How does trust affect performance in the supply chain? The moderating role of interdependence

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The moderating role of the supply chain interdependence structure

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Abstract

This paper analyzes the positive relationship between trust and performance in the supply chain and investigates into whether the interdependence structure of the supply chain moderates this relationship. Interdependence occurs in supply chains because supply chain partners depend upon one another for product and process accomplishment and for the resources and knowledge owned by their partners, which they need. Framing the supply chains as complex adaptive systems, we argue that both the overall supply chain interdependence pattern (i.e., which partner depends on which other(s)) and the degree of interdependence in the supply chain (i.e., the average number of interdependencies) moderate the relationship between trust and performance in the supply chain. The proposed conceptual model is operationalized through the NK fitness landscape methodology and tested using simulation. The results confirm that the specific interdependence pattern that characterizes the supply chain has a significant moderating effect on the relationship between trust and performance, while the moderating effect exerted by the degree of interdependence is not statistically relevant.

Keywords: Interdependence; Interdependence pattern; trust; benefits of trust; supply chain; agent-based simulation

1. Introduction

Extant literature has widely emphasized that trust is beneficial in the management of supply chains and shown that trust is a significant predictor of positive performance outcomes (Ireland

and Webb, 2007; Laaksonen et al., 2009, Lee et al, 2010, Panayides and Venus Lun, 2009). The positive relation between trust and supply chain performance has in fact been documented in several different industries including the automotive, computer, printing, electronic and electrical component industries (Noteboom et al., 1997; Smith and Barclay, 1997; Sako and Helper, 1998**;** Dyer and Chu, 2000), and the performance improvements generated by trust have been verified both in terms of cost reduction and improved flexibility (Handfield and Bechtel, 2002; Laaksonen *et al*., 2009, Morash et al., 1996; Narasimhan and Nair, 2005). Nevertheless, what factors moderate the relationships between trust and supply chain performance is an issue largely unexplored to date, which this paper intends to tackle.

We advance that the extent to which trust improves supply chain performance is affected by the supply chain interdependence structure, which describes all the interdependencies existing among supply chain firms. Interdependence occurs in supply chains because firms depend upon one another for product and process accomplishments and/or for strategically relevant resources owned by their partners (Pfeffer and Salancik, 1978).

Following a recent trend in the literature, supply chains can be framed as complex adaptive systems (CASs), i.e. a set of interconnected buyers and suppliers who self-organize and emerge without any entity controlling this process (Choi et al., 2001; Choi and Hong, 2002; Surana et al., 2005; Pathak et al., 2007; Bozarth et al., 2009). In contrast, the supply chain interdependence structure is conceptualized by using two complexity variables: 1) the pattern of interdependencies, mapping with whom each firm interacts and 2) the degree of interdependence, i.e. the average number of interactions each firm in the supply chain has. Based on CAS theory and supply chain management literature, the moderating effects played by the two variables on the relation between trust and performance are also advanced.

The prescribed conceptual model is operationalized by using the NK fitness landscape methodology. This is an agent-based simulation technique which has become popular in management studies (see Ganco and Hoetker, 2009 for a review) and is applied preferably to the study of single organizations (Siggelkow, 2011). However, in recent years it has also been extended to multi-firm contexts such as alliances (Aggrawal et al., 2011) and supply chains (Giannoccaro, 2011). The NK fitness landscape methodology was chosen because it has been successfully applied when the system under investigation is characterized by many actors interacting among each other in non-linear ways and when the aim of the simulation is to investigate the effect of the complex network of interactions among the actors on the system's performance (Davis et al., 2007). Furthermore, we preferred simulation to empirical research because we believe that the latter would have required a challenging and perhaps unaffordable effort in data collection, due to the need to consider a very high number of firms in order to include sufficient variety of both supply chain interdependence structures and trustworthy firm behaviors in the sample.

The rest of the paper is organized as follows. We first illustrate the theoretical foundation of our conceptual model, providing the definitions of trust, reviewing the literature concerning the positive relation between trust and supply chain performance, summarizing key properties of CASs and explaining the rationale for the proposed model hypotheses. Then, we develop the simulation analysis through the NK fitness landscape model to test our theoretical hypotheses. Finally, we discuss results and implications.

