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Integrator's Coordination on Technological Innovation Performance in China: The Dual Moderating Role of Environmental Dynamism

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Received: 13 December 2019; Accepted: 27 December 2019; Published: 30 December 2019

Abstract: As the backbone of national strategic development, Complex Product Systems (CoPS) have made great achievements in China, the world's largest demand market and second largest economy. However, their further development is challenged by the dynamic environment, including the ongoing Sino-US trade friction, for example. The aim of this research is to investigate the influence of the dynamic external environment on CoPS innovation. Based on contingency theory, this study identifies and investigates the moderating effects of technological and market dynamism on the relationship between the integrator's coordination and its technological innovation performance. Using survey data from 209 CoPS integrator enterprises in China, the findings show that (1) the positive effect of an integrator's coordination on technological innovation performance is strengthened by technological dynamism, while (2) weakened by market dynamism. In addition, (3) the technological dynamism acts as a higher-order moderating role in inhibiting the negative moderating effect of market dynamism on the main effect in general. Furthermore, (4) an unexpected but inspiring finding shows that the integrator's coordination facilitates innovation most when both the technology and market dimensions are highly dynamic. This study may indicate that managerial recognition may have significant influence on enterprise's behavior.

Keywords: integrator's coordination; technological innovation performance; technological dynamism; market dynamism; Complex Product Systems (CoPS)

1. Introduction

Since 2006, Complex Product Systems (CoPS), as the backbone of national strategic development [1,2], have been emphasized in China, the world's largest demand market and second largest economy. Among the implementations, the C919 finished its maiden flight in 2007, allowing China to be ranked in the top 3 in the airline industry in the world. Meanwhile, high-speed trains have been exported to many countries worldwide. Notably, it is under the highly dynamic environments both at home and abroad that China makes these achievements by persisting with rapid technology developments [3]. The sources of the international dynamism include the industrial Internet plus, intelligent manufacturing, and the Sino-US trade friction. In particular, the trade friction affects both the technology side by constricting China and the market side by limiting its go-global strategy mainly to America and Europe. Furthermore, the internal sources are mainly from the market dimensions, such as supply-side reforms or economic structural adjustments, where the clients' preferences change or insufficient demand will finally affect capital goods innovation and production on the upper side of the supply chain. Faced with the above environmental dynamism mainly from the technological

and market dimensions, CoPS innovation in China experiences a much more dynamic and severe environment compared with other international economies.

While early CoPS innovation studies have been mainly examined under the context of more developed economies [4,5], the amount of CoPS research in developing countries has been increasing [6,7] in recent years. For instance, Naghizadeh et al. (2017) examined the necessary capabilities of the integrator and its structure of the innovation network in Iranian firms during the airplane design stage in addressing the challenging issue of integration among the main project players [8]. However, studies in increasingly important Chinese contexts have not received enough attention compared to its extraordinary achievements.

Moreover, as one extensive stream of innovation theory [7], the existing CoPS literature are mainly based on the classical CoPS theoretical framework represented by Davies and Hobday [4], and focus on the internals of the complex and highly interdependent system [5,9], exploring the antecedents and process of CoPS innovation [10,11]. For example, Mondragon and Mondragon (2018) emphasized the integrator's role in managing a CoPS project under different types of modular architectures during innovation activities [12]. Gholz et al. (2018) explored the supply chains for three major US weapon systems using the case study method to examine how systems integrators balance between the economies-of-scope benefits of general-purpose technologies and the benefits of horizontal supplier specialization [13].

However, one recent study has called for a more macro view of investigation in the field of CoPS [7] to better understand the changes and new trends in these industries. From this perspective, the forces from external environments are not sufficiently concerned in CoPS, especially under current dynamic environment that is beyond the degree of complexity and uncertainty in more advanced economies. Although some conceptual and qualitative studies regarding the role external environments have played in investigating CoPS innovation process [14], a more fine-grained understanding of this contingent external environmental condition as a multiple dimension variable is scant [15].

To explore the impact of the external environment in depth, this study first extracts the integrator's coordination as the core dimension reflecting the nature of the compatibility of the technologies and functions across various CoPS modules [16] and the underlying joint innovation effort with its key suppliers, which has also been highlighted as one critical characteristic of CoPS in previous studies [7]. Second, it distinguishes two critical dynamic sources as technological and market dynamism in the CoPS context, based on contingency theory. In addition, the moderating effects of technological and market dynamism and their combined moderating role on the relationship between the integrator's coordination and its technological innovation performance are explored and verified using survey data from 209 Chinese CoPS integrator enterprises collected in the latter half of 2018, during which period the trade friction started showing its profound influence.

Our study contributes to the existing literature in the following aspects. First, we verify the positive linear relationship between the integrator's coordination activities and its technological innovation performance in CoPS, highlighting the prominent role that the integrator plays in the integrator-dominant modular innovation mode. Therefore, managers in CoPS integrator enterprises are encouraged to put more emphasis on establishing superior coordination capability in a variety of ways to increase the flexibility and efficiency of the CoPS project [9]. Second, this study deepens our understanding of the role of environmental dynamism in a more fine-grained way. Although the influence of a dynamic and uncertain environment in the CoPS context has been previously discussed, the distinguished impact and the underlying logic of its sub-dimensional sources are unclear. Third, this research extends the CoPS innovation literature in developing countries by extending the previous research via an empirical study of China. The unexpected but inspiring finding indicates that in the most dynamic and seemingly desperate situation, the potential of CoPS enterprises in China can be inspired to provide the greatest contribution to CoPS innovation.

The remainder of this paper is divided into five parts. Section 2 develops our theoretical hypotheses. Section 3 presents the variables adopted and data collected. Section 4 exhibits our empirical findings.

In Section 5, we discuss the unexpected but inspiring results and provide theoretical contributions and managerial implications. Finally, in Section 6, the paper is concluded by providing a summary, the limitations of this research, and future research recommendations.

