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LINKING SUPPLY CHAIN NETWORK COMPLEXITY TO INTERDEPENDENCE AND RISK-ASSESSMENT: SCALE DEVELOPMENT AND EMPIRICAL INVESTIGATION

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Abstract. Concepts like supply chain network complexity, interdependence and risk assessment have been prominently discussed directly and indirectly in management literature over past decades and plenty of frameworks and conceptual prescriptive research works have been published contributing towards building the body of knowledge. However previous studies often lacked quantification of the findings. Consequently, the need for suitable scales becomes prominent for measuring those constructs to empirically support the conceptualized relationships. This paper expands the understanding of supply chain network complexity (SCNC) and also highlights its implications on interdependence (ID) between the actors and risk assessment (RAS) in transaction relationships. In doing so, SCNC and RAS are operationalized to understand how SCNC affects interdependence and risk assessment between the actors in the supply chain network. The contribution of this study lies in developing and validating multi-item scales for these constructs and empirically establishing the hypothesized relationships in the Indian context based on firm data collected using survey–based questionnaire. The methodology followed included structural equation modeling. The study findings indicate that SCNC had significant relationship with interdependence, which in turn significantly affected risk assessment. This study carries both academic and managerial implications and provides an empirically supported framework linking network complexity with the two key variables (ID and RAS), playing crucial roles in managerial decision making. This study contributes to the body of knowledge and aims at guiding managers in better understanding transaction relationships.

Keywords: supply chain, complexity, risk assessment, interdependence, scale development.

JEL Classification: C83, D22, D81, L14.

Introduction

As a buyer firm plans of strategizing its relationship with its major suppliers, a plethora of vital questions peep in the minds of the decision making managers: what are the pros and cons involved? How complex is the network environment? What will be the level of dependence? What are the alternatives? What is the risk involved? While searching for answers to these frequently asked questions, often one word keeps flashing in mind, 'network complexity'. The word "network complexity" nowadays has become a very common vocabulary in supply chain parlance and frequently heard in managerial discussions on network issues. It has been highlighted as a major breeding ground of supply chain issues and conflicting network wide partner relationships (Gilmore 2008; Bode, Wagner 2015). One of the most vital and omnipresent stumbling blocks that stares glaringly at the managers before such decision making is, how complex is the system or the process or the network in the question? Thus, network complexity has become inherent to today's business scenarios, which cannot be avoided; rather understanding the complexity involved and quantifying it becomes vital for making effective and viable decisions aimed at managing complexity. In modern business setting the competition for competitive advantage

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and excellence has progressed to the very next level where the competition is no longer between firms, rather between their respective supply chains. However, this does not undermine the fact that complexity and conflicting interest mark most of the supply chain network relationships. Thus the challenges that the supply chain managers face these days are also unique and are actually a mix of three streams of highly sensitive balancing blocks which the managers should carefully balance without underestimating any of them. Those three stumbling blocks that managers face and need to manage and balance are: complexity management, risk assessment and last but not the least understanding the interdependence of their own firm's processes on their partner firm's processes. However the understanding of network complexity, here after interchangeably also referred to as supply chain complexity or in a even generic sense supply chain network complexity, needs revisiting for a better clarity. Thus this paper aims at first establishing a rational framework linking those three stumbling blocks that managers face in course of their day to day supply chain management duties and then progresses to empirically validate the hypothesized relationships based on perceptions of the industry practitioners (i.e. the managers); thereby aiming at providing supply chain managers with a handy empirically proved understanding framework indicating how perception about supply chain network complexity impacts inter-dependence and risk assessment between partners in the network.

Extant literature highlights that complexity in the supply chain network is critical for understanding network transactions and relationships. Studies highlight that complexity impacts performance of the chain and also that of the individual network actors (Bode, Wagner 2015; Choi, Krause 2006; Waldrop 1992). Though, different studies have defined complexity from different perspectives, a clear and easily comprehendible working definition of supply chain network complexity remains lacking. So arises the need to propose an acceptable working definition and also develop a scale dealing with supply chain (SC) network complexity (Manuj, Sahin 2011; Milgate 2001). Extant studies took the view of SC network complexity as multi-dimensional and multi-faceted phenomenon affected by varied sources and described complexity from different perspectives: number of elements and subsystems (Bozarth *et al.* 2009; Manuj, Sahin 2011; Choi, Krause 2006; Choi, Hong 2002; Handfield, Nichols 1999) and high number of elements affecting the complexity and the supply chain network functioning in terms of disruptions (Chopra, Sodhi 2014; Bode, Wagner 2015); quality and nature of relationship (Lian, Laing 2004; Ferlie, Pettigrew 1996); Inter-relationship between network elements (Choi, Krause 2006; Wycisk *et al.* 2008; Johnsson *et al.* 2007); frequency of interaction (VanVactor 2011; Noorderhaven, Harzing 2009); degree of differentiation (Choi, Krause 2006; Burt, Doyle 1993), etc.