2. Literature review

2.1 Trust

Trust has been widely investigated in management research (Blomqvist, 1997; Ring, 1996; Uzzi, 1997; McEvily *et al.*, 2003; Capaldo, 2007) and dozens of definitions and categorizations have been offered in previous studies (Dirks and Ferrin, 2001; Seppänen et al., 2007). This makes trust a multidimensional concept which comprises several components, such as fairness, loyalty, vulnerability, dependability, opportunism, benevolence, and collaboration (Seppänen et al., 2007).

In supply chain contexts, the categorization of trust advanced by Sako (1992) is usually adopted (Ireland and Webb, 2007), which distinguishes among contractual, competency, and goodwill trust. Contractual trust incurs when partners trust that the others will adhere to contractual clauses. Competency trust arises when the partners believe that the others possess the needed capability for performing a task. Goodwill trust occurs when partners act to benefit with reciprocity, going over what the specific contractual clauses rule. It is the highest level of trust and is developed through repeated exchanges within long-term relationships.

For our purposes here, we focus on trust as expected collaboration by the participating organizations in the supply chain, which will do what is better for the overall system, even when the collaboration may lead a local disadvantage (Zaheer et al., 1998, McCarter and Northcraft, 2007; Rousseau *et al*., 1998). In other words, trusting organizations collaborate because they trust that their partners will behave in the interest of the overall system and will not adopt opportunistic behaviors (Barney and Hansen, 1994; Bradach and Eccles, 1989, Lai et al., 2012).

Therefore, trust operates as an informal governance mechanism (Bradach and Eccles,1989; Heide, 1994) which induces the organizations participating in the supply chain to behave altruistically in the best interest of the entire supply chain, so as to increase its overall performance, even when this is locally detrimental for them.

On the contrary, when trust is absent in the supply chain, partners will not be prone to collaborate when collaborative behaviors leads to a local disadvantage. In such a context, it follows that partnering firms are likely to agree to collaborate in order to improve the overall system performance, but only if this is not detrimental to their local performances.

These described behaviors of the supply chain firms in case of presence and absence of trust are used as stylized facts to develop our simulation model of "*trust*" and "*no trust*" supply chains.

2.1.2 The relation between trust and supply chain performance

The valuable effect of trust in inter-organizational relationships is well established in the literature. Benefits associated with trust have been investigated in different fields and economic sectors (Noteboom et al., 1997; Smith and Barclay, 1997; Sako and Helper, 1998**;** Dyer and Chu, 2000, Seppanen et al., 2007) and explained through the adoption of diverse theories, mainly the transaction cost economics and the relational exchange theory. Within the transaction cost economics theory, trust is of economic value because it reduces transaction costs, negotiation costs, monitoring and oversight costs, and uncertainty in information sharing, acting as a substituting of control (Dyer and Chu, 2003; Zaheer et al., 1998). Within relational exchange theory, trust is seen as critical to fostering and maintaining relational exchanges. It increases the probability that organizational actors will exchange information and knowledge, will be involved in joint learning processes, and will share costs for exploring and exploiting new opportunities (Inkpen, 2001; Lado et al., 2008; Nahapiet and Ghoshal, 1998, Cai et al., 2013).

In strategic management studies, trust is recognized as a determinant of successful partnership relationships among firms, is associated both with improved adaptability and strategic flexibility, and with enhanced predictability of partners behavior (Mohr and Speakman, 1994, Yang, 2009).

In supply chain studies, it has been emphasized that trust is a significant predictor of positive outcomes in supply chain performances in terms of improved flexibility, responsiveness, and cost reduction (Handfield and Bechtel, 2002; Ireland and Webb, 2007; Laaksonen et al., 2009, Narasimhan and Nair, 2005). Trust in fact enables partners to collaborate more intensively (Gambetta, 1988) and to engage in risk-taking initiatives (Mayer et al., 1995).

Based on the above, we assume that trust positively affects supply chain performance and then go beyond this by investigating the factors affecting the relationships between trust and supply chain performance, which have received scant attention so far in previous literature. Thus, our first hypothesis is the following:

H0. Trust has a positive effect on supply chain performance.