2. Research Context and Hypothesis Development

2.1. Research Context

2.1.1. Integrator's Coordination in the Context of CoPS Innovation

CoPS refer to one-off projects of major complex capital goods customized to meet the requirements of its clients [17]. As the backbone of national strategic development, CoPS is critical in shaping and enabling modern technological, economic progress [7], and national competitiveness improvement [1,2]. Therefore, a fairly large number of scholars are motivated to study CoPS and its innovation [8], making CoPS innovation one extensive stream of innovation theory [7], because of its vital importance. Since then, research on CoPS innovation has increased in both more advanced countries [17] and latecomer economies [2], mainly from a micro perspective of the system [7]. As every CoPS project is customized and unique, no innovative solutions that already exist can fit and thus solve technical problems. Hence, the management of the complexity in various aspects makes CoPS innovation a challenging task for the integrator [4].

Innovation in CoPS adopts a low-volume customization mode with the integrator in a dominant position. Therefore, the production process is also its innovation process. Among the numerous studies focusing on the antecedents of CoPS innovation, the compatibility of the technologies and functions across modules [16], with the underlying coordination effort made by the integrator to work jointly with its various key suppliers, is the far more fundamental and critical factor that contributes to the success of CoPS innovation, especially in the CoPS context of highly interdependent tasks and closely coupled technologies [18]. In this vein, the lean [19–21] and agile [22,23] manufacturing practices share the same core dimension as coordination with CoPS innovation in improving the efficiency of productive and innovative activities.

To make the integrator's coordination more important and complex in the CoPS context, the integrator's coordination is much more challenging [24] compared to other mass production contexts due to the following reasons: (1) complexity and difficulties such as higher interdependency among the closely coupled technologies [18] and the large-scale supplier network; (2) higher level of specialization under the modular innovation mode [25], which may underestimate the interrelationships between tasks and the importance of coordination activities [26] and create new barriers to understanding each other's work [27]; also (3) the uneven development of various technological fields [26,28].

In this research, the integrator's coordination refers to "the integration of each module of the system by the integrator under conditions of task interdependence and complexity to achieve innovative goals jointly with its key suppliers" [24,29] in the inter-organizational context of CoPS innovation [30,31]. During the interactive process [32], it involves the integrator's specification and operation of information-sharing, decision-making, and feedback mechanisms in the supply chain relationship to unify and bring order to key suppliers' efforts [12,33] and to allocate their resources in productive ways [30,34].

2.1.2. Environmental Conditions

To test the contingent influence of the external environment, the contingency approach assumes that there is no "one best way" to structure or strategize, nor is there one best format for daily operations. The success of one enterprise depends on the alignment of several factors. When the factors are aligned, firms experience higher performance than when they are not [35]. Mintzberg (1989) created four dimensions to assess the environment: dynamism, complexity, diversity, and hostility. Among these dimensions, dynamism, which is identified as the rate and unpredictability of changes in

an organizational environment, has been shown to have a more significant impact on innovation [36]. This makes sense because rapid changes and uncertainty require quick organizational responses and adaptation through innovation [35,37,38], which is especially critical during the long duration in CoPS innovation.

Previous studies have shown that environmental dynamism is a multidimensional concept [39,40] in which each dimension may have a distinguished influence. In this research, technological dynamism and market instability [39] are recognized in the CoPS context. Among them, technological dynamism refers to the rate and unpredictability of the changes in technology within the industry [38,41], emphasizing the velocity of uncertainty and the acceleration of technological knowledge updating [41], which is a major challenge for technology-intensive CoPS enterprises. It is worth mentioning that technological dynamism reflects the state of “technology competition” among the oligopolistic integrators since it is the result of the interaction between the focal integrator and its competitors. Therefore, technological dimension exhibits a unique characteristic in the CoPS industry.

Meanwhile, market dynamism is defined in a broader way as the rate and unpredictability of changes in the non-technological social aspects of the external environment, reflecting the rate of changes in a client’s demand or preferences, and the more fundamental economic structural reform and international trade situation such as the Sino-US trade friction [42] in CoPS. This is because under the long production duration of the make-to-order mode in CoPS innovation, clients cannot easily change their orders. Instead, it is the economic and international trade situations that are the underlying driving forces that impact the behavior of both the integrator and its key suppliers. Furthermore, this study argues that these two sources of dynamism have different influencing logics and effects on coordinating activities and innovation in CoPS. Understanding these two aspects of environmental dynamism is helpful in avoiding potential troubles and conflicts that may occur in the future.

2.2. *The Effect of Integrator’s Coordination on Its Technological Innovation Performance in CoPS*

This paper argues that the integrator’s coordination has a positive effect on its technological innovation performance in the CoPS context.

First, a convergent goal, mutual understanding and the capability of joint action, is the precondition ensuring the success of innovation activities [29]. However, in a collaborative relationship, coordination difficulty and failure usually stem from the cognitive limitations of those who design and implement coordination mechanisms [30]. Due to cognitive limitations, individuals’ ability to fully recognize, project, and adjust to the impacts of different types and levels of interdependence among tasks, roles, and modules is restrained [25,30]. To avoid the above bounded rationality, architectural innovation decisions and tasks are performed by the assistance and joint work of all participants, while modular innovation decisions and tasks are mainly done by the key modular suppliers who are given high autonomy. Therefore, the whole project is processed with the integrator in the leading and supervisory position, based on the authority from a formal contract and the integrator’s understanding of the overall system [28]. Under this joint contribution method, key suppliers’ professional technological knowledge and capabilities can be fully used to facilitate the CoPS innovation process in a more synergistic way [30].

Second, under the modular innovation mode in CoPS, the integrator’s coordination improves its innovation efficiency and effectiveness. We illustrate this by looking at the three main innovation stages in CoPS. In the modular design stage, by conducting joint design with its suppliers, the integrator maximally uses its partners’ professional technology capabilities and their predictions on future development, securing the technological compatibility [16,32] and “backward consistency” [28] between modules. During the paralleled module innovation stage [16], the key suppliers’ innovation activities, schedules and processes are supervised [43,44] for process control. The feedback or suggested modifications will be addressed in a timely manner by the integrator to avoid any flaws. In fact, the information exchange and feedback channels are highly sufficient and efficient among CoPS modules. For example, Chrysler has established its communication routines with its suppliers, such

as face-to-face meetings and daily phone calls [45]. After the partially optimal solution of individual modules are completed [32,46,47], the integrator assumes the duty of conducting the system integration process with its key suppliers to make the whole system function well. However, the nonlinear iterative nature of technological development [28,46] during this process makes it not a simple assembly process, but a process of technical analysis and joint modification [16,32] which requires the integrator to systematically think and test together with its key suppliers.