Few papers which particularly focus at different aspects of complexity are: Milgate (2001) describing supply related complexity from uncertainty, technological intricacy and organizational systems perspective; Choi, Krause (2006) from number of suppliers, differentiation among suppliers and relationship among suppliers perspective; Bozarth *et al.* (2009) discusses detailed and dynamic complexity while other contemporary papers have highlighted the multi-facets of quality of relationship, frequency and volume of interaction, number of entities, degree of differentiation and inter-relationship among entities while discussing complexity in healthcare perspective. Thus although much attention has been drawn, what lacks, is a unified definition of supply chain network complexity, a convenient consolidation of the complexity aspects. Even more importantly, the conceptualization of a supply chain network complexity construct and a multi-item scale for measuring network complexity remain wanting. Following Gilliam and Voss's (2013) procedure for construct definition development based on past literature, the definition for the constructs are developed in this study. Based on extant literature the preliminary definitions are developed and based on the definitions, the measurement items are generated, which are in turn subjected to judging by experts and professionals and also subjected to validity testing, finally followed by exploratory factor analysis the details of which are mentioned in methodology section; thereby aiming at reducing vagueness and ambiguity. In this study supply chain network complexity (SCNC) is defined as the extent of inter-relationship among the supply chain network partners/actors, their degree of differentiation in terms of practices, their frequency of interaction and their volume (i.e. numbers) in network (Bode, Wagner 2015; Bozarth *et al.* 2009; Handfield, Nichols 1999; Simon 1962; Choi, Krause 2006; VanVactor 2011; Noorderhaven, Harzing 2009; Milgate 2001; Prater *et al.* 2001; Meepetchdee, Shah 2007; Johnsson *et al.* 2007; Burt, Doyle 1993). In this study SCNC is investigated as an antecedent to two vital relationship and behavioral aspects of the network partners: interdependence (Kumar *et al.* 1995; Vijayasarathy 2010) and risk assessment (Tummala, Schoenherr 2011; Ha *et al.* 2011; Wagner, Bode 2006; Ellis *et al.* 2010). Interdependence and risk assessment are the two variables being introduced in the study as consequence of SCNC. Figure 1 shows the conceptual model. The rationale behind introducing these two constructs can be linked to theoretical underpinnings and key extant literature. Like most studies which have their basis deeply ingrained in the theoretical underpinnings, this study draws its inspiration from two related theories: relational exchange theory (Dyer, Singh 1998) and bilateral deterrence theory (Bacharach, Lawler 1981). Relational theories sees firms as social entities and thus highlights the vital influence or linkage between social constructs like trust, commitment, power, conflict, risk assessment, network complexity etc having controlling influence on interactions and exchanges. Dyer and Singh's (1998) relational view theory suggests that firm's critical resources can span firm boundaries and get embedded in inter-firm processes(routines) and interaction; thereby shifting the focus of prime interest to 'relationships'. Relational exchange theory highlights that cooperation, communication and trust plays pivotal role in exchanges and even at times surpasses formal contracts. In the study, the objective is to analyze the perceptual measures to understand how they affect the transactional norms. Many of those norms that are mentioned, gets affected by the different aspects of the complexity variable as discussed earlier and hence finds rational linkages, needing deeper probing. Herein comes the relevance of the theory can be linked. Another theory which can be indirectly linked is the bilateral-deterrence theory (Bacharach, Lawler 1981; Lawler, Bacharach 1987) which in a nut-shell suggests that one network entity's desire to engage in conflict depends largely on its understanding about the retaliation from the entities with which it involves in conflict and also the available alternatives it has, since retaliation poses a greater threat. Thus interdependence is an important measure for understanding each other's position and retaliation objectives. Greater the measure value, lesser should be the fear of conflict occurrence. As per the definition of the SCNC and the extant literature, complexity of the network entails the nature of bonding between entities, their number and inter-relationship ship is bound to affect the interdependence and also the eagerness for ensuring risk assessment in their transaction relationship. Extant literature highlights that interdependence involves how the network transaction partners perceive their dependence on each other and hence essentially involves both the buyer and supplier side (Vijayasarathy 2010; Kumar *et al.* 1995). This interdependence may be symmetric where both parties have equal dependence or asymmetric i.e. unequal level of dependency. In this study, interdependence is defined as the extent to which the supply chain network partners/actors depend on each other and are unable to replace each other for their transaction relationship (Vijayasarathy 2010; Kumar *et al.* 1995). Vijayasarathy (2010) gave an effective way of measuring interdependence using a summated scale involving respondent dependence and supplier dependence which also tackled the skewed dependence aspect by subtracting the absolute difference between the two dependence variables. This study adapts similar measures with modifications which are discussed in details in the measures section.