3. Theory

3.1 Supply chains as complex adaptive systems

Complex adaptive systems (CASs) are networks of adaptive agents that emerge over time into coherent forms through interactions, without any singular entity or central control mechanism deliberately managing or controlling the overall system (Holland, 1995). CASs show the following important properties: non linearity, adaptation, self-organization, emergence, state at the edge of chaos, and co-evolution with the environment (Dooley, 1999; Arthur, 1991).

Non-linearity means that there is not a direct correlation between the size of the cause and the size of the corresponding effect. Adaption entails that the system changes, improving its fitness for its environment, and creates new forms of emergent order consisting in new structures, patterns, and properties. Adaption is possible thanks to self-organization, i.e. the new order arises from the interaction among agents without being externally imposed on the system (Goldstein, 1999); Self-organization results in emergence, that is, a new order of some kind. Both self-organization and emergence, which are considered the most important features of CASs, are enabled by the complex web of interactions existing among the agents and are affected by its nature and pattern (Kauffman, 1993). Self-organization and emergence characterize the quasi-equilibrium state at the edge of chaos in which CASs operate, a state of non-complete order just short of chaos. It is a combination of regularities and randomness, which leads to the best adaptive outcome for the system. A further point is that CASs co-evolve with a changing environment. That is, the dynamic environment, by interacting with the CAS, forces changes in the entities that reside within it, which in turn induce changes in the environment (co-evolution).

The complexity theory postulates that the properties above are general principles valid for any system (e.g., cells, animals, populations, firms, and networks of firms) and explain how real systems are structured, behave, and evolve (Lissack, 1999).

Following a recent scholarly trend, we frame supply chains as complex adaptive systems (Choi et al., 2001; Surana et al., 2005; Pathak et al., 2007) and conceive of the supply chain as a set of interdependent firms and their interactions, which self-organize and co-evolve with the rugged and dynamic external environment, without any entity controlling this process (Surana et al., 2005; Pathak et al., 2007). We focus attention on the network of interactions occurring among firms because it is critical in defining the structure and the system behaviors, as postulated by CAS theory.

We recognize that the interactions among supply chain firms occur because of the existing interdependencies among them (Capaldo and Giannoccaro, 2010). Interdependence takes place when firms depend upon one another for product and process accomplishments and/or for strategically relevant resources owned by their partners (Pfeffer and Salancik, 1978). This happens in supply chains because firms participating in supply chains are “operationally, strategically, and technologically integrated” (Hult, Ketchen, and Slater, 2004). Thus, the interdependence structure of the supply chain describing which firm depends on each other is conceptualized in terms of interaction structure among the firms and described in terms of degree of interaction and pattern of interactions, as for any CAS. The degree of interaction corresponds to the degree of interdependence of the supply chain; The interaction pattern corresponds to the interdependence pattern. Both variables are expected to influence the relationship between trust and supply chain performance on the basis of CAS theory and supply chain management literature. In the next sections we provide the rationale for which we hypothesize these moderating effects.

3.2 The effect of degree of interdependencies

When one firm depends on another, e.g. for product supply, process accomplishment, or the use of shared resources, interactions occur among them for the need to accomplish coordination among their activities.

It is acknowledged in CAS theory that the dynamics of the system are largely influenced by the degree of interaction among agents. In particular, as the degree of interaction increases, adaptation to the environment becomes more difficult, the system behavior is more chaotic and in turn the fitness performance decreases (Kauffman, 1993). As the number of interactions grows and the actions of firms become more and more interdependent, the management of the supply chain becomes in fact more difficult, due essentially to the need to resolve multiple conflicting aims (Simchi-Levy et al., 2000; Nair et al., 2009). In such a case, in order to be effective and efficient, it is required higher coordination and collaboration among firms in the supply chain (Choi and Hong, 2002; Giannoccaro, 2011). High collaboration entails long-term relationships and a high degree of information sharing among partnering firms regarding processes, quality, and even cost structure ((Helper, 1991; Helper and Sako, 1995, Mohr and Spekman, 1994), which in turn makes it feasible to improve the overall performance of the entire supply chain, while a low degree of collaboration determines supply chain inefficiency due to the impossibility of solving conflicting aims and adopting optimal global solutions. Conversely, when interdependence among firms is low, the decisions of one firm do not impact on those of another, the number of conflicting aims decreases and the firms, while pursuing their local interests, at the same time improve the global supply chain performance, with the consequence that even though the degree of collaboration is low, the supply chain performance is not reduced.

