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ARTICLE

Achieving Responsiveness through Supply Chain Integration: A Moderating Effect of Industry-4.0

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ABSTRACT

This article is aiming to investigate the emerging impact of industry-4.0 on supply chain integration and responsiveness in the electronics industry in China. Specifically, it is to investigate the moderating effect of industry-4.0 as a strategic factor on the causal relationship from operational integration to supply chain responsiveness. This study develops hypotheses based the on selected literature reviews in the relevant research areas, and tests the hypotheses in the empirical sample data set collected from 76 electronics firms by using *hierarchical multiple regression* method. The results of this study shows that industry-4.0 as an emerging strategic factor has not only directly helped the level of market responsiveness of the firms, but also has significantly strengthens the already proven positive causal relationship from operational integration within the supply chain to the overall market responsiveness as part of supply chain performance. To improve the supply chain responsiveness in the electronics industry, managers can now make more confident and informed decisions to channel their resources towards the initiatives of industry-4.0 by up-grading perhaps their current information systems and business processes, knowing full well the dual benefits offered by the Industry 4.0 initiatives. The study extends the concurrent literature by conceptualising the moderating effect of industry-4.0 on the causal relationship between supply chain integration and business responsiveness.

1. Introduction

Alongside with the continuing development towards a highly integrated and market responsive supply chain through sharing more demand and supply information [1-3], recent years have witnessed a number of emerging digital data processing technologies, such as internet of things, big-data, cloud-computing and artificial intelligence and so on [4]. In fact, many scholars claim that the 4th industrial revolution is dawning, and a nomenclature of "Industry-4.0" was born [5]. However, this is more than just a trendy jargon. Its active roles and profound implications in our understanding of those essential managerial theories and practices are far from being clear.

Evidently across many manufacturing sectors, proper application of digital information processing technology has strengthened the supply chain integration and improved supply chain visibility, and resulted in higher level of supply chain responsiveness [6]. It is also evident that Industry-4.0, as a leading application of such digital

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technologies, has become a major strategic driver for supply chains to gain competitive advantages by delivering a renewed level of customer responsiveness [7-9]. However, many questions remain, such as how organisations can exploit the increasingly powerful information processing capabilities that today's digital has to offer; and in doing so, how supply chain integration (SCI) might be harnessed with the Industry-4.0 initiatives specifically.

This study, however, is not about re-visiting the SCI and supply chain responsiveness (SCR), but about exploring the conceptual development in our understanding of SCI and its effect on SCR *under the impact of industry-4.0*. The key intention, therefore, is to theorise the notion of *industry-4.0* into a key *independent construct* of a relevant business model which may offer better assistance for effective managerial decision-making. The departure point of the study is to stop addressing the industry-4.0 as a sweeping industrial phenomenon at the practice level under the backdrop of digital technology development, but to re-define it as a conceptual construct that engages with other existing constructs at the theoretical level. For that purpose, the chosen domain of this research is identified at the on-going discussion area of causal relationship between SCI and SCR, where a plethora of supporting literature is helpfully available.

Previous researches on the supply chain's integration-responsiveness relationship appear to be diverse and abundant. However, none has been specifically carried out under the influence of industry-4.0, at least not at the time of writing. It looks though that most researchers agree that SCI in general contributes significantly to SCR, and to other measures of supply chain performances too [10, 11]. But, over the years, the debate appears to be not so conclusive as to whether and how such a causal contribution is to be influenced or moderated or even controlled by other major exogenous factors. Taking a hypothetical perspective of the *contingency theory* [12], the strength of such established causal relationship between the SCI and SCR would more likely to be influenced by or contingent upon some exogenous factors, such as environment uncertainty, market dynamism, supply complexity, and international network [13-15]. Today, industry-4.0 has emerged as one of the most prominent exogenous factors for the supply chain development especially for the fast moving consumer goods manufacturing industries. Thus, two research questions arise: 1. to what extent industry-4.0 might moderate the effectiveness of SCI-SCR causal relationship; and 2. if so, in which way the moderating effect of industry-4.0 might engages with the sub-dimensions of SCI.

The *research objective* of this study, therefore, is to investigate whether there is any substantive moderating effect that Industry-4.0 could impinge upon the integration-responsiveness relationship for a manufacturing supply chain; and to construct a conceptual framework whereby the inter-play of the constructs, including Industry-4.0, responsiveness, and the three sub-dimensional components of SCI, are captured. The research's methodological approach is primarily empirical in nature. Hypotheses are developed based on literature review. Survey instruments are designed to collect real-world data from the fast growing electronics industry sector in China, where Industry 4.0 has been sprawling rapidly in recent years. *Hierarchical multiple regression (HMR)* method is used to test the hypotheses, and the results are critically analysed to arrive at some conclusions.