Risk assessment literature is in existence since a long time and extant conceptual research works highlights its relevance and importance in management context involving transactions and inter-actor relationships (Ha *et al.* 2011; Wagner, Bode 2006). Risk assessment has been portrayed as a vital building block of interaction among the network actors (Prahalad, Ramaswamy 2004). Different studies have discussed about risk in different perspectives. Ellis *et al.* (2010) discussed and empirically examined the link between supply disruption probability and magnitude with that of overall supply disruption risk. Using a single item scale for disruption risk they highlighted that a positive relationship existed between magnitude of disruption and probability of disruption with overall disruption risk. Further in a recent study Bode and Wagner (2015) linked upstream supply chain complexity drivers and supply chain disruption. Blackhurst *et al.* (2008) in their conceptual risk framework for supplier risk assessment indicated that risk as a whole is very generic and can be segregated as risk identification, assessment, decision-making and monitoring. Prahalad and Ramaswamy (2004) mentioned that risk assessment is one of the most vital aspects that decides the course of transaction relationships and is thus an integral building block of network-wide actor to actor relationship. In complex business scenarios, especially where options of switching between actors is high, where often frequency of interaction varies, and where the network entities remain inter-connected, assessment of risk becomes most vital because the strategies like transferring risk, taking risk, eliminating risk, reducing risk, etc that are implemented follow the risk assessment stage (Hallikas *et al.* 2004). The need for purchasing organizations to have superior risk assessment platform and techniques in place for superior business relationship with network actors have been highlighted by contemporary studies (Zsidin *et al.* 2004; Harland *et al.* 2003). However risk assessment literature lacks empirical support and also most studies are conceptual framework driven and mostly prescriptive in nature. Established scales, giving a fair understanding about risk assessment remain wanting. This study aims at plugging this gap and proposes a multi-item risk assessment scale and operationalizes that. Based on extant literature, in this study risk assessment (RAS) is defined as the extent to which the supply chain network partners/actors can make informed decisions by adequately assessing the stakes involved in their transaction relationship with network partners (Prahalad, Ramaswamy 2004; Tummala, Schoenherr 2011; Ha *et al.* 2011; Wagner, Bode 2006; Ellis *et al.* 2010).

1. Hypothesis development

In this study it is postulated that supply chain network complexity increases the extent of interdependence among the network partners/actors and also enhances the extent of risk assessment among the transacting network actors. The study also postulates that higher interdependence in turn should also foster greater extent of risk assessment among the network partners.

1.1. Supply chain network complexity and interdependence

Network Complexity is defined in terms of number of transacting actors, extent of inter-relationship among actors, degree of differentiation among them in terms of practices and also their frequency of interaction (Choi, Krause 2006; VanVactor 2011). Interdependence signifies the level of dependence of the buyer firm on the supplier firm and vice versa in terms of alternatives, ease of shifting from one set of partners to another, the cost involved etc. Usually when the number of actors on both fronts i.e. buyer and sellers are high which extant research characterizes as a complex network criteria, there remains a fear that the buyer or the seller can easily switch and hence they try to bind each other through firm specific investments aiming at increasing each other's onus in the relationship. Also in situation when the actors in the network are linked or related to one another closely then in case of a break-up in the transaction relationship, finding an alternative becomes difficult and this fosters moving into a state of higher dependence from both sides to secure such fallout. In case the degree of differentiation in practices is severely disparate the situation is complex as the one network actor cannot easily go in sync with the other partner with ease and hence through investments or contracts or binding systems try to enhance each other's dependence. When the interaction frequency is less, there remains scope of ambiguity and this leads to a complex situation and under this circumstances also fall out may occur. Thus when the supply chain network complexity is higher in order to secure future fallout in the transaction relationship, which might add high economic burden or implications, the network partners try to move into a stable relationship state which is marked by higher levels of interdependence. So it is hypothesized that:

H1. Supply chain network complexity has a positive effect on partner interdependence.

1.2. Supply chain network complexity and risk assessment

In the presence of complex network relationships an overall environment of uncertainty prevails where the network actors are often confused to open up and do business and often deter themselves from cooperating each other and try to play safe. Risk assessments (Prahalad, Ramaswamy 2004; Blackhurst *et al.* 2008; Ellis *et al.* 2010) plays a pivotal role in deciding the course of action for the downstream activities and concerns about informed decision making so as to completely understand the stakes involved in the transaction relationship. In scenarios of supply chain network complexity being on the higher side, the inherent uncertainty in the system remains at a higher level and gives more importance to even thorough understanding about the risks involved and assessing the consequences in the case of relationship catastrophe. Thus increased complexity levels should foster increased onus of risk assessment. So it is hypothesized that:

H2. Supply chain network complexity has a positive effect on partner risk assessment.