Based on the above, and because trust favors collaboration and commitment among supply chain firms (Mohr and Speakman, 1994), we expect that the degree of interdependence plays a moderating role on the relationship between trust and supply chain performance. In particular, when the degree of interdependence is high, the beneficial impact of trust on supply chain performance is expected to be higher than when the degree of interdependence is low.

Considering that the degree of interdependence corresponds to the degree of interaction, we hypothesize that:

H1. *The degree of interdependence moderates the relationship between trust and supply chain performance in such a way that the positive effect of trust on performance increases for increasing degrees of interdependence.*

3.1.1. The effect of the interdependence pattern

Diverse interaction patterns among agents can be identified in CASs. The random pattern, which is very popular especially within network theory studies, was the first to be noted/pinpointed. Its distinguishing characteristic is that most nodes will have approximately the same number of links, while very few nodes will show a considerably lower or higher number of links than the average (Erdos and Renyi, 1959). The local pattern, instead, is recognized when the connections occur only between adjacent nodes. Its variant is the small-world pattern, where although most connections occur among adjacent nodes, a few exist between more distant nodes (Watts, 1999). The block-diagonal pattern is characterized by clustered connections among nodes, i.e. they occur only inside blocks (i.e. modules) and not between different blocks.

In many real world networks, nodes do not have the same probability of being connected, but connections follow specific rules. In the preferential attachment pattern, the nodes preferentially attach to other nodes having a large number of connections (Barabasi and Albert, 1999). When the node distribution connectivity follows a power law the pattern is scale-free (Barabasi and Albert, 1999).

Four further complex interaction patterns are the hierarchical, the diagonal, the centralized, and the dependent (Siggelkow and Rivkin, 2007). The hierarchical pattern assumes that nodes are hierarchically ordered and that each node may influence only those with lower ranks. The diagonal pattern is similar, except that node 1 is not the most influential, as occurs in the hierarchical pattern. The centralized and the dependent are specular. In the centralized pattern, a few nodes affect all the others, which in turn have no other? interactions. Conversely, in the dependent pattern a few nodes are affected by all the others, while not exerting any influence themselves.

Capaldo and Giannoccaro (2010) show that supply chains may adopt any of the 10 different complex interdependence patterns above, i.e. random, local, small-world, block-diagonal, preferential attachment, scale-free, hierarchical, diagonal, centralized, and dependent. They are shown in Figure 1 by means of a network graph, where the nodes stand for the firms and the arrows for the dependencies.

