Operations Management Research
https://doi.org/10.1007/s12063-024-00498-w

Combining internal functional integration with product modularization and supply chain alignment for achieving mass customization

Zhigang Fan[1] · Fei Dai[2] · Mingu Kang[3] · Kihyun Park[4] · Gukseong Lee[5]

Received: 3 March 2024 / Revised: 18 May 2024 / Accepted: 24 May 2024

Abstract
Mass customization poses one of the primary challenges for manufacturing firms seeking to maintain competitiveness by satisfying diverse and ever-changing demands. The purpose of this study is to present a mechanism illustrating how internal cross-functional integration promotes mass customization by leveraging external supply chain partners and emphasizing the contingent role of product characteristics. Using 223 samples collected from multi-sources of manufacturing firms worldwide, regression and bootstrap analyses are applied to test the proposed moderated mediation research model. Our findings reveal that a firm's capability of cross-functional integration plays an important role in directly promoting its mass customization performance and indirectly doing so through supply chain alignment. Moreover, our findings underscore that this indirect mechanism is more pronounced when products are designed to be highly modular. Based on our findings, manufacturing firms can enhance mass customization more efficiently and effectively by integrating internal cross-functional collaboration and product modularization, thereby fostering alignment within the external supply chain.

Keywords Cross-functional integration · Supply chain alignment · Product modularization · Mass customization

1 Introduction

As a new manufacturing paradigm that integrates the economies of scale of mass production with the benefits of custom manufacturing (Jafari et al. 2022; Selladurai 2004), mass customization can tailor products to specific customer needs, thereby enhancing customer value (Shen et al. 2023) and market competitiveness (Ahmad et al. 2010; Sheng et al. 2021). Mass customization, a production process integrating the value-added effects of product customization with the cost-saving benefits of mass production (Liu et al. 2006), has emerged as a critical capability for manufacturing companies. It enables the production of a diverse range of products without sacrificing quality or inflating costs (Huang et al. 2008; Liu et al. 2021). The intensifying market competition, shorter product lifecycles, and rapidly evolving customer demands underscore the increasing importance and complexity of implementing mass customization (Gholami et al. 2023; Kim and Lee 2022).

Therefore, there is a growing need for research to explore strategies for promoting mass customization more effectively. Numerous recommendations for enhancing mass customization capability have been extensively documented in prior literature. The recommended approaches encompass designing the internal structure and processes of the organization (Ahmad et al. 2010; He and Smith 2024; Jain et al. 2022; Sheng et al. 2022; Ullah and Narain 2021a), adopting product configuration systems (Aldanondo and Vareilles 2008; Campos Sabioni et al. 2022; Helo et al. 2010), coordinating inter-organizational collaboration (Liao

✉ Fei Dai
dfei116@zju.edu.cn

Zhigang Fan
20100091@hznu.edu.cn

Mingu Kang
jiangmq@zju.edu.cn

Kihyun Park
parkk@rmu.edu

Gukseong Lee
jameslee@kookmin.ac.kr

1 Alibaba Business School, Hangzhou Normal University, Hangzhou, China

2 Polytechnic Institute, Zhejiang University, Hangzhou, China

3 School of Management, Zhejiang University, Hangzhou, China

4 Department of Management, Rockwell School of Business, Robert Morris University, Moon Township, PA, USA

5 College of Business Administration, Kookmin University, Seoul, South Korea

et al. 2011; Liu et al. 2018; Ullah and Narain 2021b; Zhang et al. 2014), acquiring knowledge from supply chain (SC) partners (Zhang et al. 2015), and striving to meet individual customer needs in terms of product design (Ahmad et al. 2010; Salvador et al. 2015; Zhang et al. 2014). Of particular importance is the organizational structure that facilitates flexible production to accommodate evolving and diverse customer needs (Huang et al. 2010; Sheng et al. 2022). For example, a flat and decentralized organizational structure can foster coordination both within and outside the organization, thereby enhancing mass customization (Huang et al. 2010; Ullah and Narain 2022). Given that mass product customization is closely related to uncertain market demands and necessitates complex solutions, existing literature emphasizes the importance of internal coordination and organizational capabilities, such as agility, flexibility, lean, and knowledge sourcing, in advancing mass customization capability (Hong et al. 2010; Sheng et al. 2022; Ullah and Narain 2021a; Zhang et al. 2015). Besides, managing the external supply chain is recognized as a pivotal component in both realizing and exploiting mass customization (Liu et al. 2018). On one hand, since customized products are tailored to meet individual customer needs for products (Ahmad et al. 2010), mass customization encourages customer involvement in the early stage of product development and design (Salvador et al. 2015). On the other hand, mass customization necessitates close cooperation with suppliers to swiftly address customer demands (Ahmad et al. 2010). The application of robust coordinating mechanisms and the establishment of effective cooperation between manufacturers and their SC partners are imperative in implementing product customization (Ullah and Narain 2022).

Previous studies have underscored the significance of both intra- and inter-firm collaboration as precursors to mass product customization. However, there remains a limited understanding of how to bridge internal organizational factors with external SC factors to facilitate mass customization. In addressing this research gap, the present study endeavors to build upon previous mass customization literature by investigating how internal CFI fosters external SC alignment, thereby influencing mass customization capability. This aligns with prior research that emphasizes the importance of internal operational practices and capabilities as key drivers for implementing external SC collaboration (Huo 2012; Lai et al. 2012; Shou et al. 2017; Zhao et al. 2011). Particularly from the perspective of transaction cost economics (TCE) theory, internal CFI and external SC alignment act as mechanisms for mitigating transaction costs, thus serving as pivotal drivers for implementing a mass customization strategy. Considering the potential transaction costs arising from the inherent uncertainty and complexity of this strategy, such measures assume heightened importance.