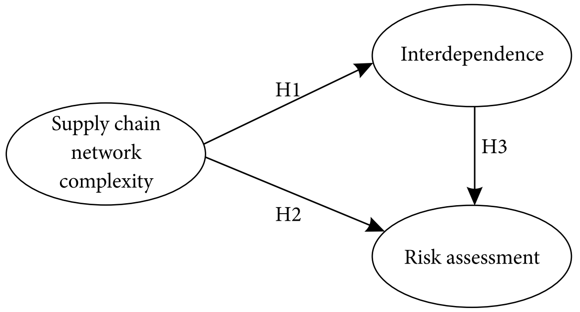


Fig. 1. Conceptual model

1.3. Interdependence and risk assessment

Informed decision making is the key aspect of risk assessment. The salient attributes that characterize risk assessment are making informed decisions about the transactions (i.e. the partners are aware about the details of the decision they are making), understanding the stakes involved in the relationship (what to gain and what might be lost), remaining aware about the implications/outcomes of the ensuing transaction relationship (i.e. aware about the expected and worst case unexpected outcomes) and most importantly understanding the responsibilities/liabilities involved with the transaction relationship. Ellis *et al.* (2010) highlighted that perceptual assessment of risk guides decision making. As the notion of loss is inherent in risk, understanding of vulnerability is critical in deciding the course of relationship as it gives a feeling of being exposed while including an element of uncertainty or risk (Handfield, Bechtel 2002; 2004). In the presence of high level of interdependence, both the transacting partners are at higher risk of incurring losses in case they fallout and hence often enter long-term binding contracts (Casciaro, Piskorski 2005), which necessitates a deeper understanding about what is at stake. Thus higher level of interdependence should foster higher degree of risk assessment as they need to understand the level of vulnerability/risk involved in the relationship. But when a relationship is marked by high degree of interdependence and the fallout of a relationship breakup might be catastrophic for both partners, the urgency of risk assessment increases since both are aware about the cost of breakup, keeping chance of opportunism remains low (Kumar *et al.* 1995; Wagner, Bode 2006). So, it is hypothesized that:

H3. Partner interdependence has a positive effect on partner risk assessment in supply chain network.

2. Methodology

The current research is aimed at deeply understanding the supply chain network complexity (SCNC) and risk-assessment (RAS) constructs and thereafter developing relevant scales for detailed empirical study. In the process, a survey was prepared using two new scales and another existing multi-item scale. There was the need for developing and using the new scales for SCNC and RAS, in the absence of relevant multi-item scales. For the inter-dependence construct, despite a pre-existing scale was identified as mutual dependence (Vijayasarathy 2010); it was further revalidated in the course of the study for better adaptability to the sector-context and country-context. The methodology steps followed are as follows.

2.1. Pretesting and scale development

In this study, Churchill's method for developing and testing reflective scales was followed (Churchill 1979). The entire method can be segregated into four broad steps: first, construct development followed by checking its content and face validity; second, dimensionality testing; third, checking for internal consistency; fourth, checking and thus ensuring that convergent, discriminant, and nomological validity of the measures are fulfilled (Anderson, Gerbing 1988; Churchill 1979). In the first stage, based on the literature and existing definitions, pools of items were generated through thorough probing of the literature for the two constructs. After the successful generation of the initial pool, a substantive validity test was carried out followed by scale purification (Anderson, Gerbing 1991).

10 items for SCNC and 9 items for risk assessment were there in the initial pool which was given to two senior professors from the faculty of management of two reputed Indian business-schools and four industry experts from well known firms. Based on their feedbacks, necessary modifications were done to the initial pool items. This pool was given to 68 industry experts in the pretesting stage. Following Lawshe (1975), a substantive validity testing was carried out based on those expert responses. Such techniques had been used in another contemporary study for newly developed construct-scale validation (Ambulkar *et al.* 2015).

As part of the validity testing, the experts were asked to rate if the items were essential or non-essential in the construct and study contexts and were asked to give their responses (satisfied/dissatisfied). The coefficient (C_{sv}) for measuring substantive validity was calculated as $C_{sv} = (n_c - n_0)/N$ (Lawshe 1975; Anderson, Gerbing 1991) where n_c represented number of respondents who assigned the items as essential and satisfied, which n_0 indicated respondents who marked the item as non-essential. In this way the C_{sv} value varied between –1 to +1. Based on the highest and most appropriate values the items were chosen. Next, in consultation with 2 academic researchers who knew about the aforesaid technique, finally 4 items were chosen for SCNC and RAS constructs each. In the following steps the reliability and validity testing were done. Using SPSS software, the two constructs, based on the collected 68 responses in the pilot stage, were separately subjected to exploratory factor analysis and the results gave clear single factors explaining 73% of the variance in case of SCNC and 70% in case of RAS. The Keyser-Meyer-Oklin (KMO) indicating sample adequacy was 0.80 and 0.76 respectively. Also the chi-sq values were significant for both indicating single-factor solution to be significant. Convergent validity

