is constructed following the sequential test of Schroeder et al. (2011). Accordingly, we divided the four manufacturing capabilities into high and low according to median and constructed 16 possible sequences (Table 5). So far the sequential test had been utilized to test the Q-D-F-C model alone but in this study we applied the test to examine all possible cumulative sequences. Based on the number of plants that fit with each sequence we identified four major sequences with the largest number of plants (Table 6). As shown in Table 5, both Q-D-F-C (182 plants with configuration numbers 1, 5, 7, 8 and 16) and Q-D-C-F (180 plants with configuration numbers 1, 3, 7, 8 and 16) had the largest number of plants, compared to Q-C-F-D, Q-C-D-F and other sequences. In summary, approximately 52% of the plants possibly fit with the Q-D-F-C (sand cone model) and 51% of the plants possibly fit with the Q-D-C-F model. Since a large number of plants (162 plants with configuration number 1, 7, 8 and 16) possibly share the Q-D-F-C and Q-D-C-F sequences (44% of the plants) the sequential test cannot adequately distinguish (Q-D-F-C or Q-D-C-F) the dominating sequence in the samples.

<< Insert Table 5 and Table 6 here >>

As shown in Table 7 we first examined four non-extended models and then moved on to selected extended models using AMOS 18.0. The table shows three out of the four non-extended models had acceptable model fits. The model fit for Q-D-F-C is questionable due to AGFI < 0.9 having very similar model fit with Q-D-C-F in terms of AGFI, NFI, CFI and RMSEA. In addition, AIC clearly indicates that the Q-D-C-F model, which had the smallest AIC according to Paulraj (2011), is better than other models. Hence, the overall fit of the Q-D-C-F model was the best: $\chi 2 = 182.73$, $\chi 2/df = 1.66$; RMSEA = 0.04; AGFI=0.98; NFI= 0.94; CFI=0.97; AIC = 302.73.

<< Insert Table 7 about here >>

Next, we used SEM to examine whether extended models can improve the model fit for the best fit model (Q-D-C-F). Even though we suggest that the Q-D-F-C model did not have adequate model fits we continued examining its extended model in order to check whether the model extension could help the model to achieve acceptable fits. As shown in Table 7, the extended Q-D-C-F model has the overall best fit statistics; the CFI, RMSEA and AIC for the extended Q-D-C-F model is better than all other models: $\chi2$ = 160.04, $\chi2/df$ = 1.50; RMSEA = 0.03; AGFI=0.99; NFI= 0.97; CFI=0.99; AIC = 286.04. Comparing the Q-D-C-F with the extended Q-D-C-F model, with an increase of degree of freedom, the χ^2 value decreased by 22.69, which was significant at p = 0.05 level ($\Delta\chi^2 > 3.841$). This implies that the extended Q-D-C-F model has significantly better fit, compared to the non-extended Q-D-C-F model. Finally, we selected the extended Q-D-C-F as the best representation of the "true model".

4.2 Analysis of the cumulative relationships

Path analyses are used to examine the relationships among manufacturing capabilities. Overall, there are only positive paths meaning there is no trade-off, only cumulative capabilities. Figure 1 presents the extended and non-extended Q-D-F-C and Q-D-C-F models and their path estimates. The extended and non-extended Q-D-F-C models, though with less fits, are included for comparison purposes. The figure shows that all paths in the two non-extended models are positive and significant at $p < 0.01$ and these paths are still significant at $p < 0.01$ when the models are being extended. When the Q-D-C-F model is extended, we find new paths with significant $p < 0.01$ and $p < 0.05$ levels meaning that cumulative relationships do not only occur in a sequential manner owing to indirect effects (Q-D-C-F) but also in a divergent manner due to direct effects (paths Q-C, D-F, Q-F). These results show that cumulative capabilities do not have to be purely sequential. The divergent paths (paths Q-C, Q-F and D-F) together with the sequential path (Q-D-C-F) are better representatives of cumulative capabilities, at least in the case of Thai manufacturers.