2. Theoretical Basis and Conceptual Model

2.1 Advent of Industry 4.0

"Industry-4.0" was first proposed as part of the "High-Tech Strategy 2020 Action Plan" of the German government [16]. The concept has since been endorsed by researchers around world [9, 17, 18]. The term *Industry-4.0* means the fourth industrial revolution whereby smart shop floor devices and machines form a self-organised system, and the big data analytics provides global feedback for their coordination. Industry-4.0 thus represents a production oriented *Cyber-Physical System* that integrates production facilities, warehousing systems, logistics, and even social requirements to establish the value creation networks [19]. It is more than just a technology advancement. It is now convincingly an emerging business paradigm for manufacturing supply chains.

The core idea of Industry 4.0 is to use the emerging information technologies to create unprecedented information processing capability that integrates market information with supply chain resource to deliver greater flexibility and responsiveness. The key feature of Industry-4.0 is the digital technology-facilitated platform, including integration through value networks to facilitate inter-organisational collaboration, internal vertical integration to create reconfigurable manufacturing system, and end-to-end engineering integration to support product customisation [20-22]. It is precisely because of this unique capability of facilitating the supply chain *integration* and *responsiveness*, Industry-4.0 has been defined as one of the key conceptual constructs in this study.

The scope of the study has been selectively focused on China's electronics industry, since China is a leading country for the development of Industry-4.0. Like many major economies around world, China has already embarked on the journey to transform its manufacturing industry through the 4th industrial revolution. According to the report 'China – Industry 4.0 Index 2015' produced by Staufen (China Tech, 2016), 65% of China's manufacturing companies, many of them electronic product manufacturers, have already begun to implement the initiatives. From 2013 to 2015, Chinese inventors registered more than 2,500 patents for Industry 4.0 enabled technologies, comparing with 1, 065 in the USA. By 2015, China's Industry 4.0 Index was ranked 6th in the world, with Germany being the 1st. Furthermore, in 2015, Chinese government had launched a 'Made in China 2025' programme with an aim to bring China onto an equal footing with the Western industrial nations within 10 years (China Internet Watch, 2014). A focused research on the Industry-4.0 could benefit the country's continuing development in the direction.

2.2. Impact on SC Responsiveness

Extant literature on the direct causality between Industry-4.0 and SCR appears to be few and far in between. However, the literature base for a descriptive interpretation on the influence of Industry-4.0 on SCR can be established, especially when it is taken from the perspective of the organisational information processing theory [23].

Newly emerged digital technologies have been widely recognised as a powerful information processing capability that delivers the flexibility and responsiveness for businesses [24]. An adequate information platform is also essential to the intended integrative performance of a supply chain [25]. Previous researches have largely endorsed the notion that information sharing will engender positive impact on supply chain responsiveness [26, 27]. Researchers have also developed theoretical models to explain the causal relationships between the level of information sharing and the responsiveness as one of the supply chain performances [3, 28]. Without doubt, Industry-4.0 represents such information sharing platform, if not a lot more.

The effects of information sharing system on supply chain responsiveness can also be interpreted by the Organisational Information Processing Theory (OIPT) [23]. The central theme of OIPT is that in order to survive the more volatile market place organisations must seek better and more information and to use it effectively. OIPT also states that the information processing capabilities must be aligned with an organisation's specific needs in order for it to take effect [29]. This means that filtering and selecting the most relevant information from the overwhelmingly large pool of data is the key for the effective applications. Industr-40 represents such intelligent cyber-physical data gathering and filtering systems for specific purposes. In fact, literature shows that Industry-4.0 has begun to radically transform the accesses to the timely information from the upstream and downstream of a supply chain like no other has done before [9]. Such a cyber-physical data technology driven transformation of the supply chain's information processing capability has already enabled supply chain's market responsiveness directly and significantly [6].

An empirical study by Gosain, Lee [30] concludes that effective information systems that inter-connecting the supply chain organisations were required if the supply chain was to be elevated to a higher level of responsiveness. In analysing the roles that an e-hubs or the cloud-based information services have played, White, Daniel [31] concludes that such systems have strengthened supplier partnership and markedly increased the supply chain's operational flexibility and responsiveness. Thus, it is reasonable to extrapolate and hypothesis that adopting Industry-4.0 initiatives in a manufacturing supply chain will significantly enhance its overall responsiveness. Hence we postulate:

H1: Industry 4.0 is positively related to the supply chain responsiveness.

2.3. SCI and Its Dimensions

We need to draw upon literatures to establish two basic fundations for the study. We ask what is the most commonly agreed structural definition of SCI in the literature? Based on the 'information decoupling point model' [32], a manufacturing supply chain has an *information decoupling point* (IDP), at which the supply chain can be divided into two constituent segments: upstream and downstream. According to Mason-Jones and Towill [32], IDP is the point where the market driven information flow and forecast driven information flows meet. Recognising the IDP was a major step forward in the development of understanding the structure of a supply chain. Many subsequent researches in SCI have apparently adopted this perspective.