Moreover, firms often encounter challenges in effectively integrating different functional departments to achieve intended performance outcomes, largely due to complex environmental factors (Kang et al. 2022). To address this issue, this study incorporates product modularization into the indirect effect of CFI on mass customization via SC alignment. By doing so, the study seeks to explore a more effective utilization of CFI in enhancing mass customization capability. The impact of product modularization on mass customization has been extensively explored, because of the advantages of product modularization during product design and manufacturing, such as flexibility in product design, production scalability, production mixes, cost efficiency, and faster time-to-market (Ahmad et al. 2010; Gauss et al. 2019; Zhang et al. 2014). Moreover, modularity has been identified as a crucial boundary condition in the relationship between intervention practices and performance (Wei and Sun 2021). The mass customization strategy entails a complex process that necessitates the integration of internal processes, external collaboration, and product design to function harmoniously. However, despite this necessity, there is limited knowledge regarding the combined role of these three factors (i.e., intra- and inter-firm collaboration factors, and product characteristics) in driving mass customization. To address this research gap, this study attempts to examine the relationship between CFI, SC alignment, and mass customization capability, particularly by considering the contingent role of product modularity. This study aims to address the following research questions:

RQ1) How does internal CFI influence manufacturing firms' mass customization capability by promoting external SC alignment?
RQ2) How does the impact of CFI during the implementation of mass customization strategy vary according to the level of product modularization?

By answering these research questions, this study contributes to advancing our understanding of improving mass customization capability efficiently and effectively.

2 Theoretical background and hypotheses development

2.1 Transaction cost economics and mass customization capability

The fundamental premise of transaction cost economics (TCE) posits that organizations strive to adopt the most appropriate governance structure to optimize the profitability of transactions (Williamson 1989). This pursuit is necessitated by bounded rationality and opportunistic behavior, which give rise to transaction costs associated with negotiating, coordinating, and reallocating resources among trading partners (Hobbs 1996; Langlois 1992).

TCE posits that the characteristics of transactions influence how firms engage with one another (Williamson 2008; Wong et al. 2021), leading to the adoption of diverse governance mechanisms to manage transactions (Grover and Malhotra 2003). Consequently, transaction attributes are regarded as the primary determinants of transaction costs (Williamson 2010). Initially, TCE underscored three transaction attributes affecting corporate governance: asset specificity, transaction uncertainty, and transaction frequency. Subsequent research has also recognized transaction complexity as a determinant influencing coordination and transaction costs among organizational transactions (Shelanski and Klein 1995; Wong et al. 2021).

As a manufacturing capability, mass customization capability refers to the ability to fulfill customer requirements by offering a high volume of customized product options (Liu et al. 2021). Moreover, the primary aim of the mass customization capability is to provide customers with cost-effective products characterized by extensive customization, swift responsiveness, and consistent product quality. (Jafari et al. 2022; Liu et al. 2006). Within a mass customization strategy, each transaction necessitates the manufacturer's engagement and collaboration with the customer, including the accurate acquisition and definition of information about the customer's specific product needs (Shi et al. 2022). This depth of interaction entails higher transaction costs (Piller et al. 2004). Achieving mass customization requires addressing the additional costs associated with individualized production to realize economies of scale. Likewise, given that effectively managing transaction costs is a crucial priority for manufacturing firms seeking to implement mass customization (Piller et al. 2004; Shao 2020), this study utilized TCE as an appropriate theoretical foundation to formulate research hypotheses.

In the realm of mass customization transactions, characterized by diverse and heterogeneous customer demands, manufacturers must cope with an uncertain and complex market environment to fulfill specific product requirements (Ullah and Narain 2022). On one hand, market fluctuations engender considerable demand uncertainty for manufacturing companies (Alptekinoğlu and Örsdemir 2022), which can persist throughout the production and supply chain (Cheng et al. 2022). On the other hand, mass customization necessitates the provision of a wide array of products and the utilization of manufacturing processes with a high level of flexibility (Liu et al. 2006). Production tasks no longer adhere to the simplicity and repetitiveness of mass production but have evolved into complex operations (Wang et al. 2014). From a TCE perspective, the heightened transactional uncertainty and complexity inherent in mass customization significantly escalate transaction costs. Therefore, addressing transaction costs becomes paramount in enhancing mass customization capability.

2.2 Cross-functional integration and mass customization

Internal integration refers to the degree of integration across various organizational functions (Ellegaard and Koch 2012; Ferreira et al. 2019; Turkulainen and Ketokivi 2012; van der Vaart and van Donk 2008). This entails interaction, communication, information sharing, coordination, and cooperation among diverse functions or departments. Such integration can yield positive outcomes by fostering harmonious collaboration among these business functions, thereby enhancing problem-solving efficiency and conflict resolution (Bardhan and Pattnaik 2017; Droge et al. 2012; Nakata and Im 2010; Pellathy et al. 2019). Previous research has emphasized the pivotal role of internal integration in bolstering operational efficiency and facilitating new product development processes (Engelen et al. 2012; Jean et al. 2014; Troy et al. 2008; Xu et al. 2024; Zhang and Tang 2017).

The literature indicates that a critical aspect of enhancing mass customization capability involves designing appropriate organizational internal structures and processes. (see Appendix 1). Achieving mass customization necessitates flexible manufacturing (Ullah and Narain 2021a), with tasks in each department tailored to meet diverse business requirements (Zhang et al. 2014). CFI has been shown to improve manufacturing flexibility (Chaudhuri et al. 2018), suggesting its potential to facilitate mass customization capability. Additionally, market-oriented CFI, achieved through the strategic collaboration between sales and other functions, can assist firms in navigating market uncertainty (Tokman et al. 2011) and lowering inventory costs while ensuring timely deliveries. Through CFI, departments involved in product development, manufacturing, and inventory management can be strategically planned and coordinated, enabling rational resource allocation, knowledge sharing, and skill utilization. This facilitates swift responses to customer demands (Jung et al. 2007). Furthermore, the production of diverse products necessitates organizational flexibility that can be facilitated by internal communication and coordination, thus coping well with the complexity of transactions (Jain et al. 2022). From the viewpoint of TCE, CFI amplifies the manufacturer's capacity for market monitoring by fostering information sharing across diverse functional departments within the organization. This facilitates a nuanced understanding of uncertain market dynamics and customer demand, consequently, diminishing coordination costs linked to information asymmetry. Additionally, given the complexity of products and production processes, the sales department may lack awareness of the company's R&D technology and production capacity. Consequently, they might inadvertently over-promise in offering customized services to customers, resulting in default costs. These issues can be addressed through close collaboration and coordination among different functional departments. Thus, we derive the following hypothesis:

H1. Cross-functional integration is positively related to mass customization capability.