Therefore, we propose the following hypothesis:

Hypothesis 1 (H1). *The CoPS integrator's coordination has a positive effect on its technological innovation performance.*

2.3. The Moderating Effect of Environmental Dynamism

2.3.1. The Moderating Effect of Technological Dynamism

Technological dynamism is an integral dimension of environmental dynamism. We argue that higher technological dynamism facilitates the impact of the integrator's coordination on promoting technological innovation performance at least in the Chinese context for three reasons. First, compared with the low technological dynamism situation, in a highly dynamic environment, technological changes are the only thing that will not change. Therefore, both the integrator and its complementary key suppliers are more willing to focus on R&D activities and are more prepared for the rapid changing technological development [48].

Second, though technologies within the industry are frequently updated, the flexibility enabled by the modularized coordination approach makes it possible for the integrator and its key suppliers to quickly adjust both their resource allocation and behaviors according to external technological changes [9]. In addition, the higher level of specialization in modular innovation also enables the integrator to test new technical solutions and thus realize recombination and innovation [49] by conducting numerous experimentations, and learning by doing [50] jointly with its key suppliers in a more flexible and efficient way [9,51]. Third, as the professionals from both the integrator and its key suppliers have been engaged in CoPS related industries for a long time, they have rich experience and a sense of direction regarding the technological development in the future. Therefore, the integrator has a higher chance to reserve resources and prepare for the changes in advance.

Therefore, we propose the following:

Hypothesis 2 (H2). *Technological dynamism strengthens the relationship between the integrator's coordination and technological innovation performance.*

2.3.2. The Moderating Effect of Market Dynamism

Market dynamism is another key dimension of environmental dynamism that will create discontinuities [52], or bring more uncertainty and risk to enterprises according to previous studies [53,54]. In this paper, we argue that under high market dynamism, the integrator's coordination will have a lower effect on technological innovation performance, mainly for three reasons.

First, under the economic structural adjustment process in China, insufficient demand for end users will influence the value chain up to capital goods innovation and production, which will cause CoPS orders to decrease. In addition, during the long innovation duration in CoPS, the client's probability of cancelling or postponing their orders may increase under higher market uncertainty. Once this project is paused, it is difficult to find a new buyer for these highly customized products in a relatively short time, leaving the project at stake.

Second, under market structural changes, the previously balanced right-obligation relationship between the integrator and its key suppliers may become dis-equilibrated, which will lead to the integrator losing control over its suppliers, and may even induce opportunistic behaviors in key

suppliers, such as withdrawing extraordinary personnel that were previously involved in this project, shoddy raw materials [55], or other types of conflicts, therefore exacerbating the integrator's coordination difficulty.

Third, the frequently changing international trade situation makes it harder for the integrator to predict its trend. Additionally, a severer and more restrictive trade policy may limit the potential orders from abroad, and restrain the collaborative potential for the integrator to work with its existing international suppliers, therefore making the previously accumulated knowledge and experience embedded in the relationship useless [49,50]. Moreover, the newly established suppliers are unable to easily meet all the customized requirements for a CoPS project in a short time period. Thus, the integrator will have to disperse more effort and time to help their new partners. In summary, under dynamic market circumstances, it becomes harder for the integrator to achieve synchronization and flexibility [50] with its key suppliers [30,36] in CoPS innovation.

Therefore, we propose the following:

Hypothesis 3 (H3). *Market dynamism weakens the positive relationship between the integrator's coordination and technological innovation performance.*

2.3.3. The Dual Moderating Effect of Market and Technological Dynamism

In the real world, it is the combined effects of the external environment that influence an enterprise's operation and its outcomes. In this vein, it is the interaction of the two environmental dynamism sources identified in this research that has a more sophisticated influence on an integrator's innovation activities and its final performance in the CoPS context. Technology is the fundamental power that supports economic and social development. Specifically, under current transition of technological catch-up into technological surpassing in China [2,3], technology updates and development have been highly emphasized and encouraged in the Chinese context, especially in the CoPS industry. Therefore, this paper argues that technological dynamism acts as a more fundamental external factor that will weaken the inhibitory moderating effect of market dynamism on the relationship between an integrator's coordination capability and the technological innovation performance in CoPS. There are three reasons supporting this point.

First, while the integrator's available resources for allocation and its possibility for joint action with key suppliers are constrained by the dynamic market, the call for conducting successful and efficient R&D activities requires the integrator to improve its innovation capability and efficiency [49] with limited suppliers using methods such as reorganizing operational routines and processes in a more simplified and flexible way [55]. Second, based on their complementary interdependency, the integrator and its key suppliers' enthusiasm have been further simulated under the severe social environment. Therefore, they will all strive to fully understand the characteristics of the existing and new technology to meet the functional requirements of the CoPS with respect to both their breadth and depth. Third, the deeply embedded R&D network and reciprocal relationships enable the collaborators to provide more substantial supports to help each other, in forms such as more specific asset investments, loans, etc., once any project member runs into financial or other operational difficulties [37,38].

Therefore, we propose the following:

Hypothesis 4 (H4). *The technological dynamism will inhibit the negative moderating role that market dynamism has on the relationship between the integrator's coordination and technological innovation performance in the CoPS context.*

Overall, we develop a conceptual model illustrated in Figure 1.

Figure 1. Theoretical model.

3. Research Methods

3.1. Data Collection and Sample

The data were collected by a perceptual survey from July to November 2018, during which the Sino-US trade friction has become severer and shown its influence. The limited direct access to target respondents and their reluctance to respond to questionnaires has caused a poor response rate when adopting random sampling in China, similar to the situation in the construction industry [56]. This situation is even severer in the CoPS industry due to the smaller number of enterprises and more restrictive safety concerns and regulations. Thus, this study adopted the nonprobability convenience sampling method, which is effective in improving response rates and has been widely used in the construction industry [56].

We collected information about the potential enterprises from the website of professional conferences, forums, or expos, also through communication with the organizers and the participants. For the expos, the enterprises exhibit their profile publicly, so we can get relevant information with ease. Furthermore, because these are precious opportunities for us to collect data, we have a group of postgraduate students and one PhD candidate in our research team to collect data on site, to guarantee the validity and improve the efficiency. These volunteers are divided into several groups and conduct the survey simultaneously. Once we get permission from the potential respondents, we ask them to answer our questions face to face. In this way, we can explain to them any queries or misunderstandings they have about our items and get relatively high-quality data.