<< Insert Figure 1 about here >>

The above results lead us to further clarify the direct and indirect effects for the Q-D-C-F model. According to Table 8, there are direct and indirect effects shown by standardized effect (β) between quality and cost (β = 0.10 indirect; 0.19 direct), quality and flexibility (β = 0.14 indirect; 0.17 direct), and delivery and flexibility (β = 0.05 indirect; 0.11 direct) indicating that quality has the strongest direct effect on all three other capabilities as well as indirect effect on cost and flexibility.

<< Insert Table 8 about here >>

Comparing the non-extended and extended Q-D-C-F models in Figure 1, the D-C path coefficient decreased from 0.27 to 0.17 and the C-F path coefficient decreased from 0.41 to 0.29 after being adjusted for the direct and indirect effects. These adjustments show that the serial sequential path (Q-D-C-F) is still the dominant cumulative behaviour; nevertheless, there are equally important indirect paths that improve the model fits. When the direct and indirect effects are added together, the total effect sizes in all cases are moderate to strong in magnitude. In other words, it can be said that even though the indirect effects are substantial (representing the sequential Q-D-C-F effects) the direct effects (especially the Q-C and D-F paths) appear to be equally important in building up the cumulative capabilities model.

5. Discussion and practical implications

The main contribution of this paper is that it demonstrates how to examine the two most possible models using a more robust multi-method approach instead of theorizing and testing only one model. Although cumulative capability behaviour has been widely accepted, the different models (sequences) of cumulative capability have never been comprehensively compared in a single study. While the work of Schroeder et al., (2011) set the precedence of using multi-methods, this paper set a new guideline in comparing two competing models using the multi-method approach. Whether it is the learning required to move on to the next sequence (Q-D-F-C) that determines cumulative progression (Rosenzweig and Roth, 2004), the sand-cone (Q-D-F-C) model (Ferdows and de Meyer, 1990) or "the most comfortable (Q-D-C-F) sequence" (Schmenner and Swink, 1998), the main drawback is that previous empirical studies only tested one of the many possible models. In order to search for the true model that fits the most data, this study demonstrates that not only is there a need for a comprehensive model comparison, it also requires multiple methods. This paper introduces a more robust multi-method approach to compare models of cumulative capability, supplementing the repeated cross-sectional approach used by Narasimhan and Schoenherr (2013).

Multiple methods help to robustly test different models of cumulative capability. The results show that correlations are good initial indicators of the positive relationships among capabilities, which rule out trade-off behaviours (Ferdows and De Meyer, 1990). However, correlations cannot statistically prove any sequence of capability progression and behaviour of cumulative capability. Correlations cannot be used for model comparison. Thus, other methods are required to supplement correlations. Sequential test (Schroeder et al., 2011; Narasimhan and Schoenherr, 2013), together with a particular cumulative capability theory (i.e., Competitive Progression Theory), can be used to rule out some less theoretically acceptable models of cumulative capability (Narasimhan and Schoenherr, 2013).

An interesting observation is that the sequential tests suggest that only half the plants under study possibly follow a particular model of cumulative capability. The sequential tests indicate that only 52% of Thai manufacturers possibly follow the famous sand-cone or Q-D-F-C model. This is very close to the findings of Narasimhan and Schoenherr (2013) at 49% and Schroeder et al. (2011) at 47%. Our sequential tests indicate that only 51% of Thai manufacturers possibly follow the Q-D-C-F model. One major contribution of this paper is that it demonstrates that sequential test is not a statistic capable of differentiating the 52% plants (Q-D-F-C) from the 51% plants (Q-D-C-F) and, therefore, its results are inclusive. Though it is useful for indicating progression sequences, sequential test cannot tell whether cumulative capabilities exist because it does not prove statistical relationships among capabilities. However, the sequential test helps to narrow the number of likely models down to two.

This paper shows that the third method, structural equation model (SEM), is a crucial step for verifying cumulative progression sequences and cumulative capabilities. The analyses show that if we use Competitive Progression Theory (Rosenzweig and Roth, 2004) to perform sequential test without model comparison we would have selected a less-fit model (Q-D-F-C). However, using SEM alone for model comparison can lead to confusion, but when its results are supported by correlation and sequential test they become more robust. The analyses show that Q-D-F-C and Q-D-C-F have acceptable fit with slightly different fit indexes. In order to search for the best-fit model, we introduce the use of the lowest Akaike Information

Criterion (AIC) as it has the least information loss. Finally, we show that Q-D-C-F is the best fit model for Thai manufacturers.