2.3 Mediating role of supply chain alignment

Manufacturers cannot effectively meet their customers' product needs with high quality and efficiency without adeptly managing the SC relationships with their suppliers and customers (Min and Mentzer 2004; Sabahi and Parast 2023). Moreover, effective SC management is crucial for manufacturers to attain superior mass customization outcomes (Liu et al. 2018). Specifically, it is proposed that SC alignment may improve mass customization capability. In this study, SC alignment refers to a congruent state of goals, vision, and processes among internal and external SC partners (Van Hoek et al. 2014; Wong et al. 2012). Min and Mentzer (2004) argue that establishing a shared vision and goals is a pivotal aspect of SC management. The absence of a unified and coherent vision and goals can lead SC partners to diverge in their actions and may even foster opportunistic behavior (Jones et al. 2009; Rossetti and Choi 2008). Kohli and Jensen (2010) posit that congruence in vision and goals fosters enhanced cooperation, thereby improving the efficiency of SC operations. Furthermore, an appropriate configuration of the firm's SC supports mass customization (Salvador et al. 2015). Therefore, aligning the vision and goals among SC partners may be critical in fostering mass customization capability. Also, Stavrulaki and Davis (2010) emphasized that aligning a firm's manufacturing processes with its SC can lead to a well-coordinated SC, which in turn enhances operational efficiency and flexibility. This alignment enables the firm to effectively address the diverse and complex demands of customers. Consequently, high-quality SC partnerships such as well-designed and implemented SC alignment, are imperative to ensure the availability of supply and demand information, raw materials, and resources needed to fulfill the requirements of mass customization (Jafari et al. 2022).

Drawing from TCE, the congruence of vision, goals, and processes among SC partners is inherently oriented toward long-term relationships (Macneil 1977). Such relationships effectively deter opportunistic behavior among partners (Huo et al. 2016), thereby reducing coordination costs (Mustafa Kamal and Irani 2014). In addition, within SC alignment, firms can significantly diminish communication costs with partners and efficiently drive operational processes, leading to expedited response times to market demands. For example, a unified vision, goals, and processes among SC partners enable accurate identification of mass customization requirements, thereby facilitating more efficient component sourcing and driving product and process development (Larson and DeChurch 2020). Furthermore, aligning vision and goals across SC fosters trust among partners, promoting knowledge and resource sharing between suppliers and customers (Panayides and Lun 2009; Rossetti and Choi 2008), which enhances mass customization capability (Zhang et al. 2015). Consequently, SC alignment may be positively associated with a manufacturing firm's mass customization capability.

In addition, research has demonstrated that intra-firm communication and coordination foster collaboration between firms and SC partners (Freije et al. 2022; Huo 2012; Lai et al. 2012; Shou et al. 2017; Zhao et al. 2011). Thus, we posit that CFI may have a positive impact on SC alignment. Previous studies have highlighted the importance of companies having clear goals within partnerships (Goffin et al. 2006), and CFI facilitates mutual understanding among different functions and teams, resolves conflicts, and fosters the development of a shared vision and alignment of goals across departments (Genç and Di Benedetto 2015). Moreover, existing literature suggests that intra-firm communication and collaboration can facilitate cooperation and joint problem-solving with external partners (Kang et al. 2021b; Lai et al. 2012; Li et al. 2022c). Strengthening horizontal communication links between firms through direct messaging among functions further enhances communication between partners (Kakati 2002). This implies that efficient internal collaboration can enhance a firm's communication and coordination with its external SC partners. Through internal CFI, firms can systematically plan their activities, thereby establishing synchronized processes with their SC partners and resolving potential conflicts (Zhao et al. 2011). Collaborative communication can facilitate consensus-building between partners on vision, goals, and processes by mitigating conflicts (Cao et al. 2010). Therefore, we posit that CFI may be positively associated with SC alignment.

In summary, the higher the level of integration between cross-functional departments, the greater the likelihood of achieving alignment with external SC partners, ultimately resulting in improved mass customization. Thus, we propose the mediating role of SC alignment in linking CFI to mass customization, and posit the following hypothesis:

H2. SC alignment serves as a mediator in the relationship between cross-functional integration and mass customization capability.

2.4 Moderating role of product modularization

Product modularization is a design strategy employed to generate product variety at a reduced cost compared to designing unique products for various market and customer segments (Wang et al. 2024). This approach involves designing products into independent modules that can be reused and interchanged to maximize product diversity (Zhang et al. 2014). Product modularization entails the deconstruction and integration of the product value chain, simplifying complex systems (Ahmad et al. 2010). Moreover, product modularization establishes a common language for information exchange within and outside a manufacturer's boundary, enabling flexible responses to customer demands (Hsuan Mikkola and Skjøtt-Larsen 2004). Research has demonstrated that product modularization reduces the complexity of SC collaboration (Wang et al. 2024) thereby facilitating communication and coordination along the supply chain (Jacobs et al. 2007). The literature has also indicated a complementary effect of product modularization and CFI on enhancing operational capability development. For example, The interaction between product modularization and internal integration leads to shorter new product development times (Danese and Filippini 2010). Therefore, product modularization and CFI are closely intertwined and jointly influence enterprise performance outcomes (Ahmad et al. 2010; Davies and Joglekar 2013).

When the level of modularity is low, manufacturing processes tend to be complex and lack a clear structure. Despite there being adequate communication and coordination between functions to collaborate with SC partners using operational information gathered from each sub-process, this information is often extensive and complex to analyze and interpret, thereby hindering collaboration outcomes with partners (Shamsuzzoha and Helo 2017). Thus, under the condition of a low level of product modularization, the positive impact of CFI on SC alignment may be weakened due to less efficient inter-organizational communication and coordination with partners. In contrast, when the level of modularity is high, standardized product modules enable companies to define the parameters and structure of product information more clearly (Jacobs et al. 2011), allowing for more streamlined communication between organizations and further facilitating accurate communication (Wang and Zhang 2020). Hence, a high level of product modularization may strengthen the impact of CFI on SC alignment by fostering more efficient and accurate communication. From a TCE perspective, product modularization simplifies internal manufacturing operations and external outsourcing by streamlining product structures and business processes (Salvador et al. 2004). Reduced complexity translates to fewer transaction costs and a diminished need for information processing, enabling manufacturers to communicate more effectively with multiple partners through internal coordination to achieve a common vision and goal (Rossetti et al. 2023; Wong et al. 2021). Consequently, the delivery of more truthful and accurate information through CFI facilitates SC alignment more readily. Therefore, we suggest that product modularization strengthens the impact of CFI on SC alignment, subsequently improving mass customization capability. We propose the following hypotheses:

H3: Product modularization will moderate the positive relationship between CFI and SC alignment, such that the effect of CFI on SC alignment will be stronger when product modularization is high.