The potential respondents are from integrator enterprises in CoPS, who are mainly senior and middle managers or experienced professionals in departments such as supply chain management, engineering manufacturing, or R&D departments. People from these positions usually have a good understanding of the relationship with their key suppliers. The respondents were asked to answer the questions regarding the collaborative relationship in one particular current or recently completed project.

In this survey, we only ask the respondents to answer their positions and departments to decrease the potential bias or concern. In addition, the reason we ask this question is that we think it is the most important indicator reflecting the validity of this questionnaire. Therefore, this questionnaire does not require detailed information about the respondents, project names, or construction duration. Additionally, a declaration is made ensuring that their information will be kept confidential.

Following prior studies [57], the items in this questionnaire were mainly adopted from existing studies, and the standard back-translation process was conducted to guarantee the accuracy of this survey. Afterwards, we pretested the survey instrument with five experts who are also senior managers in different CoPS enterprises. These experts were asked to comment on the readability, structure, and ambiguity of the questionnaire. We then formed our final questionnaire based on the suggestions and feedback that we received from these experts (see Table 1).

From July to November 2018, we conducted the final survey mainly by attending several conferences, professional forums, and expos, including the 13th China International Die Casting Congress (and Expo) in Shanghai in July 2018 (some of the delegates attending this conference and symposium are senior or middle managers in CoPS enterprises), the 18th China International Equipment Manufacturing Exposition held in Shenyang, Liaoning Province in September 2018, which is one of the largest Expos in China with more than 1000 CoPS and related enterprises participating, and the Third Equipment Development Project Management Forum in Hangzhou, Zhejiang Province in November, 2018, where more than 100 managers from CoPS industry enterprises attended. In addition, the practitioners in the CoPS industry who are friends, alumni, or are acquainted with the authors were also asked for their assistance in sending questionnaires.

Through the above approaches, 400 questionnaires were sent out, and 246 were returned. After removing 37 invalid surveys, 209 valid responses were obtained, for an effective response rate of 52.25%. Moreover, these diverse sample sources with respect to both geography and industry guaranteed the diversity of the projects and respondents. The samples in this research include both the enterprises from traditionally three northeastern provinces, like Shenyang Blower Works Group Corporation, TBEA Co., Ltd., SIASUN, SHENYANG YUANDA ENTERPRISE GROUP, Northern Heavy Industry Group Co., Ltd., and the enterprises from Yangtze river delta, Pearl river delta and other geographic location of China, like DERATECH, Jiangsu Zhenjiang Shipyard, (Group) Co., Ltd., HAN'S LASER, SANY HEAVY INDUSTRY CO., LTD., RAILWAY CONSTRUCTION HEAVY INDUSTRY Co., Ltd.

The sample features include enterprise size, industry distribution, respondents' information, enterprise duration, proportion of R&D personnel, enterprise ownership, industrial ranking of R&D investment, and the enterprise's geographical location. Among them, 28.71% of the enterprises have from 100 to 499 employees, 78.95% of the enterprises are in the equipment manufacturing industry, 20.09% of the respondents are middle managers/experienced professionals in the engineering department, 28.71% of the enterprises have existed from 11 to 15 years, 33.49% of the enterprises have from 10% to 20% of their personnel working in R&D, 77.99% are private enterprises, 45.93% of the enterprises have R&D investment that is slightly higher than that of their competitors, and 44.98% of the enterprises are in the Yangtze river delta area. Table 2 shows the descriptive statistics of the respondents.

3.2. Measures

In this study, items were drawn from the existing literature and adapted to the CoPS context. They were measured on a five-point Likert scale, and they included items that measured the integrator's coordination [58,59], technological dynamism [60], market dynamism [61], and technological innovation performance [62].

3.2.1. Dependent Variable

There is much research that involves the measurement of innovation performance [34]. However, various innovative strategies and divergent research contexts have led to differentiated measurements of technological innovation performance. In our work, the technological innovation performance measurement was adopted from Chen Jin et al. (2008) [62], using three items. The scale captured the extent to which the integrator can shorten its product development and production time or extend the life-cycle of the product, make technological progress, and better improve its innovation success rate by working with key suppliers.

3.2.2. Independent Variable

Adopted from Whipple, Wiedmer et al. (2015), and Schreiner, Kale, et al. (2009) [58,59], the integrator's coordination (COOR) reflects the integrator's coordination when working with its key suppliers in CoPS project. Four items were adopted to measure the extent to which the integrator will learn from its previous collaborative experience, identify and resolve conflicts, and establish internal and cross-organizational processes to monitor and manage the collaborative process with key suppliers.

Table 1. Construct measurement and confirmatory factor analysis.

Construct and Measuring Items	CITC	SFL
Integrator coordination effort (Cronbach's $\alpha = 0.816$; AVE = 0.530; CR = 0.8183).		
COR1: We will learn from previous experience working with key suppliers.	0.633	0.74
COR2: We will identify and resolve conflicts arising from cooperation with key suppliers.	0.650	0.74
COR3: Processes within the organization will be established to monitor and manage the collaborative process with key suppliers.	0.587	0.68
COR4: Coordination mechanisms will be established among enterprises to supervise and manage the cooperation process with key suppliers.	0.685	0.75
Integrator technological innovation performance (Cronbach's $\alpha = 0.809$; AVE = 0.5916; CR = 0.8119)		
TIP1: Work with key suppliers helps to shorten the product development, production time, or extend the life of the product.	0.614	0.68
TIP2: Work with key suppliers helps us advance in technology.	0.718	0.82
TIP3: Work with key suppliers contributes to the accumulation of technology to improve our enterprise internal innovation success rate.	0.646	0.80
Market dynamism (Cronbach's $\alpha = 0.748$; AVE = 0.5067; CR = 0.7540)		
M.D.1: Users continuously put forward new functional requirements for the product/system.	0.542	0.69
M.D.2: Competition for similar products in the market is fierce.	0.657	0.78
M.D.3: Policies related to project development are changing rapidly.	0.530	0.66
Technological dynamism (Cronbach's $\alpha = 0.862$; AVE = 0.6177; CR = 0.8657)		
T.D.1: How likely will major changes occur regarding functionality improvements during the next three years?	0.705	0.77
T.D.2: How likely will major changes occur regarding price/performance improvements during the next three years?	0.715	0.77
T.D.3: How likely will major changes occur regarding major product innovations during the next three years?	0.768	0.85
T.D.4: How likely will major changes occur regarding major manufacturing innovations during the next three years?	0.655	0.75
Model fit index		
$\chi^2/df = 2.123$; $p = 0.000$; RMSEA = 0.073, TLI = 0.917, CFI = 0.935, IFI = 0.936.		