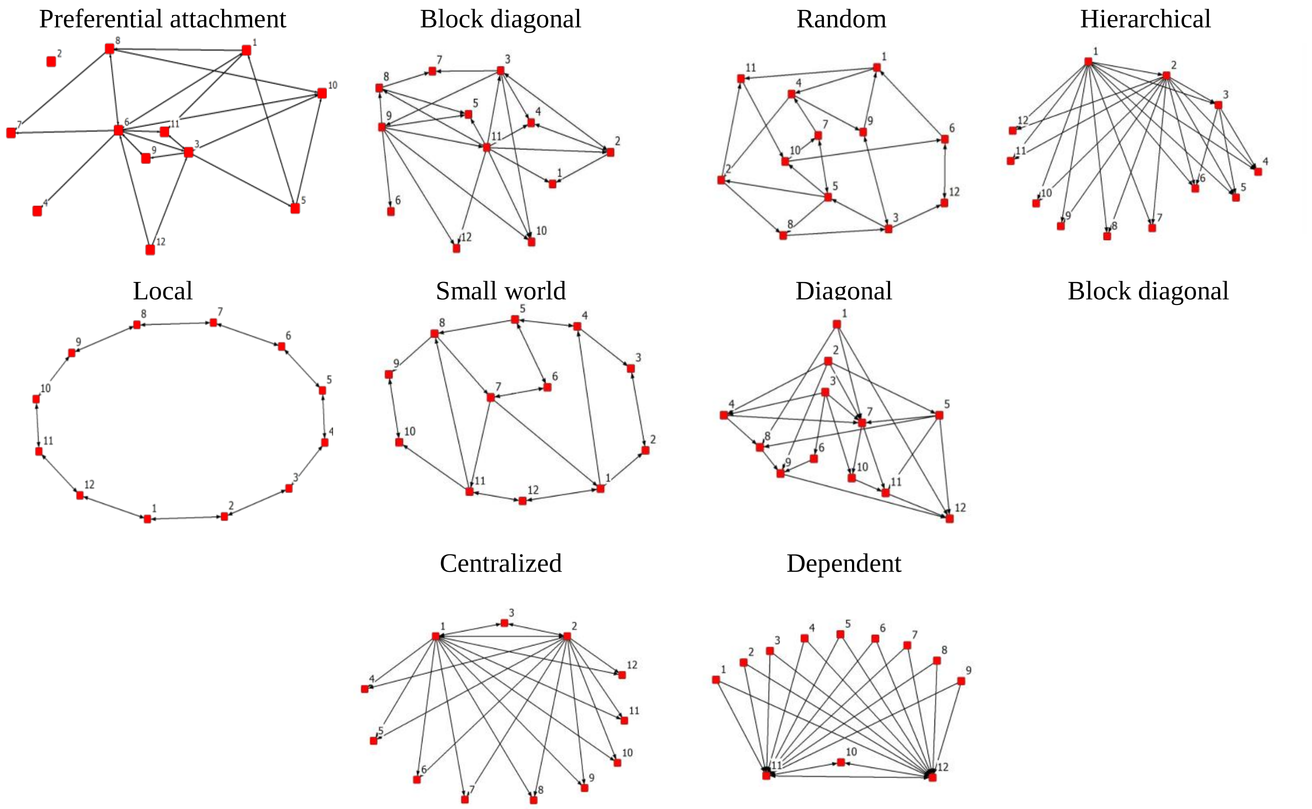

Figure 1. Network graphs of the interdependence patterns in supply chains.

In a recent study by Siggelkow and Rivkin (2007), the ten complex system patterns have been compared and it is shown, by means of a computational analysis, that adaptive behavior varies across them and that the same adaptation strategy (in this case the degree of exploration) determines varying system performance. It is also observed in alliance contexts that the diverse patterns of interactions occurring among firms require diverse levels of coordination and moderate the relationship between coordination and alliance performance (Aggrawal et al., 2011).

Based on these arguments and given that trust operates as a governance mechanism accomplishing coordination (Bradach and Eccles,1989; Heide 1994), we expect that trust leads to different performance outcomes across the diverse interdependence patterns, and that interdependence pattern plays a moderating role on the relation between trust and supply chain performance.

Based on the above, we hypothesize that:

H2. *Interdependence pattern moderates the relationship between trust and supply chain performance in such a way that the effect of trust on performance varies across the different patterns.*

Figure 2 depicts our conceptual model.

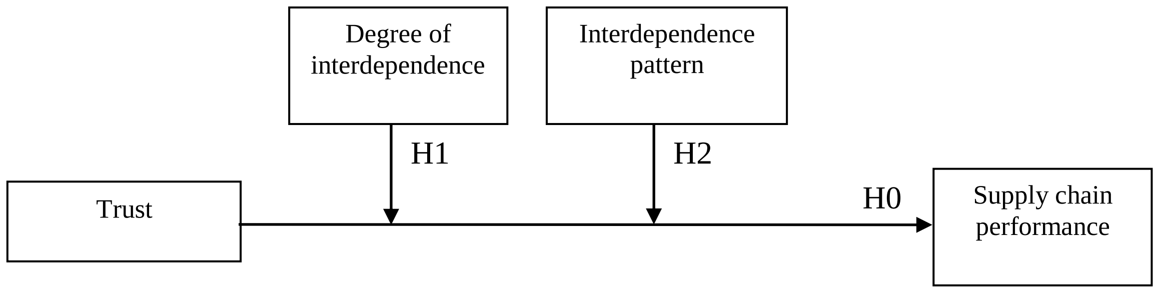

Figure 2. Conceptual model.

3. The simulation model

Our aim in this section is to provide an operationalization of our conceptual model through the NK fitness landscape model. We first present the NK fitness landscape model applied to the firm, then we extend it to the supply chain context and, finally, we describe how each construct of the conceptual model is operationalized.