Table 1. Demographic characteristics of the sample

Job title	Number of respondents	% of total responses
Supply Chain Manager/ Executive/Specialist	109	53.69
Vice-president/director/ partner	54	26.6
Sr. Executive/Buyer/ Analyst	32	15.76
Logistic Manager	6	2.96
Others	2	1
Sector/type of firm	Number of respondents	
Manufacturing	78	38.42
Retail	43	21.18
Food processing	19	9.35
Telecommunication	21	10.34
Leather	03	1.48
Textile	03	1.48
Chemical (including pharmaceuticals)	36	17.73
Firm Sales (data in INR converted to US$)	Number of respondents	
$10 million or less	45	22.17
More than $10 million to $50 million	62	30.54
More than $50 million to $100 million	81	39.9
Above $100 million	15	7.39
Experience (in years)		
Less than 5 years	39	19.22
More than 5 to 10 years	128	63.05
Above 10 years	36	17.73
Total	203	100

and reliability were also established from the cronbach alpha values of 0.81 and 0.87 respectively for SCNC and RAS and the range of factor loadings were all above 0.6. The discriminant validity was also checked using chi-square difference test (Stratman, Roth 2002). In the first confirmatory factor analysis (CFA), the two latent constructs were allowed to freely correlate and in the second CFA they were constrained to one. The difference in the chi-square between the unconstrained and constrained models involving the SCNC and RAS construct pair was calculated and it emerged significant, establishing discriminant validity. The predictive validity was established during the course of large scale survey study. It was established for the RAS construct, however for the SCNC construct it could not be established as it lacked an antecedent variable in the study conceptualization. However the nomological validity for both the studies were established as the final questionnaire before sending for survey was given to 10 new experts and 2 other academicians (different from those involved before) who agreed with the conceptualization of the constructs.

2.2. Sample and data collection for final study

The survey was distributed to professionals holding important positions and having responsible designations in the supply chain of reputed Indian firms belonging to 7 different sectors like manufacturing, retail, food processing, telecommunication, leather, textiles and chemical. However, this choice of sectors was based on a leading Indian business magazine's report for the financial year ending March 31st, 2014, where they highlighted these 7 sectors as top seven performing sectors. The database for the survey was obtained from two sources; first, a professional membership list of a regional supply chain professional body (the list was purchased from a market survey firm); second, list of alumni oftwo reputed Indian b-schools (obtained from known sources to the author), who graduated between 2000 and 2012 and had their alumni profile updated in their respective institutes with roles which fall within the generic purview of supply chain management. The survey was conducted using online mode only and the survey was hosted by using online platform. The respondents were sent online survey links along with a forwarding email explaining about the survey in details, its purpose and also the mandatory disclaimer. First, all the three databases were combined and subjected to a careful sorting exercise, looking for supply chain related roles and a consolidated list of 1914 unique individuals was generated. But out of those in the list, 120 entries had missing email IDs. Second, the online survey was administered to 1794 potential respondents, of which 64 emails had delivery failure issues and the respondents were not reachable through any other means, bringing the final effective distributed survey questionnaire number to 1730. Out of the 1730 potential respondents, 203 completed surveys were obtained at a response rate of 11.73% which is quite acceptable as per online survey response rate standards (Ambulkar *et al.* 2015). Table 1 provides the demographic details of the respondents. Majority of the respondents were Supply chain managers (53.7%) and most respondents were from manufacturing (38.4%) and retail (21.2%) sectors. The obtained responses can be considered to be quite representative keeping into consideration that the final consolidated list was prepared by combining the three databases giving specific attention to the roles and the original consolidated list had 49% names with roles as supply chain managers /executives /specialists, nearly 30% as vice-president/director/partner, around 17% as Sr. Executive/Buyer/Analyst, while the rest fell in the category of logistic managers. The respondents' profile of the final survey indicated proportionate responses which were within +/−5% of that of the original list. Again, looked from the sector perspective, the manufacturing sector accounted for around 41% of respondents in the original consolidated list, whereas textile and leather industry accounted for 3% each. In the final survey, the distributions of the respondents were acceptably proportionate because manufacturing sector accounted for 38% while textile and leather accounted for around 2% each. Thus the obtained response and the sample can well be generalized as representative.

However one important note should be made when studying supply chain professionals in the Indian context, especially their sectors and job-roles. In India manufacturing, retail, telecommunication, chemicals, etc. account for lion's share of the organized industrial sector, whereas very few leather and textile firms belong to that category which can be considered under organized sector. Now, that all the databases represented executives and managers who were either affiliated to a reputed professional body or graduated from two reputed b-schools, it can be rationally assumed that most of them went into organized sectors and very few got opportunities to venture into textile and leather industry as those firms recruit very few people from established b-school campuses (though exceptions are there and this comment should not be always generalized). Thus keeping all these factors into consideration, while understanding the study's sample profile and hence its possible scope of generalization will help managers and academicians in analyzing the study outcomes.

The respondents came from firms having sales figures as high as well above 100 million USD (converted ≅ 1 USD = 60 INR) and also those below 10 million USD. The experience level of the respondents also varied and most respondents (63%) belonged to between 5 years to 10 years experience band. A reminder email was sent to the respondents for bettering the response rate. Thus two waves of responses were received (before and after the reminder). Non-response bias testing was performed comparing the early responses (before reminder) with the later responses (after reminder) (Armstrong, Overton 1977; Ambulkar *et al.* 2015). Chi-square test results showed no significant difference between the first-wave and second wave along two categories of firm size by number of employees and firm revenue at level of 0.1; thereby assuring an unbiased sample.