This is the second study to find Q-D-C-F as the cumulative capability model for developing countries (see Sum et al., 2012) against the famous sand-cone model (Q-D-F-C) applied by largely developed countries. Thus, results from this study have some theoretical implications with regards to national contingency. This raises the question of whether it is easier to master flexibility than cost capability argued by Competitive Progression Theory (Rosenzweig and Roth, 2004) for manufacturers in developing countries. This study suggests future research to examine if cost capability is not more difficult to master than flexibility capability in developing countries, according to the following arguments. Firms in Thailand have the potential to more efficiently achieve cost advantage, which is an important factor for global firms when deciding on their manufacturing locations. There are many ways to achieve cost capability for firms in Thailand such as mass production (economies of scale), cost reductions in terms of low inventory and short production time, capacity utilization of resources, and short term focus. By achieving cost advantage, firms can further improve their level of flexibility based on the shortest flow time and low level of work-in-process (WIP). As a result, firms can react to the change and uncertainty quickly. Firms in Thailand also have more potential than simply lower cost. A combination of cost advantage and the potential for building capability in flexibility make it more attractive for multinational firms to set up businesses in developing countries such as Thailand. Perhaps differences exist among developed and developing worlds. This study shows that more progress in cost capability over flexibility capability was made by Thai manufacturers, probably owing to a cost competitive environment, especially facing manufacturers in developing worlds or emerging countries (Amoako-Gyampah and Meredith, 2007).

The analyses of the extended cumulative model (Q-D-C-F) reveal that cumulative reinforcement patterns among capabilities are more complex than existing theories (e.g., sand-cone, Cumulative Progression Theory) can explain. We argue that this insight has a major contribution to cumulative capability theory. The analyses show that quality has strong direct links with all other capabilities, in addition to indirect links to cost and flexibility. Similarly, delivery has strong direct links to flexibility via cost meaning that manufacturers do not need to wait until they make progress from one capability. Cumulative capability does not necessarily have to be linear or purely serial in sequence. Cumulative capability is more a divergent phenomenon meaning that investing heavily in developing quality and delivery capabilities up front can lead to speedier progress in developing more comprehensive cumulative capabilities. That means capabilities are not simply cumulative in a sequential manner; they can progress simultaneously. These results suggest future research to examine the argument that it is the relative levels of capability proficiency rather than the pursuit of a particular sequence that truly matter (Narasimhan and Schoenherr, 2013) because it is possible that the relative levels of capability enable the formation of "simultaneous" cumulative capability.

6. Conclusion

This paper demystifies the debates whether Q-D-F-C, Q-D-C-F or other cumulative capability models are more prevalent. The paper tests various models of cumulative capabilities using multiple methods, and concludes Q-D-C-F as the best-fit model, indicating that the widely accepted sand-cone model (Q-D-F-C) and Competitive Progression Theory (CPT) are not necessarily the best theories for explaining cumulative capability patterns of manufacturers from an emerging country. The paper also demonstrates how multiple methods (i.e., correlation, sequential test, structural equation model) can be applied to robustly search for the best-fit model and refute the other models of cumulative capability. This approach provides a new guideline for future cumulative capability research. Furthermore, the paper shows that there are direct and indirect links between capabilities and it is possible to accelerate cumulative progression when manufacturers understand how capabilities such as quality and delivery can simultaneously improve the next sequential capability as well as other capabilities. This new finding, called "simultaneous" cumulative capability, paves new ground for future research.

Like any research this research has some limitations. This is a cross-sectional study of cumulative capabilities so the temporal dimension of cumulative capabilities has not been tested (Narasimhan and Schoenherr, 2013). Also, the generalizability of this research is limited because it examines manufacturing industries in an emerging country; hence, there is a need for further empirical evidence to confirm if the findings also apply to similar industries elsewhere. Even though models Q-C-D-F and Q-C-F-D did not stand out as the best sequences in the sequential test and they are not supported by Cumulative Progression Theory (Narasimhan and Schoenherr, 2013), it would be interesting to include Q-C-D-F and Q-C-F-D for the model comparison. In addition, business performance has not been included in the structural models. Kim and Arnold (1993) found that manufacturing capabilities (operationalized as competence index) appear to have more significant statistical relationships with some performance measures but not equally to all financial and market performance. They also found that manufacturing capabilities of different industries do not have the same influence on business performance. Thus, further research to relate manufacturing capabilities with business performance for different industries is desirable. Furthermore, this research has several unexpected findings which provoke more studies of the various possible contextual (contingent) factors, which may influence the sequence of cumulative capabilities. Competitive priorities and environmental uncertainty appear to be contextual factors; nevertheless, further examination is required. Swink and Way (1995) and Cai and Yang (2014) suggest the identification of the environmental contingencies which favour cumulative capabilities as one of the important challenges for future research in operations strategy.