H4: Product modularization will positively moderate the indirect effect of CFI on mass customization capability, such that the indirect effect of CFI on mass customization capability through SC alignment will be stronger when product modularization is high.

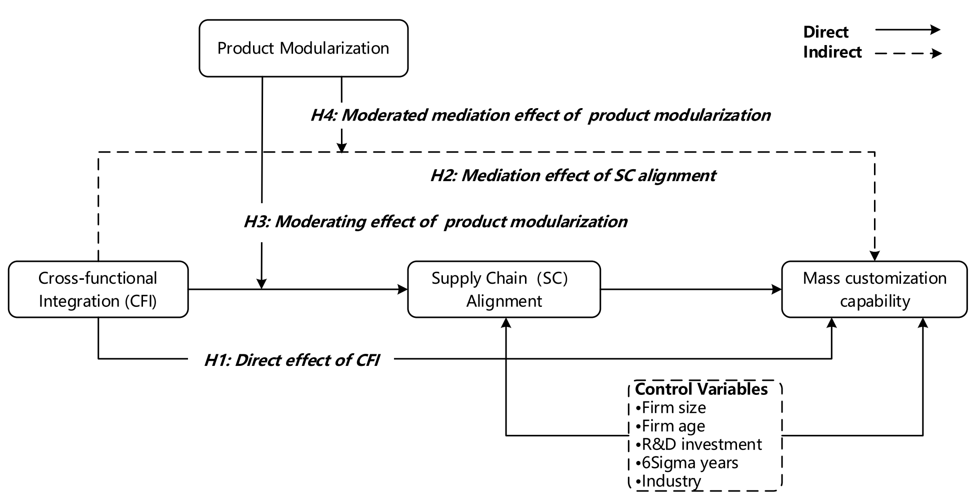
Figure 1 shows the conceptual research model that addresses research hypotheses.

3 Research methodology

3.1 Data collection

We used the database of the fourth round of the High-Performance Manufacturing (HPM) survey project as the empirical

Fig. 1 Conceptual research model



dataset for this paper. This survey dataset has been widely employed in previous research on operations and supply chain management (Beraldin et al. 2022; Li et al. 2022a; Shou et al. 2021; Veiga et al. 2021). The survey encompassed 15 countries and regions, with respondents representing three manufacturing sectors - machinery, electronics, and transport. In addition, only companies with more than 100 employees were included in the survey, as smaller companies may lack the sophisticated operational practices required for mass customization. A total of 330 manufacturing firms participated in the survey. After excluding samples with more than 10% missing values, we obtained 223 valid samples for hypotheses testing, as detailed in Table 1.

3.2 Measures

The survey instruments utilized in this study were adapted from previous empirical research. To measure CFI, four items were selected from two previous studies by Yang and Tsai (2019) and Thun (2008). The four measurement items on mass customization capability were derived from an empirical investigation of mass customization conducted by Wang et al. (2016). In addition, SC alignment was measured using items developed by Min and Mentzer (2004). Product modularization was measured using three items from the research of Zhang et al. (2014). All items for the aforementioned variables were rated on a five-point scale ranging from 1 = not at all to 5 = to a very great extent (see Appendix 2). In addition, we incorporated several control variables that may influence company practices or performance, including firm size (represented by the natural logarithm of the number of employees), firm age (years since firm incorporation), R&D investment (percentage of sales spent on R&D), and Six Sigma (years of Six Sigma implementation). Moreover, we included control variables for industry variation, specifically the machinery industry and the electronics industry.

Table 1 Sample demographic

	No.	%		No.	%
Country and region					
Brazil	6	2.69	100–249	64	28.70
China	25	11.21	250–499	55	24.66
Spain	12	5.38	>=500	104	46.64
Finland	16	7.17			
Germany	17	7.62	Firm age(years)		
Israel	3	1.35	< 19	45	20.18
Italy	28	12.56	20–34	47	21.07
Japan	16	7.17	35–49	67	30.04
Korea	25	11.21	>=50	64	28.71
Sweden	5	2.24			
Swiss	7	3.14	Industry		
Taiwan	28	12.56	Machinery	82	36.77
U.K.	12	5.38	Electronics	84	37.67
USA	9	4.04	Transportation	57	25.56
Vietnam	14	6.28			
Total	223	100			

Number = 223

3.3 Common method variance

The data were collected from cross-sectional surveys, which can raise concerns about common method bias. To address this issue, we implemented several strategies. First, we collected data from multi-informants to mitigate the potential of common method variance (CMV) (Podsakoff et al. 2003). For instance, plant management managers responded to the survey questionnaire for CFI, R&D managers for product modularization, SC managers for SC alignment, and process engineering managers for mass customization capability. By obtaining data from different informants for independent and dependent variables, we aimed to alleviate concerns regarding CMV. Second, we conducted Harman's one-way test as a post-hoc statistical test to check potential general method deviations. CMV may arise if a single factor explains more than 50% of the total variance. We employed principal component factor analysis to test all items of the focal constructs. The results showed that the first factors accounted for 29.17% of the total factors, far less than 50%, indicating the absence of obvious CMV in our study.

3.4 Reliability and validity

To measure convergent validity, we utilized exploratory factor analysis (EFA) and confirmative factor analysis (CFA). First, we applied Bartlett's test and a Kaiser-Meyer-Olkin (KMO) test to check the appropriateness of data. The results indicated that the KMO value was 0.792, which is well above the threshold value of 0.6, based on Kaiser (1974) 's guidance. Moreover, Bartlett's test revealed a p-value of 0.000, which is satisfactory (Howard and Henderson 2023). Principal component analysis (PCA) was used to extract factors in the study, and the Varimax rotation method with Kaiser normalization was applied. Table 2 presents the final four-factor model's rotated component matrix. The EFA results indicated that all variables had high loadings above 0.6, and there were no cross-loading, supporting further CFA analysis (Raut et al. 2021).