Common method bias was also checked using Harman's single factor test (Harman 1976). In the current study the largest variance explained by a single factor was 32.17% which is not the majority of the total variance. Also further absence of common method bias was checked following latent factor test (Podsakoff *et al.* 2003). With introduction of a latent factor to the main model, no significant loss in the factor loadings was observed, indicating minimal common method bias in the current study.

2.3. Measures and data analyses

There are three overall research variables in the model: Supply Chain Network Complexity (SCNC), Risk Assessment (RAS) and Interdependence (ID). Supply Chain Network Complexity has been operationalized using four items, measured on a seven-point Likert scale (1 = strongly disagree and 7 = strongly agree). The items described different aspects of SCNC, varying levels of which should represent varying levels of network complexity. The items that characterized SCNC: high number of first tier suppliers, strong inter-relationship relationship among the tier-one suppliers, high degree of differentiation in terms of levels of operational practices among the actors, and Low frequency and the volume of interaction among the actors (Bode, Wagner 2015; Bozarth *et al.* 2009; Handfield, Nichols 1999; Simon 1962; Choi, Krause 2006; VanVactor 2011; Noorderhaven, Harzing 2009; Milgate 2001; Prater *et al.* 2001; Meepetchdee, Shah 2007; Johnsson *et al.* 2007; Burt, Doyle 1993).

Risk Assessment too has been operationalized using four items, measured on a seven-point Likert scale (1 = strongly disagree and 7 = strongly agree). The items characterizing RAS were: ability to make informed decisions while transacting, ability to understand the stakes i.e. risk involved in the relationship, awareness about the implications of the transaction relationship, and understanding the responsibilities/liabilities involved in the transaction relationship (Prahalad, Ramaswamy 2004; Tummala, Schoenherr 2011; Ha *et al.* 2011; Wagner, Bode 2006; Ellis *et al.* 2010; Zsidin *et al.* 2004; Harland *et al.* 2003; Blackhurst *et al.* 2008).

Interdependence scale measure was adapted with necessary modifications from Vijayasarathy (2010) where it was referred to as mutual dependence. However as the entire scale was being tested in a completely different context, the same steps were repeated. Totally six items represented buyer dependence (BD) and supplier dependence (SD). In order to ensure that the respondents had a similar understanding of the two different constructs as in Vijayasarathy (2010) study, the responses for the six items were subjected to principal component analysis (factor analysis) using varimax rotation. The results supported a clear two-factor structure explaining 67.3% of the variance and had eigen values above unity. The factor structure is provided in table 2 and all the six items show good loadings (above 0.6) and all cross-loadings were below 0.2. Also the reliability was established by calculating Cronbach alpha which came to 0.76 and 0.81 for BD and SD respectively. The complete wording of the scale items are provided in the appendix section.

Table 2. Results of the principal component analysis of the factors contributing to interdependence measure

Items	Factors	
	Buyer dependence	Supplier Dependence
BD1	0.617	0.036
BD2	0.795	0.119
BD3	0.679	0.101
SD1	0.064	0.718
SD2	0.112	0.632
SD3	0.023	0.761

Table 3. EFA findings

KMO: 0.868 Bartlett: significant at 0.1% Total variance explained: 69.7%			
Factors	Measurement Items	Item loadings	Cronbach's Alpha
Supply Chain Network Complexity	SCNC1	0.889	0.906
	SCNC2	0.670	
	SCNC3	0893	
	SCNC4	0.705	
Risk Assessment	RAS1	0.865	0.892
	RAS2	0.755	
	RAS3	0.806	
	RAS4	0.872	
Interdependence	ID1	0.852	0.850
	ID2	0.795	
	ID3	0.863	

The validity and reliability of the scales were established, following Vijayasarathy (2010) and Casciaro and Piskorski (2005), but with certain key modifications to suit the study requirements, interdependence (ID) was calculated as follows: ID = [(BD + SD) – Absolute (BD–SD)]/2. This division by 2 was necessary to bring the ID items to the same 7-points scale being used for the rest of the variables. Uniqueness of this ID variable measures happen to be that, all the three interdependence items were calculated separately corresponding to the BD and SD item scores and also the ID score was adjusted for the skewed dependencies (by subtracting the absolute differences between BD and SD) to capture appropriate magnitude of it. Subsequently again the SCNC, RAS and ID items were subjected to exploratory factor analysis (EFA) to ensure that the factor structures hold well.

The EFA results involving the perception measures for SCNC, RAS and ID items, indicated an acceptable KMO value of 0.868 and also the Bartlett's coefficient got significant at 0.1%. Three well laid and rotated factor structures emerged from the principal component analysis results using varimax rotation. The loadings were all good (above 0.6) and most importantly all the three variables (SCNC, RAS and ID) showed satisfactory Cronbach alpha values above 0.8. The complete results are provided in Table 3.