In a similar vein, Flynn, Huo [33] has argued that SCI can ultimately be collapsed into three dimensions: customer (downstream), supplier (upstream) and internal (decoupling point firm) integration. One of Flynn's contribution is to reinstate the internal integration as an indispensable part of SCI. Accordingly, this study chooses to adopt Flynn's three integrative dimensions as the basis, but to define the internal integration as at the decoupling point. The intention is to make it largely built on the established research and hopefully be more acceptable; and also based on the fact that the cyber-physical information process takes places mostly at the decoupling point [9, 21, 34]. We view the *focal firm* at the information decoupling

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point as the internal environment; and the upstream and downstream of the decoupling point as the firm's two external environments. In close relevance to the Industry-4.0 initiatives, we define the supply chain responsiveness in terms of its operational flexibility in design, volume, variety, and services for the purpose of satisfying the market demand [35-37].

2.4 Influence on Responsiveness

Next, we review what are the established conceptual models on the causal relationship between SCI and SCR? In the contemporary literature there is an overwhelming general consensus that SCI exerts positive influences on supply chain's performance outcomes including responsiveness [38-41], many of which address the causal influences at the SCI's sub-dimentional level.

For Internal integration, Flynn, Huo [33] notes that internal integration breaks down functional barriers within the organisation while the external integration engenders cooperation between the participating members of the supply chain resulting in better responsiveness. Stevens [42] described the internal integration as the "stage 2 integration" whereby the barriers between functions of the manufacturing organisations must be broken down. Internal integration provides the structural basis upon which cross functional teams can work seamlessly together to improve the product and process design [43]. Internal integration also provides the conduits through which information flows can reach the functions and manufacturing units [44]. Internal integration offers coordination of process capabilities which leads to improve production flexibility [45], higher delivery performance [46], enhanced logistics service performance [47], and reduced product development cycle time, and ultimately a better responsiveness to the market [46]. It is therefore reasonable to suggest the following hypothesis.

H2a: Internal integration is positively related to supply chain responsiveness.

Upstream integration has been widely discussed in terms of supplier integration [48]. Literature in supplier integration tends to address much wider implications than just the responsiveness, albeit some exert that sourcing from the right suppliers do improve the supply chain agility [49]. It seems that upstream integration can help the supply chain to improve the operational coordination with the suppliers, reduce cost, enhance the quality alignment, develop partnership, and share technological knowhow [50]. Some literatures do specifically link supplier/upstream integration with customer responsiveness [51]. Lee, Padmanabhan [52] find that external supplier integration can improve the supply chain responsiveness by alleviating the Forrester effect, which occurs when customer demand information is distorted. Hallgren and Olhager [53] realised that an highly integrated operational system with suppliers will be able to deliver not only the performance but also the flexibility simultaneously. Supplier integration also cultivate and enhances the cooperative behaviour and facilitates inter-firm problem-solving [54]. Yi, Ngai [55] notes that the responsiveness of a supply chain is often more effectively improved by involving and integrating suppliers and customers in the supply chain. Thus, we may hypothesis:

H2b: Upstream integration is positively related to supply chain responsiveness.

Downstream integration is essentially a forward integration strategy designed to get more direct access to the demand information flows [47]. Its intention as well as result are often demonstrated in the improved supply chain responsiveness to the market demand changes. It is an important part of the supply chain's external integration that enables it to better share the demand information [56]. Failing in the forward integration with its customer, the OEM could struggle with the accuracy of demand information, resulting in poorer operational performance in general [57]. A high level of customer integration often leads to new product development, higher production flexibility, synchronised capacity management, and higher delivery responsiveness [58]. Downstream integration also enhances inter-organisational process flexibility that allows the downstream supply chain to become more responsive [59]. The key reason as to why the downstream integration may enhance the supply chain responsiveness more than other segments lies in its capacity of information gathering and sharing [38, 44]. In line with those findings we propose the following hypotheses.

H2c: Downstream integration is positively related to supply chain responsiveness.