3.1. The NK fitness landscape model of the firm

The NK fitness landscape model is a simulation approach, originally developed by Kauffman (1993) to study the adaptation process of biological systems, which has been widely applied to date in organizational and strategy studies both in single-firm and multiple-firm contexts (e.g. Aggrawal et al. 2011; Giannoccaro, 2011; Levinthal, 1997; Rivkin, 2000; 2001).

Referring to these applications, the firm is seen as a set of N decisions on how to perform activities (usually binary) and K interactions among decisions. Each specific combination of choices on decisions (choice configuration) is associated with a total payoff for the firm P(**d**), generated by using a stochastic procedure that we describe below. The payoff measures the performance of the system in that specific configuration.

The map obtained from choice configurations on payoffs is called the landscape, because a configuration is assumed as a point and payoff as a height. The firm is then engaged in an adaptive walk through the landscape, made up of valley and peaks, and its aim is to discover and occupy the choice configuration with the highest payoff on the landscape (global peak). To do this, a search procedure is adopted, which can range from a simple local incremental search to more complex algorithms. The search procedure to find the global peak on the landscape is usually adopted to model the governance modes of the firm (Davis et al., 2007; Rivkin and Siggelkow, 2005, Ganco and Hoetker, 2006), so that we will use it to model trust. In the next we describe the stochastic procedure to generate a landscape, given K and the influence matrix.

3.1.1. Landscape generation

First, the contribution C_i of each decision to the total firm payoff is generated by drawing at random from a uniform U[0,1] distribution. The value of each C_i, however, depends not only on how the decision itself is resolved, but also on how the decisions interacting with it are resolved. For example, the choice to reduce the safety stock determines a greater benefit for the firm, provided that the firm also decides to invest in more sophisticated demand forecasting systems.

When K = 0, C_i can assume only two values, corresponding to $d_i = 0$ and $d_i = 1$, respectively. In other words, all the choice configurations with $d_i = 0$ will share the same C_i, while all the choice configurations with $d_i = 1$ will share a different C_i. When K = N-1, the contribution of each decision depends on how all the remaining decisions are resolved. Thus, C_i differs in any choice configuration.

Once generated the C_i for all the configurations, the overall payoff associated with a choice configuration is calculated by averaging the contributions C_i over the N decisions (i.e., $P(\mathbf{d}) = \left[\sum_{i=1}^{N} C_i(d)\right] / N$).

Table 1 presents an exemplar landscape generation for the influence matrix shown in Figure 3.

Table 1. Exemplar fitness landscape.

Configuration	Vector of configuration			C_1	C_2	C_3	System Payoff
a	0	0	0	0.67	0.74	0.86	0.76
b	0	0	1	0.67	0.58	0.31	0.52
c	0	1	0	0.77	0.31	0.86	0.65
d	1	0	0	0.24	0.74	0.91	0.63
e	1	1	0	0.02	0.31	0.91	0.41
f	1	0	1	0.24	0.58	0.12	0.31
g	0	1	1	0.77	0.19	0.31	0.42
h	1	1	1	0.02	0.19	0.12	0.11

	d_1	d_2	d_3
d_1	x	x	
d_2		x	x
d_3	x		x

Figure 3. The influence matrix of the landscape in Table 1.

3.2 The NK fitness landscape model of the supply chain

In line with the studies above, we conceive of the supply chain as set of N interacting decisions made by the supply chain firms. Such decisions concern the choices on how the firms perform their own activities. We assume that each firm carries out a single activity (e. g., production or distribution) and thus makes a single decision (e.g., how much to produce or how much to stock), just for the sake of simplicity but without losing in generalizability.

A particular N-digit string represents a specific set of choices made by supply chain firms on the decisions (choice configuration) **d** = (d_1, d_2, …, d_N), with d_i = 0 *or* 1 (i = 1,…N), and is the supply chain configuration. Each firm *i* contributes with the decision *i* to the overall supply chain payoff, where C_i is the contribution. The overall supply chain payoff in a given configuration **d** is computed by averaging the contributions C_i on the N decisions ($P_{SC}(\mathbf{d})$ = $\left[\sum_{i=1}^{N} C_i(d)\right]/N$).