The results of CFA revealed that the model fit is acceptable (chi-square/df = 1.116, $p < 0.05$, RMSEA = 0.027, NFI = 0.929, RFI = 0.911, CFI = 0.989, TLI = 0.986, IFI = 0.989). Cronbach's alpha and composite reliability (CR) were utilized to

Table 2 Rotated component matrix

	Component			
	1	2	3	4
CFI1	0.155	**0.789**	0.040	0.112
CFI2	0.053	**0.833**	0.106	0.079
CFI3	0.107	**0.840**	-0.010	0.076
CFI4	0.137	**0.703**	0.235	0.045
MC1	0.129	0.152	**0.631**	0.167
MC2	0.083	0.089	**0.781**	-0.031
MC3	0.006	0.073	**0.754**	0.070
MC4	0.081	0.010	**0.763**	-0.036
SCA1	**0.882**	0.068	0.076	0.097
SCA2	**0.790**	0.076	0.012	0.142
SCA3	**0.834**	0.106	0.074	0.054
SCA4	**0.750**	0.234	0.191	0.048
PM1	0.074	0.070	0.171	**0.847**
PM2	0.131	0.179	-0.093	**0.706**
PM3	0.087	0.024	0.078	**0.880**

Extraction Method: Principal Component Analysis

Rotation Method: Varimax with Kaiser Normalization

Rotation converged in 5 iterations

evaluate the reliability of the constructs, all of which surpassed the 0.7 threshold (see Table 3). This indicates satisfactory reliability for each construct. Moreover, factor loadings and average variance extracted (AVE) were used to test convergent validity. The AVE for all constructs, except for the mass customization capability, exceeds 0.5. Although the AVE for the mass customization capability is 0.492, which is slightly below 0.5, it is still deemed acceptable (Zhang and Zheng 2021). We observed that the factor loadings of all constructs exceed 0.5, thus ensuring convergent validity. Table 4 shows that the square root of the AVE for each construct surpassed its correlation with the other constructs, thus confirming discriminant validity.

4 Results

4.1 Hypotheses testing

Hierarchical regression analysis was used in this study to test our theoretical hypotheses, and the regression results are presented in Table 5. H1 proposed that CFI has a significant positive effect on mass customization capability. Model 2 tested the impact of CFI on mass customization capability, revealing a significantly positive coefficient (b = 0.244, $p < 0.01$). Therefore, H1 was supported.

H2 proposed that SC alignment mediates the relationship between CFI and mass customization capability. Upon controlling for SC alignment in model 3, CFI continued to exhibit a significant positive effect on mass customization capability (b = 0.190, $P < 0.05$); however, the coefficient of the direct effect was slightly smaller compared to model 2 (b = 0.244). Furthermore, the results from model 5 indicated a significant positive effect on SC alignment (b = 0.181, $p < 0.05$). These results suggest that SC alignment mediates the relationship between CFI and mass customization capability. In addition, a bootstrap analysis was used to test the mediation effect of SC alignment, following the methodology outlined by Preacher and Hayes (2008). The results showed a positive indirect effect of CFI on mass customization capability through SC alignment (indirect effect = 0.191), within a 95% confidence interval (CI) ranging from 0.047 to 0.334. This interval did not include zero, providing further support for H2.

Table 3 Construct validation

Variable	Items	Loadings	Cronbach's α	CR	AVE
Cross-functional integration	CFI1	0.737	0.807	0.823	0.539
	CFI2	0.766			
	CFI3	0.817			
	CFI4	0.601			
Mass customization capability	MC1	0.703	0.794	0.796	0.492
	MC2	0.732			
	MC3	0.697			
	MC4	0.679			
Supply chain alignment	SCA1	0.866	0.859	0.864	0.614
	SCA2	0.737			
	SCA3	0.795			
	SCA4	0.729			
Product modularization	PM1	0.815	0.813	0.821	0.608
	PM2	0.643			
	PM3	0.863			

Table 4 Assessment of discriminant validity

	Mean	SD	CFI	Mass customization capability	SC alignment	Product modularization
CFI	3.718	0.666	**0.734**			
Mass customization capability	3.739	0.673	0.280**	**0.701**		
SC alignment	3.841	0.654	0.345**	0.236**	**0.784**	
Product modularization	3.781	0.772	0.161*	0.109**	0.211**	**0.775**

"Bold" values represent the square root of the AVE values for each variable

*p<0.05; **p<0.01

H3 proposed that product modularization moderates the effect of CFI on SC alignment. In model 6, the interaction term of CFI and product modularization was tested on SC alignment, revealing a significantly positive interaction (b = 0.298, $p < 0.01$). This result demonstrates a positive moderating effect of product modularization on the relationship between CFI and mass customization capability, thereby supporting H3. Furthermore, to gain a deeper understanding of the moderating effect of product modularization, the effect of high and low levels of product modularization (one standard deviation above and below the mean) on SC alignment was plotted (see Fig. 2). The plot illustrates that CFI is positively and significantly correlated with SC alignment when product modularization is high, while this relationship becomes negligible and flat when the level of product modularization is low. Thus, these findings provide further support for H3.

H4 proposed that product modularization moderates the indirect effect of CFI on mass customization capability via SC alignment. Results obtained from the PROCESS macro analysis (refer to Table 6) revealed that the conditional indirect effect of CFI on mass customization capability via SC alignment varied significantly across different levels of product modularization. Specifically, at the mean level, the conditional indirect effect of CFI was significantly positive (indirect effect = 0.049, 90% CI [0.096, 0.110]). Moreover, this indirect effect strengthened at one standard deviation above the mean (indirect effect = 0.091, 90% CI [0.019, 0.190]). However, it became statistically insignificant (indirect effect = 0.008, 95% BC CI: [-0.036, 0.059]) at one standard deviation below the mean. In addition, Fig. 3 visually depicts that the positive conditional indirect effect of CFI on mass customization capability through SC alignment intensifies as the level of product modularization increases, providing support for H4.