2.5 Moderating Effects of Industry-4.0

Our postulated concept of 'moderating effects of Industry-4.0', however, is primarily a hypothesis in nature, since there is no direct references we may draw from the extant literature. Nevertheless, rigorous theoretical supports for this hypothesised concept can still be gathered in two theoretical ground: *contingency theory* and *OIPT.*

Contingency theory [12, 60] states that there is no best way to organize a business or to make managerial decisions; Instead, the optimal course of action is always contingent (dependent) upon the specific internal and external conditions. As Sousa and Voss [60] note when the value of SCI have become evident, researchers should shift their focus to the contextual 'conditions' under which the integration take places. To date, Industry-4.0 led cyber-physi-

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cal information system represents one of such 'conditions,' in which increasing number of manufacturing supply chains find themselves operate. It is therefore anticipated that the 'optimal action' on SCI is likely to be contingent (dependent) upon such conditions; and its effect on the intended outcome can be moderated by it accordingly. Literature has provided sufficient evidence that cyber-physical data and information processing conditions have already altered the supply chains' integrative behaviour as well as their performance. Wang, Wan [4] finds that the up-taking of advanced cyber information processing technologies strengthens external integration especially the downstream segment. Bitar and Hafsi [61] explored the concept of capabilities and their impact on integration and performance. Schoenherr and Swink [62] note that enhanced information porcessing capability will substantively underline the organisational responsiveness. A Delphi study by Lummus, Vokurka [3] shows that managers tend to associate the underlying capability of gathering and sharing timely information of their customer demand with much improved supply chain responsiveness. Li, Chung [63] phrase such information processing conditions and sharing capability as the 'alertness' that a supply chain takes towards the integrative business environment.

Organisational information processing theory (OIPT) [23] identifies three important concepts: information processing needs, information processing capability, and the *fit* between the two to obtain optimal performance. To achieve SCR represents the information processing needs, and to develop Industry-4.0 is to harness the information processing capability. Literature has ample evidence of the fit between the two. As Catalan and Kotzab [64] once described that an organisation's information processing capability enables the firm to read and understand market signals. Lee, So [28] suggest that information exchange capabilities supplement the organisational integration and coordination with respect to achieving greater responsiveness. Lapide [65] reports in his research that the key factor that impedes the organisation's competitiveness is the lack of enterprise wide information processing capability which is supposed to leverage the available market information.

In view of the two theoretical perspectives discussed above, it is reasonable to postulate that the causal effect of SCI on SCR might be positively moderated by the level of Industry 4.0 initiative as an external factor. Hence, we put forth the following three hypotheses:

H3a: Industry 4.0 positively moderates the causal relationship between the internal integration and the overall supply chain responsiveness.

H3b: Industry 4.0 positively moderates the causal relationship between the upstream integration and the overall supply chain responsiveness.

H3c: Industry 4.0 positively moderates the causal relationship between the downstream integration and the overall supply chain responsiveness.

To wrap it up, we construct a conceptual framework that captures the above seven hypotheses shown in Figure 1. It models the SCI - SCR causality subject to the moderating effects of Industry-4.0. Here, the 'level of Industry 4.0' is an empirically measurable construct that indicates the overall extent to which the 'smart factory initiatives' are up-taken. We conjecture that supply chain integration promotes responsiveness, but do so in respect to its dimensions and also subject to the moderation by the level of Industry 4.0 (Figure 1).

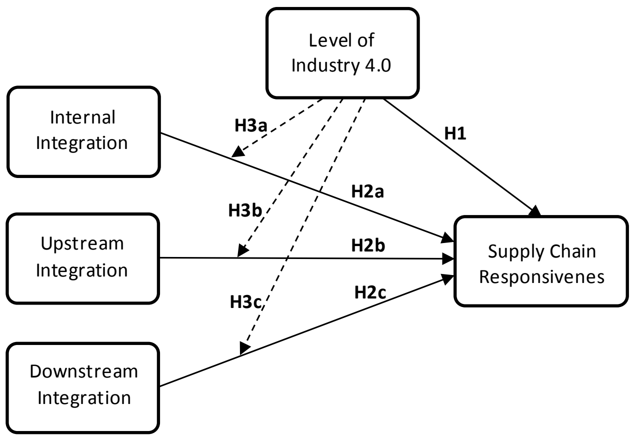

Figure 1. Moderating effect of Industry-4.0

3. Methodology

3.1 Data Collection

This study choose China's electronics industry as the unit of analysis, whereby the survey data is collected, for a number of reasons. First, China's electronics manufacturing industry is one of the largest in the world. Total revenues of major electronics information companies in China, have as expected exceeded 15.5 trillion yuan ($2.3 trillion) in 2015, doubling the gross revenues of 2010 [66]. It accounts for 35% of China's foreign trade at the end of last decade [67]. Second, many of them have already had the leading edge of technologies, including Internet of Things, Big-data, Cloud Computing, artificial intelligence (China Tech, 2016; Business Korea, 2016; Freudenberg, 2015; NE China, 2016). Third, China's electronics manufacturing supply chains have the growing global reach and are undergoing a transformation through upgrading their information system to the cyber-physical platform [6]. We identified 76 companies from the top 100 electronics companies listed by EDN Network (2007). Through

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the initial telephone contact to all the 100 companies, we captured their general profiles in terms of their up-taking of Industry-4.0. Then, we filtered the companies down to 76 companies that met our criteria, and where their executives had at least confirmed their substantive involvement in the recent Smart Factory or Industry-4.0 initiatives.