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Appendix (Survey instrument)

The following questions are aimed to assess the manufacturing capabilities of your plant. Please circle the appropriate number that accurately reflects the extent to which your present plant's performance. (1=strongly disagree; 5=strongly agree; N/A= not applicable)

Quality

We offer high performance products that meet customer needs
1 2 3 4 5 N/A
We are able to produce consistent quality products with low defects
1 2 3 4 5 N/A
We offer high reliable products that meet customer needs
1 2 3 4 5 N/A
We offer high quality products that meet our customer needs
1 2 3 4 5 N/A

Delivery

We deliver the correct quantity with the right kind of products that meets customer needs
1 2 3 4 5 N/A
We can deliver products quickly or short lead-time
1 2 3 4 5 N/A
We provide on-time delivery to our customers
1 2 3 4 5 N/A
We provide reliable delivery to our customers
1 2 3 4 5 N/A
We are able to reduce the time between customer order taking and delivery
1 2 3 4 5 N/A

Cost

We are able to produce products with low costs
1 2 3 4 5 N/A
We are able to produce products with low inventory and work-in-process costs
1 2 3 4 5 N/A
We are able to produce products with low overhead costs
1 2 3 4 5 N/A
With the same quality level, we are able to offer price as low or lower than our competitors
1 2 3 4 5 N/A

Flexibility

We are able to rapidly change production volume

1 2 3 4 5 N/A

We are able to produce customized product features to meet individual customer needs

1 2 3 4 5 N/A

We are able to produce broad product specifications within same facility

1 2 3 4 5 N/A

Our production process has the capability to make rapid product mix changes

1 2 3 4 5 N/A

Table 1. Definitions for manufacturing capability

Capability	Definitions	Source
Quality	The extent to which an organization is capable of designing and offering products that would create higher value to customers.	Flynn and Flynn (2004); Amoako-Gyampah and Meredith (2007); Koufteros et al., (2002); Tracey et al. (1999); Gröβler and Grübner (2006); Avella et al. (2011); Schroeder et al. (2011); Sum et al. (2012).
Cost	The extent to which an organization is capable of offering low cost products by reducing production costs, reducing inventory, increasing equipment utilization, and increasing capacity utilization.	Li (2000); Thun et al., (2000); Vickery et al. (1997); Jayaram et al. (1999); Wacker (1996); Ward and Duray (2000); Gröβler and Grübner (2006); Avella et al. (2011); Schroeder et al. (2011).
Flexibility	The extent to which an organization is capable of managing production resource and uncertainty to accommodate various customer requests.	Narasimhan and Das (1999); Zhang et al. (2003); Koste et al. (2004) Gröβler and Grübner (2006); Avella et al. (2011); Schroeder et al. (2011); Sum et al. (2012).
Delivery	The extent to which an organization is capable of offering the type and quantity of products required by customer(s) with short lead times.	Li (2000); Noble (1995); Fawcett et al. (1997); Swink and Hegarty (1998); Ward and Duray (2000) Gröβler and Grübner (2006); Avella et al. (2011); Schroeder et al. (2011); Sum et al. (2012)

Table 2. Respondent profiles

Demographic Characteristics	n= 368
Ownership	
100% Thai owned	178 (48%)
Foreign owned	89 (24%)
Thai-foreign joint ventures	101 (28%)
Industry	
Automotive	151 (41%)
Electronics	102 (28%)
Food	115 (31%)
Number of employees	
>700	42 (11%)
351-700	52 (14%)
201-350	102 (28%)
101-200	93 (25%)
51-100	61 (17%)
<50	18 (5%)
Position	
President/Vice President/Managing Director	19 (6%)
General Manager	74 (20%)
Purchase/Logistics/Distribution Manager	84 (22%)
Supply Chain Management Manager	80 (22%)
Production Manager	95 (26%)
Others (e.g., Plant Manager, Engineer)	16 (10%)