Note: SFL = standardized factor loading; α = Cronbach's alpha; AVE = average variance extracted; CR = composite reliability.

Table 2. Sample characteristics.

Classification	Item	Number	Percentage (%)	Classification	Item	Number	Percentage (%)
Firm Size	<50	42	20.1	R&D personnel intensity	< 5%	16	7.66
	50–99	32	15.31		(5–10%)	31	14.83
	100–499	60	28.71		10–20%	70	33.49
	500–999	21	10.05		20–30%	39	18.66
	1000–4999	33	15.79		30–50%	39	18.66
	≥5000	21	10.05		>50%	14	6.7
Industry	EQUIP	165	78.95	Ownership	SOEs	24	11.48
	TRANS	9	14.83		PEs	163	77.99
	IT	4	4.31		FIEs	10	4.79
	Others	31	1.91		CREs	12	5.74
Respondent's information	Senior manager	40	19.14	Ranking of R&D investment within industry	Far higher	41	19.62
	MM/EP in SC	33	15.79		Little bit higher	96	45.93
	MM/EP in E	42	20.09		Middle level	57	27.27
	MM/EP in R&D	39	18.66		Little bit lower	13	6.22
	others	55	26.32		Far lower	2	0.96
Firm Age (Year)	≤5	39	18.66	Geographical Location	Northeast China	68	32.53
	6–10	37	17.7		Yangtze river delta	94	44.98
	11–15	60	28.71		Pearl river delta	19	9.09
	16–20	20	9.57		Others	28	13.40
	>20	53	25.36		Total	209	100%

Note: MM/EP represents middle manager/experienced professionals; SC = supply chain management department, E = engineering department, R&D = research and development department.

3.2.3. Moderating Variable

Technological dynamism (T.D.) was adopted from Kim, Park et al. (2010) [60], and it indicates the possibility that during the next three years, major changes will occur with respect to functionality improvements, price/performance improvements, product innovations, and manufacturing technology innovations. Meanwhile, market dynamism (M.D.) was adopted and modified from Lu, Yang, (2004) [61], and it reflects the changes in clients' requirements, competition intensity, and government policies.

3.2.4. Control Variables

Firm Age

Firm age has a comprehensive impact on enterprise performance. As with age increases, a firm's ability to adjust to the changes in its relationships and the external environment improves, which helps to increase the firm's final performance. Thus, this paper includes firm age as one control variable, which was calculated using the respondents' answer to the question "the year when our firm is established".

Firm Size

Larger integrators may have more sufficient resources and stronger capabilities for coordinated activities [55,63]. Thus, firm size may affect firm performance including its technological innovation performance. We obtained this information by asking "How many employees are there in our firm?" The logarithm of this figure was then calculated.

Industry Type

CoPS cover a wide range of industries in which the innovation activities and environmental situations may be different. The industries involved in this study were divided into four categories. They are equipment manufacturing (EQUIP), transportation (TRANS), telecommunication software (IT), and others, which are represented by dummy variables.

Cooperation Duration

The longer the duration of the relationship is, the deeper the collaborative partners' understanding is of each other. Therefore, they can conduct joint actions more smoothly and effectively [63]. We adopted the question "how long has our partnership lasted with the key supplier?" to measure the duration of the cooperative relationship.

Specific Assets

Relationship-specific assets are assets invested into a business relationship with high switching costs. Therefore, once such an asset is invested in a project, it can improve the commitment made by the parties [59] and avoid or eliminate opportunistic behavior. One single item, "the extent to which we will lose the investment related to the other party, if the partnership ends", was adopted in this paper.

The Importance of This CoPS Project to Key Suppliers

According to transaction cost theory, an unbalanced benefit and power relationship will cause opportunistic behavior that damages the collaborative relationship and its final performance [64]. In this paper, two control variables were adopted to control the importance of this CoPS project for key suppliers and the integrator. They are the percentage of the project undertaken by this key supplier compared to the whole project (measured by sum of money, and represented by Program's Percentage) and the proportion of the business with this integrator per year with respect to this key supplier's total annual business (represented by Key Supplier's Percentage).

Integrator's Technological Integration

A high knowledge absorption and integration capability is more conducive to improving collaborative innovation performance [65]. In this study, we adopted two questions, “we share the same innovation goal with the key suppliers” and “we can combine knowledge in different technological fields”, to reflect the extent of the integrator's technological knowledge integration activities.

3.3. Reliability, Validity, and Common Method Variance

The following measures are taken to ensure the data reliability and validity in this study. First, we mainly adopted previously validated measurement items to ensure the validity of the measures. Moreover, we used Cronbach's alpha and the corrected item total correlation (CITC) to assess the reliability of the multi-item constructs. As the results in Table 1 show, the Cronbach's alphas of each individual construct are 0.748–0.862 and are all above the threshold of 0.7. In addition, all the corrected item total correlation (CITC) values are between 0.530–0.768 and are all greater than the threshold of 0.5. Therefore, the scale for the variables suggests an acceptable reliability. See Table 1 for more details.

Second, the results of the confirmatory factor analysis show that the model fits the data well. Table 1 also shows that all factors are significantly loaded on their corresponding latent variables with the construct reliability (CR) greater than 0.7 and the average variance extracted (AVE) values of all the variables greater than 0.5. All above indicators provide evidence for sound convergent validity. In addition, Table 3 of the correlation analysis shows satisfactory results for the discriminant validity by indicating that the square roots of the AVEs on the diagonal are greater than the correlation coefficients in the same lines and columns.