The survey instrument was developed for individual respondents in those firms that mostly OEMs at the 'decoupling point' as discussed above. Wherever possible we kept the survey items as simple as possible to avoid unnecessary confusion and inconsistency. The respondents to the survey were identified with the help of senior executives in each company. The key criteria are the adequate knowledge, experience of being involved in the company's Industry 4.0 initiatives. We screened those initially and identified 267 respondents, and eliminated those whose roles or experience were not so relevant, and ended-up with a pool of 223 respondents to send the questionnaires to. The survey invitations along with the survey questionnaire were sent through the single contact-point at each participating companies. With this approach, we had the consensus from their HR departments, which often have concerns of information security and confidentiality issues. As a result, we had higher than expected response rate of 79%. This rate is satisfactorily higher than what is recommended for empirical studies in operations management [68].

One of the limitation of this sampling method is that the respondent group were identified subjectively and may suffer from the non-response bias (NRB) (Armstrong and Overton, 1977). Our data were tested with p value well below 0.05, suggesting no significant NRB is involved. Since each survey questionnaire was collected from individual respondent at the same time, a so called common method variance (CMV) might be a threat to the validity of the results. Harman's one-factor test [69] was carried out, and the results revealed that no single factor explained anything more than 30% of the total variance in all the variables, suggesting that the common method bias is not present in any significant scale.

3.2 Variables and Measures

3.2.1 Key Variables and Measures

The key variables in this study are shown Figure 1. Supply chain responsiveness (RS) is the only dependent variable, which is the measures of a supply chain's overall operational responsiveness towards the customer demand and market changes. It is a factor representing the resultant performance of the SCI – SCR causality logic. The scales and the measurement indicators are mostly adapted from reliable literatures with only limited modifications if required. For the scale of SCR, they are adapted from Danese, Romano [70].

On the other end of the causality are the three dependent variables representing the three dimensional components of the SCI including: internal integration (II), upstream integration (UI) and downstream integration (DI). They are the factors measuring the strength of integrative activities within its respective segment of the supply chain. The scale of *II* and its observed indicators are largely adapted from Narasimhan and Kim [44]; and the scales of *UI* and *DI* are adapted from Flynn, Huo [33].

The level of Industry-4.0 (ID4.0) is defined as both the moderating factor as well as the independent factor in the framework (figure 1) owing to its multiple effects on the causality equation. The scales for the level of *ID4.0* appear to have not been reported directly anywhere in the extant literature. We, therefore, developed its scales largely by adopting and synthesising the scales from a number of existing relevant constructs from the literature, such as 'information integration and processing' from Chou, Chang [71], "smart manufacturing" from Davis, Edgar [72], "information processing capability" from Premkumar, Ramamurthy [29], and 'innovation capability' from Romijn and Albaladejo [73].

The scales adopted and/or developed from the literatures were originally in English, and were translated into Chinese by two professional translators who were specialised in business and managerial subjects. Items in the questionnaire were first reviewed by a small team of 3 academics who kindly gave their feedbacks, based on which some modification and improvement were made. The revised questionnaire was then pilot-tested with a small group of 18 participants to ensure that the questions were clear enough and relevant to the Chinese electronics manufacturing industry. Table 1 shows the scales and measurement indicators for all the five key constructs along with some reliability and validity assessment results.

Table 1. Reliability and validity of the constructs

Constructs and indicators	Loading	Goodness of fit
Internal integration (II)		
Real-time integration and connection among all internal functions	0.61	df=5, χ^2=09.05, p<0.001; CFI=0.96; TLI=0.98; IFI=0.93; SRMR=0.03;; composite reliability =0.90; Cronbach's alpha = 0.81; AVE=0.59
We implemented control systems that are largely integrated across functional areas	0.70	
We emphasize on managing the information flows among purchasing, inventory management, sales, and distribution departments	0.54	
Physical flows among production, packing, warehousing, and transportation departments are the key priority in our operational processes.	0.81	
We have high level of responsiveness to meet each other department's needs	0.59	