Individual firms in the supply chain are interdependent on one another, and because of these interdependencies, the decisions they make are in interaction. Thus, we associate the degree of interdependence of the supply chain with the degree of interaction among decisions and model it by the parameter K. Indeed, interaction means that the outcome of the decision made by a firm (e.g. how much to produce or how much to stock) depends not only on its own choice but also on the choice of interacting firms. For example, if the supplier decides to produce a component, while the buyer decides to produce a product requiring a different component, the performance for the supply chain will be lower than when the production decisions of the supplier and buyer are synchronized.

Similarly, we associate the interdependence pattern mapping which firm depends on each one with the pattern of interactions among decisions and model it by the influence matrix. The influence matrix modelling each examined interdependence pattern is shown in Figure 4 in case of N=10 and K=2. Notice that the x in (*i*,*j*) cell means that the decision of firm *i* is influenced by the decision of firm *j*, i.e., firm *i* depends on firm *j*.

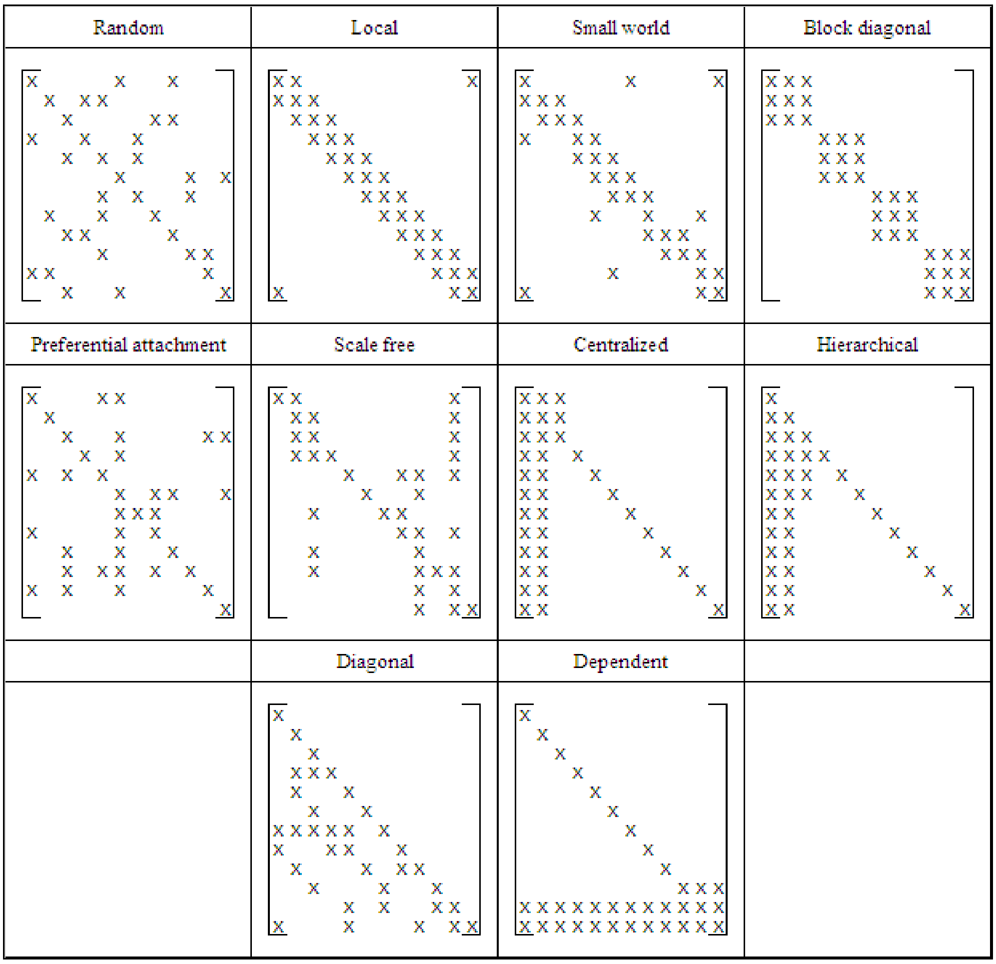

Figure 4. The influence matrices of the examined interdependence patterns (N=12, K=2).