In this paper, the following measures were taken to reduce the possibility of and the concern regarding common method variance (CMV) when perceptual data were collected by the survey method. First, for process control, to reduce potential respondents' concerns, we explained to the respondents that this questionnaire was for academic research only and that all these questionnaires were anonymous in order to reduce the social desirability problem. Second, the dependent and independent variables are located separately on the questionnaire. Third, we made the statements on the final questionnaire as easy and concise to understand as possible. With respect to statistical control, we implemented two statistical tests. First, we conducted a Harman's single-factor test. The results indicated that the first component accounted for less than the threshold of 40%, suggesting that no single factor can explain most of the variation in the data obtained from this survey. Second, the results of the confirmatory factor analysis for the single-factor model with all four constructs' items loaded in one construct showed an unsatisfactory model fit ($\chi^2/df = 8.710$, RMSEA = 0.193, TLI = 0.429, CFI = 0.517, and IFI = 0.522), indicating that the four constructs in this study did not support the single-factor model [66]. The results of the above two statistical tests all show that CMV was not a serious concern in this study.

Table 3. Result of correlation analysis.

	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. TIP	3.89	0.819	0.769													
2. COOR	4.086	0.712	0.550 ***	0.728												
3. M.D.	3.54	0.866	0.181 **	0.373 ***	0.712											
4. T.D.	3.91	0.858	0.185 **	0.299 ***	0.407 ***	0.786										
5. Firm Age	17.21	17.886	−0.087	−0.043	−0.069	−0.188 **	1									
6. Firm Size	2.42	0.928	−0.038	0.058	0.026	−0.268 ***	0.364 ***	1								
7. Coop_Duration	3.39	1.497	0.044	0.111	−0.007	−0.175 *	0.309 ***	0.310 ***	1							
8. Specific Asset	3.10	1.201	0.237 ***	0.260 ***	0.266 ***	0.100	0.100	0.050	0.102	1						
9. Program's Percentage	3.61	1.096	0.148 *	0.084	−0.057	−0.040	−0.131 †	0.017	−0.029	−0.008	1					
10. Key Supplier's Percentage	2.80	1.064	0.090	0.117 †	0.027	0.061	−0.006	0.037	0.086	0.308 ***	0.431 ***	1				
11. EQUIP	0.79	0.409	−0.028	−0.024	0.080	0.143 *	0.035	−0.006	0.120 †	0.178 **	−0.067	0.057	1			
12. TRANS	0.04	0.203	−0.040	−0.084	0.031	−0.103	0.116 †	0.158 *	0.039	−0.056	−0.204 **	−0.071	−0.411 ***	1		
13. IT	0.02	0.137	−0.110	0.008	−0.061	−0.027	−0.076	−0.026	−0.060	−0.040	−0.078	−0.072	−0.271 ***	−0.030	1	
14. Technological Integration	4.13	0.696	0.420 ***	0.430 ***	0.348 ***	0.439 ***	−0.208 **	−0.121 †	−0.078	0.088	0.079	0.001	0.083	−0.126 †	−0.052	1

Pearson correlation; *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$. The data of the diagonal (in **bold**) are the square root of AVE (average variance extracted) of the construct.

4. Regression Analysis Results

Table 3 presents the means, standard deviations, and correlation coefficients of the variables we examined in this paper. The results indicated that integrator's coordination, technological dynamism, and market dynamism were significantly correlated with the integrator's technological innovation performance.

Table 4 exhibits the results of our hypothesis testing using hierarchical regression analysis in Stata15. To reduce the potential concern of multicollinearity, we mean-centralized the independent variables and the moderators before creating the interaction term. Moreover, to further eliminate the multicollinearity concern regarding the variables, we conducted a variance inflation factor (VIF) test in this paper, and the results showed that the maximum value of the VIF was 2.19, which is far below the threshold of 5. Therefore, the multicollinearity problem is not a concern in this study.

4.1. Direct Effect

The regression results are listed in Table 4. Model 1 is the baseline model, which only contains the control variables and moderators. To test H1, we added the dependent variable—integrator's coordination—to Model 2. The result in Model 2 showed that the integrator's coordination has a positive effect on technological innovation performance ($\beta = 0.504, p < 0.001$). To further verify whether it is a linear relation, we added the squared term of the integrator's coordination in Model 3. The results showed that the coefficient was not statistically significant, indicating that the curved effect of the integrator's coordination on technological innovation performance is not supported. Therefore, H1 is supported.

4.2. Moderating Effect

To test the first-order moderating effect of technological and market dynamism respectively, in Model 4, the interaction term of technological dynamism and the integrator's coordination was added into the formula. The result showed that the interaction coefficient between the interaction term and technological innovation performance is positive ($\beta = 0.125, p < 0.1$). Thus, H2 is proved, and technological dynamism has a positive moderating effect on the main effect. In Model 5, the interaction term of market dynamism and the integrator's coordination was added based on Model 4. The results in Model 5 showed that the interaction term between market dynamism and the integrator's coordination on technological innovation performance is negatively related to the technological innovation performance ($\beta = -0.145, p < 0.1$). Thus, H3 is also supported.

Finally, to examine the dual moderating effect of these two moderating variables, a three-way interaction term of technological dynamism, market dynamism, and the integrator's coordination and all their two-way interaction terms were added in Model 6. The regression results showed that the three-way interaction term and technological innovation performance were significantly positive ($\beta = 0.182, p < 0.05$). Thus, H4 is supported.

Table 4. Regression result.