4.2 Endogeneity concerns

The potential endogeneity issues often encountered in survey research can impact the validity of our findings (Sande and Ghosh 2018). To mitigate this concern, we employed the two-stage least squares (2SLS) method

Table 5 Results of hierarchical regression analyses

Variables	Mass customization capability			SC alignment		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Firm size	-0.037	-0.040	-0.047	0.042	0.038	0.036
Firm age	-0.001	0.000	0.000	0.000	0.000	0.000
R&D Investment	0.103*	0.058	0.053	0.083	0.028	-0.015
6σ years	0.019	0.011	0.009	0.021	0.011	0.014
industry1	-0.201	-0.208	-0.218	0.067	0.059	0.072
industry2	-0.192	-0.221*	-0.259*	0.245	0.210	0.200
CFI		0.244**	0.190*		0.298***	0.274***
SC alignment			0.181*			
Product modularization						0.122*
CFI* Product Modularization						0.298**
R^2	0.067	0.116	0.142	0.072	0.150	0.171
Adjusted R^2	0.067	0.049	0.026	0.072	0.078	0.021
F	2.575*	4.033***	4.44***	2.805*	5.410***	8.083***

*p<0.05; **p<0.01; ***p<0.001

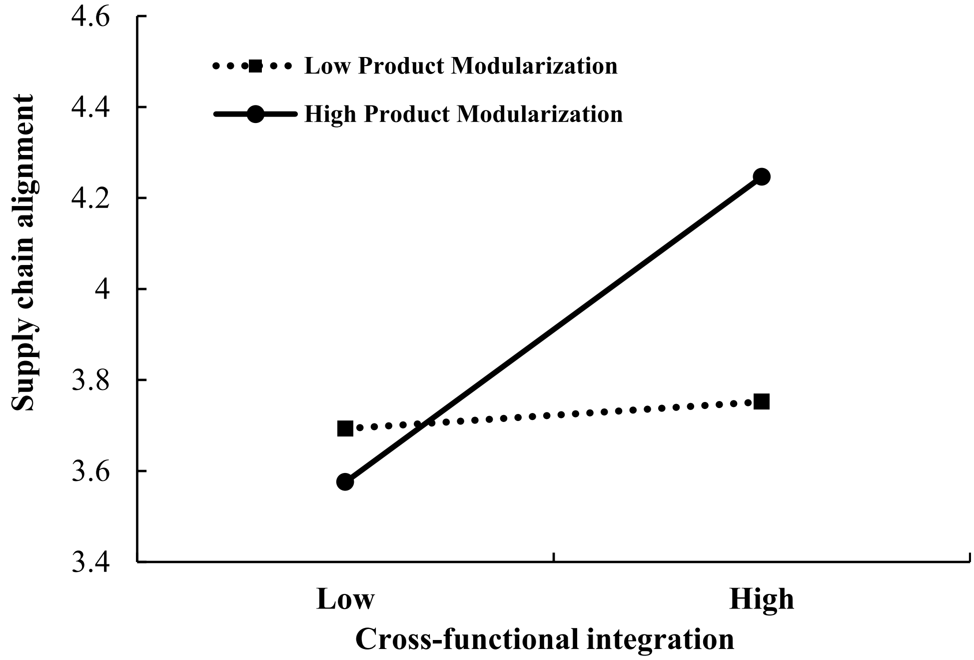


Fig. 2 Moderation effect of product modularization on the relationship between CFI and SC alignment

with an instrumental variable. In our study, we selected leadership for functional integration (LFI) as the instrumental variable. This choice stems from the notion that support from leadership for CFI may influence the extent of integration (Fan and Kang 2023), without directly affecting manufacturing alignments and market response. We used a four-item scale developed by Morita et al. (2015) for measuring LFI (see Appendix 2) and executed the 2SLS analysis using the STATA program, with the results shown in Table 7. In the first stage of the analysis, LFI exhibited a significant correlation with CFI (b = 0.326, $p < 0.001$, Cragg-Donald Wald F statistic = 18.816), indicating that LFI serves as a valid instrumental variable. Subsequently, in the second-stage, the fitted values derived from the first-stage equations were used to predict mass customization capability. The results indicated that CFI had a significant positive effect on mass customization capability (b = 0.807, $p < 0.01$). Therefore, our analysis confirms that there are no endogeneity issues affecting the relationship between CFI and mass customization capability.

Table 6 Conditional indirect effect of CFI on mass customization capability

Product Modularization	Effect	Boot SE	LLCI	ULCI
-1SD	0.044	0.104	-0.160	0.249
M	0.274	0.066	0.144	0.404
+ 1SD	0.504	0.100	0.308	0.700

5 Discussions

5.1 Theoretical implications

Grounded in TCE, this study investigates the underlying mechanisms connecting CFI to mass customization capability, as well as the associated boundary conditions. The findings revealed that CFI enhances mass customization capability not only directly but also indirectly through the SC alignment. Our results also confirmed that product modularization reinforces this indirect effect. These findings offer theoretical insights, highlighting efficient and effective strategies for fostering mass customization capability.

First, this study enriches the mass customization literature by validating internal organizational factors, such as CFI, as an important ingredient for cultivating mass customization capability. From a TCE perspective, the high transactional uncertainty and complexity level in mass customization will significantly increase its transaction costs. Szozda and Świerczek (2022) also argued that addressing transaction costs is critical to the success of mass customization strategies. Aligned with the research by Luo et al. (2010), which highlights the significant role of intra-organizational collaboration in reducing transaction costs, our findings reveal that CFI can augment firms' capacity to manage transactional uncertainty and complexity, thereby lowering transaction costs and facilitating mass customization.