Table 3. Measurement model and confirmatory factor analysis results

Factor and Scale items	CFA fit statistics: $\chi2$ = 187.95; χ^2/d.f. = 1.72; RMSEA = 0.04: CFI = 0.98: TLI = 0.97: NFI = 0.94		
	β	ε	t-value
Quality (ρ = 0.88; AVE =0.72)			
High performance products that meet customer needs	0.61	_a	_a
Produce consistent quality products with low defects	0.73	0.10	10.69
Offer high reliable products that meet customer needs	0.93	0.10	12.16
High quality products that meet our customer needs	0.87	0.10	11.88
Delivery (ρ = 0.90; AVE =0.69)			
Correct quantity with the right kind of products	0.84	_a	_a
Delivery products quickly or short lead-time	0.88	0.05	20.58
Provide on-time delivery to our customers	0.88	0.05	20.65
Provide reliable delivery to our customers	0.87	0.09	20.30
Reduce customer order taking time	0.67	0.08	12.45
Cost (ρ =0.83; AVE =0.62)			
Produce products with low costs	0.81	_a	_a
Produce products with low inventory costs	0.81	0.07	16.10
Produce products with low overhead costs	0.85	0.06	16.75
Offer price as low or lower than our competitors	0.70	0.08	11.52
Flexibility (ρ = 0.75; AVE =0.51)			
Able to rapidly change production volume	0.74	_a	_a
Produce customized product features	0.64	0.09	8.26
Produce broad product specifications within same facility	0.76	0.12	9.90
The capability to make rapid product mix changes	0.72	0.11	9.91

Notes: Loadings are common metric completely standardized estimate: all t-value *significant at $p \leq 0.01$; β = standardized coefficient; ε = standard error; ρ = scale* composite reliability; _a = fixed loading

Table 4. Descriptive statistics and correlations table

Capability	Mean	SD	Quality	Delivery	Flexibility	Cost
Quality	4.11	0.64	1			
Delivery	4.09	0.72	0.54	1		
Flexibility	3.69	0.77	0.35	0.29	1	
Cost	3.23	0.79	0.29	0.30	0.46	1

Note: All relationships are significant at $p < 0.01$ level; SD=standard deviation

Table 5. Number of plants exhibiting each sequence

Configuration number	Sequence exhibited				Number of plants	%	Sequence progressing (Q-D-F-C, Q-D-C-F, or other sequences)
	Q	D	F	C			
1	H	H	H	H	49	14	Any sequence
2	H	L	H	H	6	2	Not Q-D-F-C; Not Q-D-C-F; possible Q-C-F-D
3	H	H	L	H	18	5	Not Q-D-F-C; possible Q-D-C-F
4	H	L	H	L	13	4	Not Q-D-F-C; Not Q-D-C-F; possible Q-F
5	H	H	H	L	20	6	Not Q-D-C-F; possible Q-D-F-C
6	H	L	L	H	8	2	Not Q-D-F-C; Not Q-D-C-F; possible Q-C
7	H	L	L	L	11	3	Possible Q-(any sequence)
8	H	H	L	L	23	7	Possible Q-D-F-C; possible Q-D-C-F
9	L	H	H	H	11	3	Not Q-(any sequence)
10	L	L	H	H	16	5	Not Q-(any sequence)
11	L	H	L	H	5	1	Not Q-(any sequence)
12	L	L	H	L	24	7	Not Q-(any sequence)
13	L	H	H	L	12	3	Not Q-(any sequence)
14	L	L	L	H	26	7	Not Q-(any sequence)
15	L	H	L	L	27	8	Not Q-(any sequence)
16	L	L	L	L	79	23	Possible Q-(any sequence)

Note: H represents high; L represents low on a median split for each capability dimension; Q = quality; D = delivery; F = flexibility; C = cost.