VARIABLES	M1	M2	M3	M4	M5	M6
Control Variables						
Firm Age	−0.002 (−0.50)	−0.001 (−0.45)	−0.001 (−0.40)	−0.002 (−0.60)	−0.002 (−0.68)	−0.002 (−0.59)
Firm Size	−0.013 (−0.21)	−0.052 (−0.91)	−0.058 (−1.01)	−0.044 (−0.77)	−0.046 (−0.81)	−0.058 (−1.03)
Coop Duration	0.048 (1.29)	0.013 (0.38)	0.012 (0.36)	0.016 (0.47)	0.019 (0.56)	0.018 (0.53)
Specific Asset	0.155 *** (3.29)	0.100 ** (2.29)	0.102 ** (2.34)	0.091 ** (2.08)	0.090 ** (2.05)	0.097 ** (2.21)
Program's Percentage	0.087 (1.58)	0.076 (1.52)	0.079 (1.58)	0.081 (1.62)	0.076 (1.53)	0.089 * (1.77)
Key Supplier's Percentage	−0.031 (−0.55)	−0.037 (−0.72)	−0.034 (−0.65)	−0.036 (−0.70)	−0.034 (−0.66)	−0.040 (−0.78)
EQUIP	−0.277 * (−1.85)	−0.125 (−0.91)	−0.110 (−0.79)	−0.129 (−0.94)	−0.120 (−0.87)	−0.129 (−0.95)
TRANS	−0.054 (−0.18)	0.128 (0.48)	0.123 (0.46)	0.093 (0.35)	0.089 (0.33)	0.126 (0.48)
IT	−0.654 * (−1.66)	−0.677 * (−1.89)	−0.684 * (−1.92)	−0.653 * (−1.83)	−0.670 * (−1.89)	−0.672 * (−1.90)
Technological Integration	0.450 *** (5.34)	0.282 *** (3.48)	0.288 *** (3.56)	0.276 *** (3.43)	0.280 *** (3.50)	0.303 *** (3.77)
Market Dynamism	0.005 (0.07)	−0.049 (−0.77)	−0.047 (−0.74)	−0.055 (−0.87)	−0.065 (−1.03)	−0.101 (−1.56)
Technology Dynamism	0.019 (0.26)	−0.045 (−0.67)	−0.050 (−0.75)	−0.047 (−0.71)	−0.039 (−0.59)	−0.085 (−1.20)
Independent variable						
Integrator's Coordination		0.504 *** (6.47)	0.436 *** (4.76)	0.545 *** (6.71)	0.520 *** (6.33)	0.494 *** (5.81)

Table 4. Cont.

VARIABLES	M1	M2	M3	M4	M5	M6
Coordination $\times$ Sqr			−0.083 (−1.41)			
COOR $\times$ T.D.				0.125 * (1.69)	0.186 ** (2.28)	0.280 *** (3.02)
COOR $\times$ M.D.					−0.145 * (−1.73)	−0.089 (−0.99)
T.D. $\times$ M.D.						−0.047 (−0.76)
COOR $\times$ T.D. $\times$ M.D.						0.182 ** (2.06)
Constant	2.993 *** (7.54)	3.032 *** (8.39)	3.046 *** (8.45)	3.067 *** (8.52)	3.064 *** (8.55)	3.030 *** (8.41)
Observations	209	209	209	209	209	209
R-squared	0.256	0.388	0.394	0.397	0.406	0.419
r2_a	0.211	0.347	0.350	0.353	0.360	0.368
F	5.630 ***	9.495 ***	9.002 ***	9.105 ***	8.784 ***	8.109 ***

t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

To visually demonstrate the results, the interactive effects of these two moderating variables are drawn using the standard approach [67]. It is shown in Figure 2 that as technological dynamism increases, the integrator's coordination has a higher influence on its technological innovation performance. In contrast, Figure 3 shows that when market dynamism rises from low to high, the positive effect of the integrator's coordination on technological innovation performance is weakened.

Figure 2. Moderation effect of technological dynamism.

Figure 3. Moderation effect of market dynamism.

Furthermore, the dual moderating effect of the three-way interaction results are also drawn in Figure 4. We can see that when technological dynamism is relatively low and market dynamism is relatively high, the integrator's coordination has the lowest effect, with its influencing direction on technological innovation performance being negative. As technological dynamism increases or market dynamism decreases, the effect of the integrator's coordination in promoting innovation has been

strengthened. However, we have noticed an unexpected but inspiring situation from this figure, i.e., when both the technological and market dimensions are highly dynamic, the integrator's coordination contributes to technological innovation performance the most. We will further discuss the possible reasons for this situation below.

Figure 4. Dual moderation effect of technological and market dynamism.

5. Discussion

5.1. Discussion

This research emphasizes whether and how the external dynamic environment influences the complex innovation process in CoPS. Using 209 CoPS enterprises' data, this research verifies that the technological and market sources of dynamism have distinguished influential logics and impact directions. Additionally, there is a sophisticated interactive moderating effect on the relationship between the integrator's coordination and its technological innovation performance. In particular, technological dynamism positively moderates the above main effect, while market dynamism influences it in the opposite direction. Furthermore, the inhibitory moderating effect of technological dynamism as a higher-order moderating variable on the lower-order one of market dynamism is confirmed in this research. To see the dual moderating effect as a whole, the positive coefficient of the dual moderating term indicates that the influence from technological sources of dynamism may be stronger than that from market sources in coordinated innovation in CoPS context. In addition, at least two points of our findings on the dual moderating effect are worth noticing. First, most researchers argued that coordination is essential to collaboration success [68]. However, in this research, when both high market and low technological dynamism happen simultaneously, the integrator's coordination effort will have a negative impact on its innovation. It may indicate that under such a situation, coordination is unable to play its role, which verified the previous assertion that coordination may not necessarily lead to more benefits than costs [36].

Second, an unexpected but more inspiring finding is that when both technology and market dynamism are relatively high, the contribution of the integrator's coordination to technological innovation reaches its full potential. The possible reason is that in an extremely dynamic environment with both technology and market sources, the underlying logic of coordinated innovation may be transformed [69]. In particular, under such severe conditions with accelerated technological renewal and development, also with the concurrent great changes in both the domestic market due to market structural reforms and adjustments and the international market due to trade environment changes, it

may be that prospect theory has more influence on the cognition and behavior of the CoPS integrator and its key suppliers [70], compared with threat-rigidity theory [71].

We make these inferences based on the following facts and reasoning. In recent decades, China has experienced high-speed development and has made great achievements. Armed with previously successful experiences, the enterprises in China have confidence in going through this historical transition from technological catch-up to technological surpassing [2,3], especially for these CoPS enterprises in important strategic positions. Therefore, the severer the external situation, the higher the levels of cohesion and commitment will actively form among the integrator and its key suppliers when jointly conducting innovation activities and solving technical problems [48], rather than surrendering when faced with difficulties. Meanwhile, as a well-coordinated organization, the integrator will also conduct measures, such as downsizing, to construct a more synergetic and flexible cooperative project team [48], and minimize the restrictions of organizational inertia and stickiness [49] during innovation process. As a result, the seemingly disadvantageous market environment may become a great opportunity for CoPS innovation organizations to accelerate their developmental speeds and eliminate their desperation.