Upstream integration (UI)		
We share substantive information with our major suppliers through using various of information systems	0.72	*df* =5, χ^2=11.63, *p*<0.001; CFI=0.98; TLI=0.94; IFI=0.95; SRMR=0.06; composite reliability =0.83; Cronbach's alpha = 0.78; AVE=0.60
Formed a close strategic partnership with suppliers	0.56	
Established a joint planning process to achieve rapid response with suppliers	0.61	
Our suppliers systematically provide information to facilitate production and procurement processes	0.48	
Our suppliers are involved in in new product introduction processes	0.60	
Downstream integration (DI)		
We share substantive amount of market information with our customers	0.57	*df* =5, χ^2=10.66, *p*<0.001; CFI=0.99; TLI=0.97; IFI=0.95; SRMR=0.04; composite reliability =0.82; Cronbach's alpha = 0.72; AVE=0.64
tour information sharing with our major customers are driven by information technologies	0.60	
Our joint planning and joint forecasting is based on and facilitated by high level of supply chain visibility	0.49	
Our procurement and production processes are benefited from the information provided by our customers	0.51	
We involve our customers in our new product introduction and development processes	0.64	
Responsiveness (RS)		
We are able to rapidly adjust the volume of production to respond to the market volatility	0.51	*df* =5, *p*<0.001; χ^2=9.47, CFI=0.96; TLI=0.96; IFI=0.94; SRMR=0.05; composite reliability =0.78; Cronbach's alpha = 0.69; AVE=0.51
Our plant can produce customized product features	0.46	
Our plant can produce broad product specifications within same facility	0.71	
We have the capability to make rapid product mix changes for either market requirement or supply chain resource requirement	0.62	
We can provide flexible and fast delivery service to our customer	0.55	
Level of Industry-4.0 (ID4.0)		
We customize our production and delivery processes through real-time cyber-physical information interchange connection	0.59	*df* =5, χ^2=10.95, *p*<0.001; CFI=0.97; TLI=0.94; IFI=0.95; SRMR=0.03; composite reliability =0.89; Cronbach's alpha = 0.81; AVE=0.58
We integrate information from big-data into our smart machineries	0.48	
We strategically invest in latest cyber-physical information systems to keep up with the development	0.50	
Initiatives of Internet of Things has been launched and implemented in our production systems.	0.53	
We use cloud computing to process the market information in order to design and re-design of our products.	0.61	

3.2.2 Control Variable

We include several firm-level control variables to ensure that the test is not significantly biased by the other factors that have not been constructed into the regression model. Methodologically, however, such bias is highly likely and will typically result in so called omitted variable bias (OVB) (Clarke, 2005). A common method to avoiding the OBV is to include a number of properly identified control variables into the regression model. First, we use *company age* (AGE) as it has been suspected to be associated with its competitive performance (Zahra et al., 2000). We measure company age in terms of years commencing from its establishment, grouping into five categories from '1' for companies younger than 5 years; and '5' for companies that are 50 years or older. Second, we use *organizational size* (SIZ). Some authors (Chang and Thomas, 1989) argue that organisation size may enhance its competitive performances by leveraging on cheap loans and mitigated risks. Organisational size here is based on the company's total number of full-time employees ranging from '1' for less than 100, and '5' for over 5000 employees. Third, we use *product and market scope* (PSP, MSP) as have been discussed by Zott and Amit [74]. How a company develops its product offering for a specific market place will surely influence its performances. We adopted the questionnaire items from Zott and Amit [74]. Fourth, we use *process innovation* (PIN), which represents a creative dimension of its management processes. We measured the PIN by the survey item suggested by Su, Tsang [75]. Fifth, to reflect the unique Chinese electronics industry, we control the firms' ownership type (OWN); '1' being a government owned company and '0' being all other types. Sixth, to reflect the unbalanced economic development in China, we control the location of the firms (LOC); '1' being in the grade-1 (biggest) cities and '5' being in the grade-5 cities (county). Seventh, we also control the level of foreign investment in the company (FIV), which is now increasingly a common place; for "1" being with more than 80% of foreign investment and '5' being less than 20%.

4. Results

4.1 Regression Models Test Results

Hierarchical multiple regression analysis is used to examine our hypothesised framework. Table 2 presents the constructs and their correlations in between. The Pearson correlation value in the matrix appears to be low (< |1.0|), indicating discriminant validity in between the variables is high. However, when there are many independent variables, including control variables, in the regression model *multicollinearity* could be a concern. The values of VIF (variance inflation factors) which associated with each variables in the last column of the table 2 show that they are well below a common cut-off value of 5.0 [76], suggesting the effects of *multicollinearity* in the data set is within the acceptable limit.