Table 6. Possible sequences with highest number of plants

Possible Sequence	Number of plants	Percent
Q-D-F-C	182	52
Q-D-C-F	180	51
Q-C-F-D	153	44
Q-C-D-F	154	44

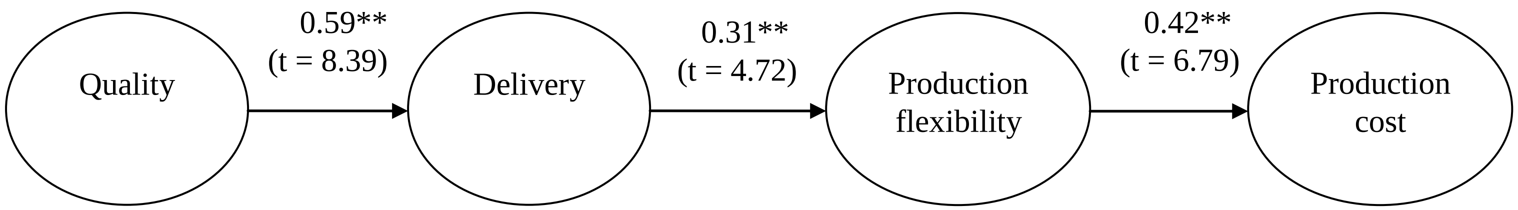
Table 7. Goodness of fit indices for competing structural models

Goodness of fit measure	Criteria	Non-extended models		Extended models	
		Q-D-F-C	Q-D-C-F	Q-D-C-F extended	Q-D-F-C extended
Chi-square of estimated model	-	232.10	182.73	160.04	160.97
Degree of freedom (df)	-	114	110	107	107
Chi-square/degree of freedom	≤ 3.0	2.04	1.66	1.46	1.50
Adjusted Goodness of Fit Index (AGFI)	≥ 0.9	0.87	0.98	0.99	0.98
Root Mean Square Error of Approximation (RMSEA)	≤ 0.08	0.07	0.04	0.03	0.04
Comparative Fit Index (CFI)	≥ 0.9	0.93	0.97	0.99	0.98
Normed Fit Index (NFI)	≥ 0.9	0.91	0.94	0.97	0.95
Akaike Information Criterion (AIC)	-	344.06	302.73	286.04	289.873

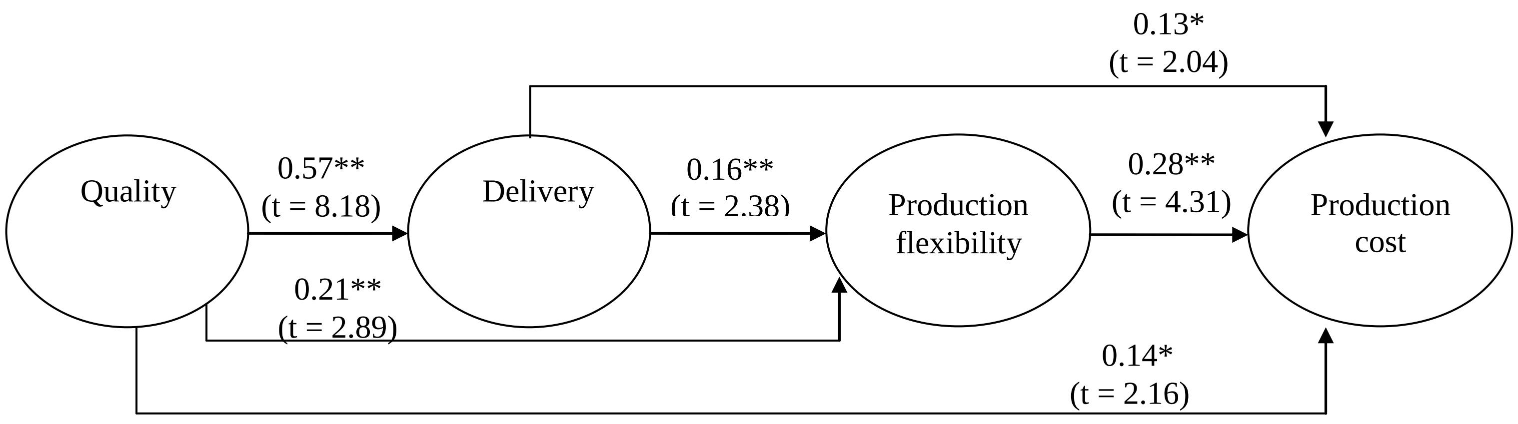
Table 8: Estimate of standardized direct, indirect and total effects