5.2. Theoretical Contribution

This research provides theoretical insights mainly in the following three areas. First, little research has empirically examined environmental dynamism's role in CoPS innovation activities [5], both in more advanced economies and developing ones, although the dynamic external environment is an important contingent factor influencing the long duration and complex CoPS innovation process. To deepen our understanding on the influence of the multidimensional environmental dynamism on CoPS innovation process, this work identifies and distinguishes two moderating conditions as technological and market dynamic sources based on contingency theory [15,39,72], responding to the call for more fine-grained analysis of external environments [15]. The opposite influencing logic of the above two dynamism sources and their sophisticated interactive effect verified in this paper provide in-depth insights on the boundary conditions of the integrator's coordinated innovation in the CoPS context.

Second, this research extends the literature on CoPS innovation from the perspective of coordination. While the integrator's coordination might be important to other industries too, their role in CoPS sectors is critical and irreplaceable [7]. In addition, while existing studies on new production innovation [12], innovation network [8,14], organization structure [4], lean [19–21] and agile [22,23] manufacturing and alliance management [16,30,59] have mainly emphasized the benefits of coordination in inter-organizational collaboration, under more complex context, higher level of coordinated activities are required to process the whole project smoothly [12]. It is exactly the case in the extreme complex context of CoPS innovation where the integrator shoulders the main responsibility for the coordinated activities. Furthermore, our finding that the role of coordination may be limited in certain conditions is in consistent with previous studies that the costs of coordination should also be considered [43,73]. Therefore, this research enriches the concept of coordination in the CoPS innovation context where the compatibility of numerous modules during CoPS innovation [16,74] and its underlying coordination effort are highly emphasized.

Finally, this research is the first one aimed at Chinese CoPS enterprises during this historical transition stage around the world, which makes significant contributions to the recent work on CoPS research in developing countries. While the CoPS literature is relatively mature, existing CoPS studies are mainly based on more advanced economies [12,13,75]. Over recent decades, the CoPS industry in China has experienced rapid growth and made fruitful achievements. Its further development has encountered more difficulties and challenges, including the influence from the external dynamic environment, with respect to both the technological and socially market sources [6]. In this vein, this research provides new insights about the sophisticated external environment for CoPS enterprises in Chinese.

5.3. Practical Implication

As inter-organizational flexibility and coordination become increasingly more important for CoPS projects [9] in the current dynamic environment, our study makes several meaningful implications for managers in the integrator enterprise. First, as with the prominent role the integrator shoulders in the integrator-dominant modular innovation mode, managers in CoPS integrator enterprises are encouraged to put more emphasis on establishing superior coordination capability through a variety of ways to increase the flexibility and efficiency of the CoPS project [9]. For example, one major task is to well understand the interdependence of the new tasks and their interactive influence [29]. Furthermore, we strongly recommend that managers in Chinese CoPS integrator enterprises carefully conduct environmental scanning and evaluate the influence that the external environment may have on CoPS innovation to better handle the fast-changing environment's influence. This is because different sources of environmental dynamism and their combined influence may have distinguished and sophisticated impacts on CoPS innovation [16].

Second, managers should have confidence in their innovation success during this historical opportunity and threat of the transition that China is experiencing. The unexpected but inspiring finding suggested that under the seemingly extremely dynamic and severe external environment, the outcome of the coordinated innovation in CoPS in China will maximize its potential. Therefore, the managerial team should stay flexible in dealing with any adjustment required during innovation process [29]. By continuing to pursue their innovation goals this way, the seemingly desperate situation will finally turn out to be a promoting driving force for CoPS integrators and their innovation activities in China.

6. Conclusions

CoPS development in China has been fruitful in recent decades. However, to get further developed, it will suffer more challenges and difficulties from both the inter-organizational level and from external environment aspects, such as economic structural adjustments, industrial regulations in China, and the Sino-US trade friction from the international environment. In this vein, this study empirically advances our understanding of whether and when an integrator's coordination facilitates its technological innovation performance in the CoPS context in China. Specifically, we have explored the moderating role of external environmental dynamism on the coordinated innovation process by distinguishing two sources of dynamism, namely the technology and the market dimension, based on contingency theory. Our research findings suggest that while technological dynamism has a positive moderating effect on the relationship between an integrator's coordination and its technological innovation performance in the CoPS industry in China, market dynamism has the opposite influence. In addition, their dual moderation effect gives a CoPS integrator confidence when pursuing innovation under the extremely dynamic environment situations in both the technological and market dimensions that China is currently experiencing.

Although our research makes significant contributions, certain limitations remain in this study for further exploration.

First, the unexpected and inspiring findings in this study under high dynamism in both the technological and market dimensions may be a new theoretical mechanism that is worth analyzing and verifying in a more detailed way in the future. Prospect theory and threat-rigidity theory may be nice perspectives to conduct further investigating on this topic.

Second, more fine-grained constructs of enterprise's behavior can be adopted to further analysis the impact from external environment. For example, lean manufacturing practice is critical dimension in enterprises' operation, as extraordinary lean practice can help bring a large amount of cost savings in the financial outcome, while agile manufacturing practice can improve flexibility for enterprises in dealing with this dynamic environment.

Third, since our findings were based on survey data collected in the CoPS industry in China, our results may be both industry- and country-specific. Therefore, it may not be suitable to generalize

our findings directly to other industries or developing contexts without further empirical testing. Nonetheless, the expansion of our research to broader contexts is also a meaningful topic.

In addition, data in this paper were collected in 2018, during which time the Sino–US trade friction had just begun to show its influence. To collect data reflecting the current situation of the relevant enterprises with well-designed theoretical model will be a precious opportunity for researchers interested in Chinese context.

Fourth, due to the difficulties in obtaining research samples for the CoPS field, the data in this paper only come from the CoPS integrator's side. Future studies should collect paired data from both sides to enhance the validity of the research conclusions.

Author Contributions: L.M.: data curation, formal analysis, investigation, methodology, and writing—original draft; J.L.: Conceptualization—original, writing—review, funding acquisition, project administration; C.G.: Conceptualization—current, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Philosophy and Social Science Foundation of China (No. 19BGL028).

Conflicts of Interest: The authors declare no conflict of interest.

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