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Table 2. Construct correlation matrix

	Variables	1	2	3	4	5	6	7	8	9	10	11	12	VIF
Control variables	1. AGE													1.123
	2. SIZ	.068**												1.022
	3. PSP	.139*	.071**											1.150
	4. MSP	.081**	.032**	.168**										1.201
	5. PIN	.021**	.168*	.133**	.171**									1.311
	6. OWN	-.052	.028**	-.024*	.160**	.010								1.299
	7. LOC	.043	-.028	.088	.149	.016**	.054*							1.046
	8. FIV	.012	.129	.142	-.103	-.0.25	-.063	.210						1.293
Construct variables	9. II	.054**	.022**	.095	.147	.017	.176*	-.012	.049					1.475
	10. UI	.101**	.008**	.148	.017*	.034	.035	.033*	-.012**	.032**				1.302
	11. DI	.010**	.082**	.002	.029	.011	.110**	.024	.178*	.020**	.097**			1.086
	12. ID4.0	.027**	.044**	.068**	.106	.035*	-.012	-.030	-.065	.052**	.013**	.109**		1.173
	13. SCR	.091*	.173	.020*	.054*	-.018	.102	.120	.028	.104**	.068**	.045**	.084**	

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

Table 3 below presents the results of *hierarchical multiple regression* which is intended to examine the proposed hypotheses. We included the *cross-product terms* as the additional predictor to estimate the interaction within the regression process.

Table 3. Moderated regression results

	Standardized estimates				
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Control variables					
AGE	-0.128	-0.103	-0.089	-0.097	-0.141
SIZ	0.038	0.027	0.018	0.041	0.050
PSP	0.119	0.123*	0.170	0.138	0.153
MSP	0.056	0.024	0.073	0.042	0.047
PIN	0.097	0.068	0.104	0.082	0.091
OWN	0.042	0.037	0.030	0.036	0.044
LOC	0.107	0.116	0.103	0.120	0.109*
FIV	-0.071	-0.029	-0.081	-0.029	-0.069
Independent variables					
II		0.071**	0.067**	0.058**	0.073**
UI		0.071	0.066	0.058	0.064*
DI		0.122**	0.153**	0.125***	0.137**
ID4.0		0.317***	0.226***	0.351***	0.314***
Interaction terms					
II x ID4.0			0.228**		
UI x ID4.0				0.109	
DI x ID4.0					0.230**
F	5.287***	6.720***	7.562***	4.980***	6.511***
R^2	0.215	0.326	0.357	0.381	0.397
Adjusted R^2	0.186	0.311	0.342	0.339	0.328
ΔR^2	-	0.111	0.031	0.024	0.016

Note: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Model 1 presents the base-line regression that only involves the 8 control variables. The result clearly shows that the beta values are not statistically significant for all the control variables; thus, they do not have any significant influences to the SCR. Model 2 captures the direct influencing effects of the three integrative dimensions of SCI as well as the moderating factor of Industry-4.0. The coefficients for the four constructs are all positive, indicating a positive direct correlation with the SCR. However, it is noted that the effect of *UI* is not statistically significant. Thus, the hypotheses H1, H2a and H2c are supported by the results but not the H2b.

Next, we use Model 3, 4, and 5 to test the moderating effects of Industry-4.0 on the causality of SCI – SCR. Model 3 - 5 add on the Model 2 with the interaction terms of 'II with *ID*4.0', '*UI* with *ID*4.0' and '*DI* with *ID*4.0' respectively and separately to investigate the moderating effects. The results shown that Industry-4.0 has a positive moderating roles to play in the causal relationship of SCI and SCR. However, the moderating role is tested statistically significant ($p < 0.001$) for *II* and *DI* dimensions, but not for the *UI* dimension. Thus, the hypotheses H3a and H3b have been supported by the test result, but not the H3b. These findings, therefore, confirms the significant existence of the moderating effects of Industry-4.0 and also confirms that such effects differ in respect to specific dimensions of SCI. Table 4 provides a summary of the hypothesis tests.

Table 4. Hypothesis test results

Hypotheses		Status
	The factors below are positively correlated with supply chain responsiveness (SCR)	
H1	Level of Industry-4.0 (*ID4.0*)	Strongly Supported
H2a	Internal integration (*II*)	Supported

H2b	Upstream integration (*UI*)	Un-supported
H2c	Downstream integration (*DI*)	Supported
	Level of Industry-4.0 moderates positively the causality of individual dimensions of SCI to SCR	
H3a	Internal integration (*II*)	Supported
H3b	Upstream integration (*UI*)	Un-supported
H3c	Downstream integration (*DI*)	Supported

5. Discussion

5.1 Results Interpretation

By taking the structural perspectives of SCI at the *decoupling point*, our results indicate that *downstream* (*DI*) and *internal* integration (*II*) appear to have significantly higher impact to the SCR than that of the *upstream integration* (*UI*). This result suggest that the effectiveness of SCI – SCR causality does not always demonstrate itself on the amalgamated overall SCI strength level, but often depends on how the individual dimensional level integration is *configured.*

From OIPT one can argue that the *upstream information flows* from the decoupling point mainly serve the functions of forecasting and scheduling needs for adjusting the capacity and resource levels from the suppliers; whilst the *downstream information flows* mainly serve the functions of 'make-to-order' and 'respond-to-demand'. It is this differentiated roles of *information process capability* at different segment of a supply chain that ultimately *fit* to the differentiated levels of effectiveness of the SCI – SCR causality.