2.4. The measurement model

After successful EFA analysis, confirmatory factor analysis (CFA) was carried out to assess the reliability, validity and dimensionality of the constructs. The CFA results indicated acceptable values for CFI (comparative fit index): 0.981; TLI (Tucker-Lewis Index): 0.976; GFI (Goodness of Fit Index): 0.882 (close to 0.9); IFI (Incremental Fit Index): 0.978; [CFI, GFI, IFI and TLI should be near 0.9 and above (Anderson, Gerbing, 1988)]; CMIN/df i.e. $\chi 2/d.f. = 1.69$ (preferably should be below 2) and RMSEA (root mean square error of approximation): 0.027 (preferably below 0.05) (Anderson, Gerbing 1988; Hu, Bentler 1999). Table 4 shows the CFA results. The measurement items are provided in Appendix. Factor loadings, composite reliabilities (CR), average variance extracted (AVE) and squared multiple correlation (SMC) were examined to assess convergent validity. All the factor loadings came out to be above 0.6 and significant at $p < 0.001$, suggestive of high levels of convergence (Hair *et al.* 2010). Composite reliability of all three factors came out to be greater than 0.7, further supporting convergent validity and internal consistency (Hair *et al.* 2010). The AVEs for all the three constructs were each greater than 0.5, supporting convergent validity. Details of the measurement model have been provided in Table 4. The AVEs for each of the constructs also sufficiently exceeded the squared correlations with the other constructs, indicating support for discriminant validity (Table 5).

Table 4. Measurement model: CFA results

Construct	Items	Std Estm.	p-Value	SMC	AVE	CR
Supply Chain Network Complexity	SCNC1	0.97	*	0.94	0.741	0.91
	SCNC2	0.67	*	0.45		
	SCNC3	0.94	*	0.89		
	SCNC4	0.71	*	0.50		
Risk Assessment	RAS1	0.81	*	0.63	0.502	0.80
	RAS2	0.79	*	0.61		
	RAS3	0.71	*	0.51		
	RAS4	0.93	*	0.92		
Interdependence	ID1	0.81	*	0.67	0.549	0.79
	ID2	0.75	*	0.55		
	ID3	0.88	*	0.76		

Note: * significant at $p < 0.001$

Table 5. Discriminant validity table

	SCN	RAS	ID
Supply Chain Network Complexity	0.741		
Risk Assessment	0.094	0.502	
Interdependence	0.166	0.025	0.549

3. Analysis and results

3.1. The structural model

In this study structural equation modeling (SEM) using Amos was used to test the hypothesized relationships, indicated in the study model (Fig. 1). The model fit indices for the structural model appears acceptable and satisfying as per the acceptable practices (Anderson, Gerbing 1998; Hu, Bentler 1999; Iacobucci 2010). The SEM results yielded acceptable fit statistics: $\chi 2/d.f = 1.44$; CFI = 0.947; IFI = 0.956; TLI = 0.942; GFI = 0.863; RMSEA = 0.043.

Amos output indicated that the standardized path coefficients between supply chain network complexity and interdependence ($c = 0.229$, $p < 0.001$) was highly significant supporting hypothesis 1 (H1); between supply chain network complexity and risk assessment ($c = 0.029$) was found to be insignificant rejecting hypothesis 2 (H2); between interdependence and risk assessment ($c = 0.231$, $p < 0.001$) was highly significant too, thereby supporting hypothesis 3 (H3). Please refer to Figure 2. The details of the structural model output are provided in Table 6.

The study findings thus supported H1, that greater SCNC was positively linked with greater levels of interdependence and again it was found that higher interdependence between

Table 6. Hypotheses testing results

Hypotheses	Paths	Standardized path coefficients	p-Value	Results
H1	SCNC→ID	0.229	***	Accepted
H2	SCNC→RAS	0.029	0.638 (NS)	Rejected
H3	ID→RAS	0.231	***	Accepted

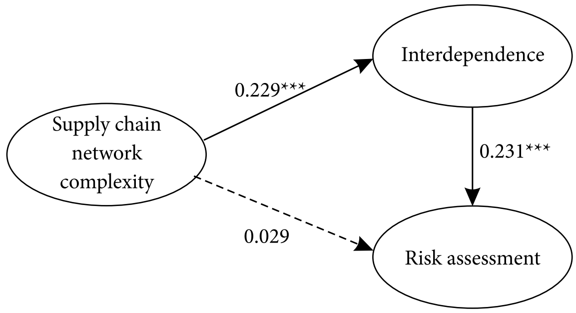
Note: *** Implies significant at $p < 0.001$ & NS implies "not significant" partners in a supply network led to greater support for higher degrees of risk assessment, supporting H3. However the non-significance of the path linking SCNC and RAS refuted H2 and threw up findings contrary to rational understanding. Thus the outcomes indicated an indirect effect of network complexity on risk assessment through interdependence.