Second, by establishing connections between internal organizational factors like CFI and external SC factors such as SC alignment, this study broadens our understanding of a mechanism enabling mass customization. Our results

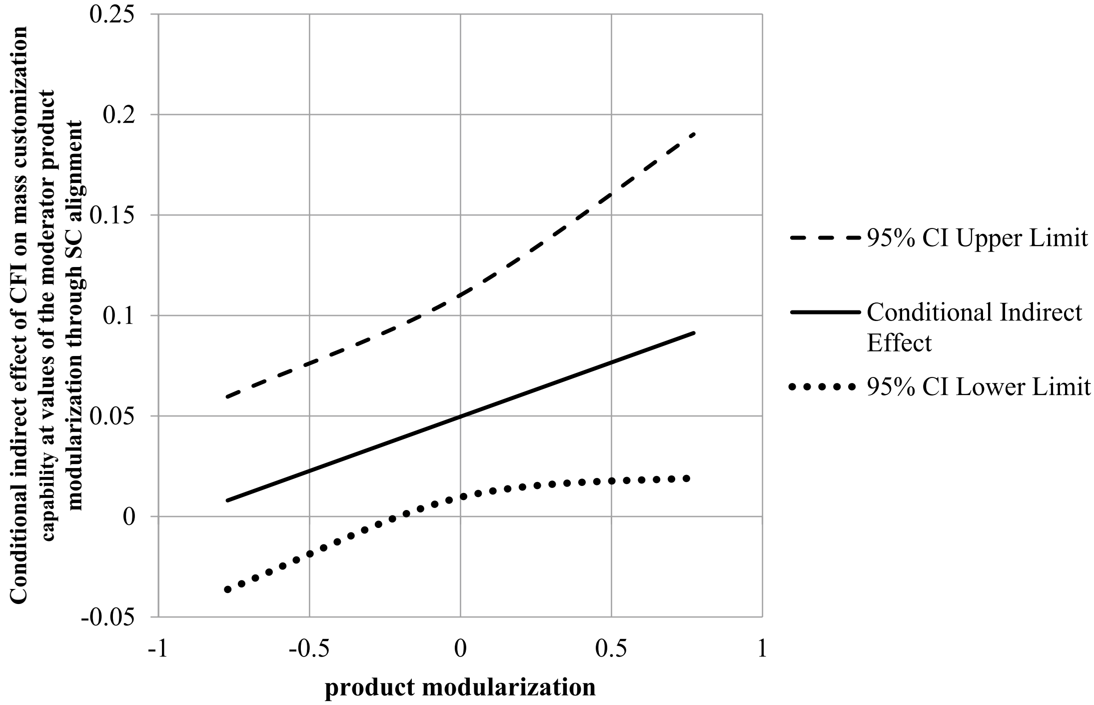


Fig. 3 Conditional indirect effect of CFI on mass customization capability at values of the moderator product modularization through SC alignment

uncover the mediating role of SC alignment in transferring the advantages of CFI to mass customization capability. Prior research in the areas of operations and SC management has emphasized the importance of internal operational practices and capabilities as key drivers for implementing external SC collaboration. For instance, numerous studies have demonstrated that internal integration can catalyze external SC integration that further influences operational and SC performance (Freije et al. 2022; Huo 2012; Lai et al. 2012; Shou et al. 2017; Zhao et al. 2011). Kang et al. (2021b) underscored that CFI within an organization can elevate the involvement of external customers and suppliers in the new product development processes, consequently enhancing innovation performance. Similarly, our findings show that CFI fosters alignment of vision, goals, and processes among SC partners, thus diminishing opportunistic behaviors and coordination costs, ultimately enhancing mass customization capability. In other words, firms can improve mass customization capability both directly through the implementation of CFI and indirectly by leveraging SC alignment stemming from CFI. By validating the intermediary role of SC alignment, this study also contributes to the current knowledge of SC alignment by providing further insight into its antecedent and positive performance outcomes.

Table 7 The results of 2SLS by using leadership for functional integration as an instrumental variable

	Dependent variable	
	First-stage: CFI	Second-stage: Mass customization capability
LFI	0.326***	
CFI		0.804**
Controls		
Firm size	-0.012	-0.048
Firm age	-0.001	0.000
R&D Investment	0.169***	-0.045
6σ years	0.023**	-0.008
industry1	-0.053	-0.222
industry2	0.056	-0.288*
Constant	1.811***	1.563

Cragg-Donald Wald F statistic = 18.816

Stock-Yogo weak ID test critical values: 10% maximal IV size = 16.38

Third, the findings of this study also enrich CFI literature by providing interesting insights into the synergetic impact of product modularization in complementing CFI within the context of mass customization. Specifically, the results of this study suggest that product modularization positively moderates the indirect effect of CFI on mass customization capability through SC alignment. In essence, product modularization facilitates the reduction of complexity in manufacturing (Ahmad et al. 2010), facilitating reduced coordination and governance costs for intra- and inter-firm collaboration (Zhang et al. 2019). Moreover, product modularization is a crucial factor in successfully implementing mass customization, as it enables firms to achieve reconfigurability to adapt to various market situations (Gauss et al. 2019). Thus, product modularization can help CFI more efficiently foster SC alignment by streamlining internal and external communication processes to achieve consensus within the supply chain (Wang et al. 2014), thereby improving mass customization capability. This finding indicates that CFI can be more effective in promoting SC alignment when the level of product modularization is high. In contrast, the conditional indirect effect of CFI on mass customization capability through SC alignment is minimal when the level of product modularization is low. This suggests that the coexistence of CFI and product modularization acts as a catalyst for realizing mass customization through SC alignment. Conversely, the absence of adequate product modularization serves as a constraint to the effective utilization of internal CFI in aligning external SC and implementing mass customization strategies.

5.2 Managerial implications

As manufacturing firms contend with pressures stemming from global business environments, increasing international competition, evolving customer expectations, and expanding customer base, mass customization has emerged as a crucial source of competitiveness. The findings of this paper suggest that CFI directly affects mass customization capability. Achieving mass customization necessitates organizational designs and practices capable of accommodating diverse and complex customer demands while ensuring seamless flows of process and product through the sharing and transfer of information and knowledge. Without well-designed and implemented CFI, firms may encounter challenges in realizing mass customization strategies. Therefore, it is imperative for firms to prioritize the development of strategic collaboration and information sharing among different functional departments to ensure successful mass customization implementation.

In addition, managers must recognize the important role of SC alignment, serving as the connecting link through which CFI translates into enhanced mass customization capability. While CFI plays a significant role in improving mass customization capability, internal integration across functions at the plant level may not suffice to fully capture the factors enabling and shaping mass customization. This is because the success of mass customization relies on a high level of collaboration, strategic partnerships, and mutual trust among participants across the entire supply chain. Therefore, firms must not only cultivate internal CFI to directly impact mass customization but also leverage CFI to synchronize their vision, goals, and processes with external supply chain partners, thereby enhancing the efficiency of achieving desired mass customization capability.