The *configuration approach*, as described in the Configuration Theory by Miller [77], stipulates that an organisation is a set of *interrelated activities* rather than pairwise relationships in isolation. The configuration approach views the *fit* in terms of 'gestalts' of various elements and their relationships [78]. The choices of managerial actions towards the upstream, downstream or internal integration is part of the *configuration design*. Thus, it is reasonable to argue that our results from the dimensional SCI analysis facilitate supply chain's configuration design, especially by being contingent upon an emergent exogenous factor – Industry-4.0.

Further on the result that the *UI* has no significant direct effect on the SCR, nor under the moderating effect of *ID*4.0, we may interpret that this could be due to the limited cyber-physical information processing capabilities in the upstream, at least it is so in case of the China's electronics industry. Upstream integration, in general, appears to benefit the supply chain through efficiency oriented re-alignment rather than customer satisfaction [79]. The information flow used to integrate upstream tends to be the aggregated ones concerning more of generic components and their stock levels, not usually the customised products. On the other hand, downstream integration appears to be particularly capable of benefiting the responsiveness through services and customised flexible delivery.

The findings on the moderating effects of industry-4.0 also echo the well-established contingency-based management thinking. It suggests that the effectiveness of a firm's promotion on the responsiveness will not only depend on the initiatives of Industry-4.0 per se, but also very much on the relevant integrative actions that are moderated by industry-4.0 with a non-trivial measure. In other words, the causal relationship between SCI and responsiveness has been significantly contingent on the level of up-taking of industry-4.0.

5.2 Theoretical and Managerial Implications

From a theoretical development perspective, this study has attempted a number of areas to enrich the existing literature. First, the concept of SCI defined in the literature as a *unidimensional entity* is no longer theoretically *fit for purpose*; and it helps when it is understood as a *multidimensional* structure which is subject to the contingency effect of exogenous factors. Our finding shows that Industry-4.0 is one of such exogenous factors, which could exert significant level of moderating effect on the causal relationship between SCI and SCR. Second, this study explores the roles of emerging industry-4.0 from a perspective of OIPT. Previous studies on industry-4.0 has been largely technological [80], and its theoretical linkage with SCI has been unexplored. It becomes clear in this study the advent of industry-4.0 has a profound implications as to how SCR should be modelled. Third, this study models both the direct effect of industry-4.0 and the indirect moderating effects on the causality of SCI – SCR simultaneously. This extends our understanding on the *contingency-based* causal connections at the integrative dimensional level.

In regards to the managerial practices, the findings of this study could also have some significant implications for the practitioners. First, the model developed could serve as a decision-making tool, which can support managerial decisions on the initiatives of integrations in a particular segment of supply chain; on the intended investment in upgrading with the industry-4.0; and on the effort to enhance the market responsiveness. All too often, managerial decisions and subsequent actions are taken in complete isolation, ignoring the interplay of those constructive factors. Second, the results showing the different moderating effects on SCI can guide the practi-

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tioners on prioritising their efforts to ensure the resources are mobilised optimally. Our results indicate that in order to reap the maximum benefit, managerial efforts on SCI must be prioritised first to the area of downstream integration, and then internal integration and finally to the upstream integration, given that a discernible level of industry-4.0 has been a contextualised factor. Third, the finding suggests that the managerial effort on upgrading the level of industry-4.0 will, according to the model developed, directly and positively promote the SCR, and more so in the downstream segment.

6. Conclusions and Limitations

This research adds to the concurrent literature some empirical exploration as to how Industry-4.0 has reshaped today's manufacturing industry in a global scale, and provides better understanding on how its resultant business impact can be interpreted more rigorously through the perspective of information process theory. In particular, a cohesive conceptual framework capturing 7 hypotheses has been developed and tested based on the empirical data collected from the electronics industry in China. The key contribution of this research can be judged from the conceptual model of the moderating effect of industry-4.0 onto the causal relationship between the SCI and the level of SC responsiveness. This research not only theorises an emerging industrial shift led by industry-4.0 across the world today, but also provides some informed guidance to the decision-makers as well as practitioners on how to better harness their SC responsiveness with industry-4.0. In view of the research developments on the long path of continuing evolution of supply chain management, a new step forward may have just been accomplished.

Limitations of this research, however, are unavoidable. Future research could address the joint moderating effects of two or more exogenous factors, although there is no definitive logic that the results of two or more factors will necessarily negate the results of a single factor analysis. Also, it might be useful to explore the impact of Industry 4.0 across different industry sectors and different geopolitical locations to capture a more complete picture.

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