3.2. Discussion and implications

This study presents a clear definition of SCNC and RAS including operationalizing of the constructs. The newly developed 4 item scale for SCNC examines the impact of network complexity on interdependence and risk assessment constructs. As noted from the extant literature, complexity happens to be a multi-faceted aspect and hence its presence and perception needed a suitable instrument. This study attempted at bridging that long awaited gap by providing a handy scale for measuring network complexity and empirically examining the impact of SCNC on the transaction relationship variables of interdependence and risk assessment. The 4 item risk assessment scale also comes in handy and helps in quantification of the long discussed conceptual risk assessment construct. Network complexity as discussed in this study indicates a business environment which is marked by presence of high number of suppliers and hence the inter-relationship and frequency of interaction between the network actors becomes critical. When the complexity is high then the chance of shifting or switching actors poses a threat because the actors tend to remain inter-related. The cost involved in switching may become high for both the supplier and the buyer. Moreover the fear remains about the fact that the switching partner may involve in spilling over the crucial key information when moving over to other network actor for transaction and also it entails cost.

3.3. Managerial and academic implication

The findings from this study should be of immense importance to the business community and especially the managers in understanding network complexity and its impact on the relationship and transaction between actors in a supply chain networks. This study discusses and develops new multi-item scales to measure network complexity and risk assessment constructs, both of which existed as conceptual constructs in the extant literature and were lacked a direct measurement instrument. Often these were measured by other reflective measures and their discussions remained at abstract levels without detailed quantification. This study also validated the measures for interdependence scale and adapted it, so as to use it with other Likert scales in similar studies. Previous studies were predominantly conceptual and lacked quantification. This will help the managers in quantifying their business network complexity and in the



Note: *** $p < 0.001$
Fig. 2. Path model

process aid in decision making. This research highlights that contrary to rational understanding, managers are more concerned about the level of dependence before probing for assessing the risk rather than just the network complexity. From academic perspective, this study opens up new direction of management research in the field of network complexity and marks the shift from predominantly conceptual studies to those of empirical investigations.

Conclusions

The aim of this study was to understand how firms perceive network complexity in the supply chain and explore how network complexity subsequently impacts the understanding of interdependence and risk assessment in the transaction relationship. The findings from this paper help in establishing a rational framework linking three stumbling blocks that managers face in course of executing their day to day supply chain management duties. This study empirically validates the hypothesized relationships; thereby providing supply chain managers with a handy empirically proved understanding framework. This study extends the extant literature, develops and operationalizes two constructs called supply chain network complexity and risk assessment, besides validating the interdependence construct in its new usable form derived from the summated composite score of two constructs: supplier dependence and buyer dependence. This study also examined the relationship between the constructs and demonstrated that network complexity has a positive and direct impact on interdependence, which in turn directly and positive affects risk assessment; however supply chain network complexity directly do not influence the risk assessment aspect in a firm network. The studies contribution lies in providing a consolidated definition of Supply chain network complexity and development of SCNC and risk assessment scales besides revalidating the interdependence construct and its scale elements. This study will open newer horizon of supply chain management research and add to its body of knowledge. It can be viewed as a unique attempt to link three somewhat rationally related but empirically unlinked streams of literature.

As with all social science research, there are some limitations of this study too. First, the study took into consideration the perceptions of the managers without segregating them as per the complexity levels of the network they belong to. All the respondents may not have given their responses with similar network complexity into consideration. Second, the study used cross-sectional data, which limits the study's ability to draw causal linkage, especially because interdependence and complexity may have some effects which lingers over time and might reveal newer aspects when looked over time. Third, the study considered mostly respondents from non-service sectors and service sector networks were grossly ignored. Therefore, future studies may segregate network complexity into groups depending on different level of complexity and study that impact on the consequent variables. Also the study findings may suffer in terms of limitation of generalization, especially to service sector scenarios. Future probing can be done keeping the service sector into consideration. Finally the supply chain network complexity construct is nascent and may be extended to take a more generic sense and also explore firm relationships involving dyadic relationships which might throw up different yet interesting findings. Moreover due to lacking in the extended conceptualization of what can be antecedents to the SCNC construct, all validity tests were done expect predictive validity testing. Thus there remains a scope of introducing a rational antecedents and then trying to establish the predictive validity.

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APPENDIX

Construct		Scale items used in the large-scale study
Supply Chain Network Complexity		Our firm's supply chain network is characterized by:
	SCNC1	Large number of first tier suppliers.
	SCNC2	Strong inter-relationship among the tier-one suppliers.
	SCNC3	High degree of differentiation in terms of levels of operational practices among the actors.
	SCNC4	Low frequency of interaction among the actors.
Risk Assessment		While transacting with major suppliers:
	RAS1	Our firm can make informed decisions.
	RAS2	Our firm understands the stakes involved in the relationship.
	RAS3	Our firm remains aware about the implications of the transaction relationship.
	RAS4	Our firm understands the responsibilities/liabilities involved in the transaction relationship.
Interdependence		
Buyer Dependence	BD1	There are other major suppliers capable of providing us with comparable orders.
	BD2	Total cost of switching to a different set of major suppliers would be prohibitive.
	BD3	It is difficult to replace our major suppliers while maintaining comparable profit margins.
Supplier Dependence	SD1	Other buying firms can provide our major suppliers with comparable orders.
	SD2	Total cost of switching to a different set of buying firms would be prohibitive for our major suppliers.
	SD3	It is difficult for our major suppliers to replace us with other buying firms and maintain comparable profit margins.

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