Lastly, the findings indicate that a higher level of adoption and implementation of product modularization reinforces the indirect effect of CFI on mass customization capability via SC alignment. Given that mass customization necessitates swift adjustments of product design, a variety of product volumes and mixes, and on-time deliveries, product modularization can significantly reduce the cost and time associated with mass customization by simplifying complexities and challenges in components, processes, and transactions through modularly designed products, intermediate modules, and assembling modules, and product platforms. By capitalizing on the advantages of product modularization, firms can more effectively harness CFI to foster SC alignment, particularly in the execution of a mass customization strategy.

6 Conclusions, limitations, and future research directions

This study proposes a moderated mediation model integrating internal CFI, external SC alignment, and product modularization to enhance mass customization capability from the TCE perspective. The results offer valuable insights into the effective utilization of CFI during the implementation of a mass customization strategy. Nevertheless, several limitations in our research warrant attention in future research. First, this study solely focuses on internal integration by investigating the impact of CFI on mass customization capability. However, research indicates that both internal and external integration contributes to enterprise performance (Li et al. 2022b). Given that mass customization strategies necessitate coordination across upstream and downstream SC members, it is meaningful to examine how external integration (e.g., customer integration and supplier integration) affects mass customization capability. Second, while this study examines the mediating role of SC alignment in the relationship between CFI and mass customization, it is worth noting that other internal factors, such as organizational agility and manufacturing flexibility, may also serve as mediators in this relationship. Hence, future research should explore these additional mediators to gain a comprehensive understanding. Lastly, in this study, we did not account for country effects in investigating our research model due to the small sample size. However, it might be important to recognize that various country characteristics, including cultural differences, economic status, and market conditions, may influence the relationship between CFI and mass customization through SC alignment. Hence, it would be valuable to explore this relationship further, particularly by considering the effects of different countries.

Appendix 1 Review of recent empirical research of mass customization antecedents

Article	Independent variable	Mediator	Moderator	Theory
(Ullah and Narain 2021a)	Flexible manufacturing competence,		Workforce management practices	Resource-based view
(Tu et al. 2004a)	Re-engineering set-ups, Preventive maintenance, Cellular manufacturing		Environmental uncertainty	
(Ahmad et al. 2010)	Product modularity	Inter-functional design coordination		
(Jain et al. 2022)	Process amenability, organizational readiness			
(Zhang et al. 2014)	Organizational flatness	Coordination, product modularity		
(Tu et al. 2004b)	Customer Closeness	Modularity-based manufacturing Practices		
(Hong et al. 2010)	Lean practices, supply chain IT			Value co-creation theory
(Liu et al. 2010)	Managing demand and supply uncertainties			Organizational information processing theory
(Liu et al. 2018)	Supply chain planning	Supply chain integration		Organizational information processing theory
(Zhang et al. 2015)	Knowledge acquisition	Knowledge application, knowledge assimilation		
(Ullah and Narain 2022)	Supply network flexibility		Information and communication technologies	Dynamic capability perspective
(Cheng et al. 2022)	Business model design	Supply chain integration		Business ecosystem theory
(Liao et al. 2011)	Free information sharing		Mutual trust	
(Sheng et al. 2022)	Operational coordination	Organizational agility	Customer need diversity, competitive intensity	Dynamic capabilities perspective
(Migdadi 2022)	Social capital	Absorptive capacity		
(Kang et al. 2021a)	Intellectual leadership	Anticipation of new technologies	Customer market knowledge	
(Wang et al. 2016)	Standardization	Innovation		
(Salvador et al. 2015)	Flexible manufacturing, Customer involvement, product management tools			
(Wang et al. 2014)	Modularity	Customization knowledge utilization, business process improvement		Organizational learning perspective
(Jitpaiboon et al. 2009)	Customer integration, supplier integration	Customer integration, supplier integration		Extended resource-based view
(Lai et al. 2012)	Internal integration,			
(Abdallah and Matsui 2008)	Customer involvement, Modularization of products			
(Huang et al. 2008)	Internal and external learning	Effective process implementation		knowledge-based view
(Ullah and Narain 2021b)	Supplier selection strategies, supplier management strategies			
(Xiaosong Peng et al. 2011)	NPD IT, Modular Prod design, Supplier collaboration IT	Configurator IT		Organizational information processing theory
(Shi et al. 2022)	Consumer preference measurement accuracy	Manufacturing flexibility	Customer participation	Theory of module decomposition and integration

Appendix 2 Construct measurement

Variable	Items	Adapted from
Cross-functional integration (Cronbach's $\alpha = 0.807$)	The functions in our plant are well integrated	Yang and Tsai (2019) and Thun (2008)
	Problems between functions are solved easily, in this plant	
	Functional coordination works well in our plant	
	Our business strategy is implemented without conflicts between functions	
Mass customization capability (Cronbach's $\alpha = 0.794$)	We can easily add significant product variety without increasing cost	Wang et al. (2016)
	Our capability for responding quickly to customization requirements is very high	
	We can quickly elect individual customer's preferences	
	We can quickly adjust the product design based on customers	
Supply chain alignment (Cronbach's $\alpha = 0.859$)	Our supply chain members understand our goals for supply chain management	Min and Mentzer (2004)
	Our supply chain members understand that we expect them to continuously improve their supply chain practices and operations	
	Our supply chain members have clearly defined goals within our supply chain	
	We all know which supply chain members are responsible for particular goals with our supply chains.	
Product modularization (Cronbach's $\alpha = 0.813$)	Our products are modularly designed, so they can be rapidly built by assembling modules	Zhang et al. (2014)
	We have defined product platforms as a basis for future product variety and options	
	Our products are designed to use many common modules	
Leadership for functional integration (Cronbach's $\alpha = 0.778$)	Our top management emphasizes the importance of good inter-functional relationships.	Morita et al. (2015)
	Our managers do a good job of solving inter-functional conflicts.	
	We are encouraged to communicate well with different functions in this plant.	
	Our managers communicate effectively with managers in other functions.	

Funding The authors have no relevant financial or non-financial interests to disclose.

Data availability The data that support the findings of this study are available from the corresponding author.

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