Exogenous construct	Direct effect	Indirect effect	Total effect
	Endogenous construct: Delivery		
Quality	0.57	0.00	0.57
	Endogenous construct: Cost		
Quality	0.19	0.10	0.29
Delivery	0.17	0.00	0.17
	Endogenous construct: Flexibility		
Quality	0.17	0.14	0.31
Delivery	0.11	0.05	0.16
Cost	0.29	0.00	0.29

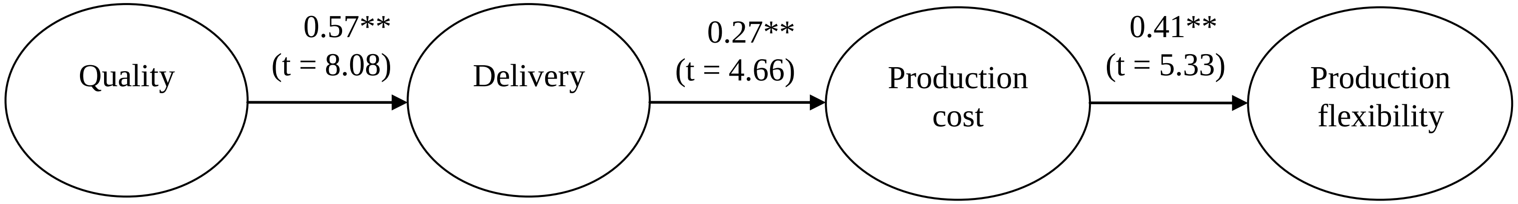
Figure 1: Structural models



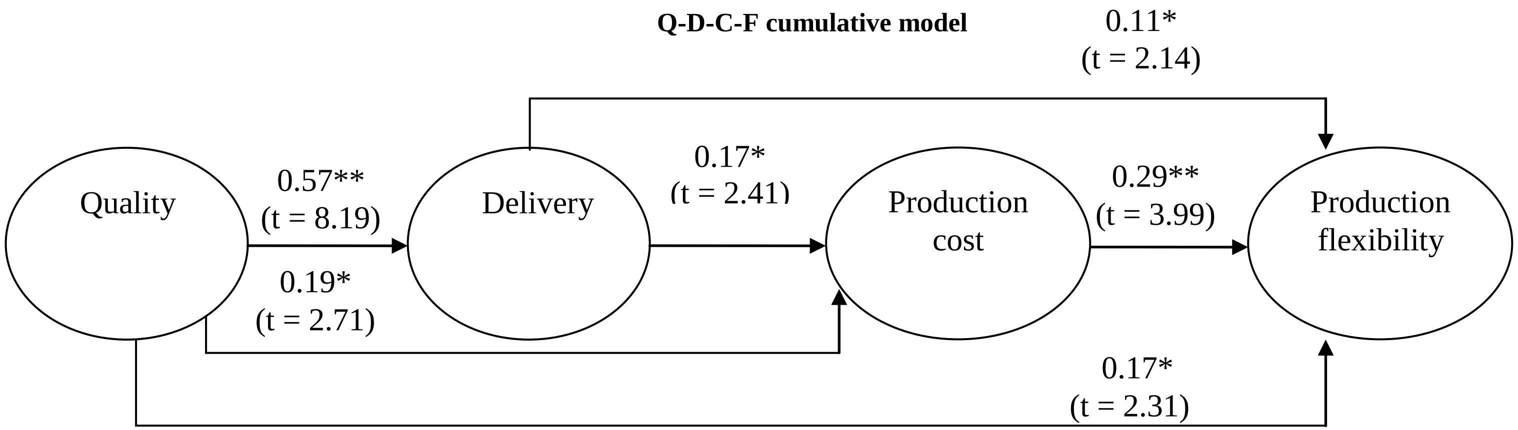
Q-D-F-C cumulative model



Extended Q-D-F-C cumulative model



Q-D-C-F cumulative model



Extended Q-D-C-F cumulative model

Note: * P <0.05; ** p<0.01