The supply chain is thought of as being engaged in an adaptive walk through the landscape defined by K (i.e., the degree of interdependence) and the influence matrix (i.e., the interdependence pattern). During the simulation, the aim of the supply chain is to find and occupy the global peak of the landscape, that is, the supply chain configuration with the highest payoff. The efficacy of the adaptive walk measures the supply chain performance. The higher the efficacy, the higher the supply chain performance (Giannoccaro, 2011; Siggelkow, 2003, 2005).

Having defined K and the influence matrix (i.e., the interdependence structure), we generate the corresponding landscape using the procedure described in sub-section 3.1.1.

3.3. Modeling trust in the supply chain

We argued above that, when trust is pervasive across the supply chain, all supply chain firms are expected to behave in the global interest (i.e., to collaborate in pursuing common goals), or in other words, to make decisions with the aim of increasing the overall supply chain performance rather than their local performances, even though this entails a disadvantage at the local (i.e., firm) level. Conversely, when trust is absent in the supply chain, partners are not eager to pursue the global interest if doing so is locally detrimental. Therefore, they will act in the interest of the overall supply chain only if this does not entail a local disadvantage.

We reproduce these two extreme levels of trust in our supply chain model, by defining two different search procedures of the global peak on the landscape. This is consistent with studies using the searching procedure to model the governance structures of the firm (Aggarwal et al., 2011; Ganco et Hoetker, 2006; Siggelkow and Rivkin, 2003, 2005).

The search process is step-by-step. At the beginning of the simulation, the supply chain adopts a configuration chosen at random, e.g., (0,0,1,0,0,0) for a supply chain made up of N=6 firms. At the next step, a new configuration different from the current one (status quo) is proposed. It differs on how one decision at random is resolved. For example, the new configuration might be (1,0,1,0,0,0). This means that the decision made by the *firm 1* is changed from 0 to 1.

In the presence of trust ("*trust" supply chain*), firms decide to adopt the new configuration if this is beneficial for the entire supply chain, regardless of the impact that such change exerts on its individual performance. Thus, the new proposed configuration is compared with the previous one on the basis of the corresponding supply chain payoff. If the new configuration is associated with a higher supply chain payoff than the previous one, the supply chain moves into the new configuration; otherwise, the system maintains the original configuration.

If trust is absent across the supply chain ('*no-trust' supply chain*), supply chain firms exclusively pursue their local interests. Thus, they accept to modify their own decisions, so as to improve the overall supply chain payoff, only if doing so also yields a local benefit. Thus, we model this by assuming that the supply chain moves into the new configuration only if the following two conditions are simultaneously verified: 1) the overall supply chain payoff associated with the new configuration is higher than that associated to the previous configuration; and 2) in the new configuration, the local payoff of the firm that must modify its decision (the *firm 1* in the example above) is higher than previous one. The local payoff is computed by the contribution C_i of the decision *i* performed by the firm *i*.

To summarize, the evolution process of the supply chain proceeds through the following steps:

a) A new supply chain configuration $\boldsymbol{v}_{\mathbf{new}}$ is proposed, changing one decision at random;

b) The supply chain payoff $P_{SC}(\boldsymbol{v}_{new})$ and the local payoffs of all the supply chain firms $P_i(\boldsymbol{v}_{new})$ corresponding to the new supply chain configuration are computed;

c) The new supply chain configuration is compared with the original one (status quo);

d) The system moves into the new configuration if:

<u>'*trust' supply chain*:</u> $P_{SC}(\boldsymbol{v}_{\mathbf{new}}) > P_{SC}(\boldsymbol{v}_{\mathbf{status\ quo}})$;

or

<u>'*no-trust' supply chain*:</u> $P_{SC}(v_{new}) > P_{SC}(v_{status\ quo})$ and $P_i(v_{new}) > P_i(v_{status\ quo})$

where *i* is the firm that should modify the decision moving into the new configuration

Otherwise, the system maintains the status quo configuration;

e) Steps a-d are repeated for a given number of times (i.e., simulation runs).

3.4. The supply chain performance model

Supply chain performance is computed by running the simulation, i.e., by letting the supply chain search for the global peak on the landscape for a given number of periods of time, and then by measuring the efficacy of the search process by calculating the overall supply chain payoff at the end of the simulation, as a percentage of the highest payoff attainable on the landscape. A value equal to 1 means that the supply chain was able to reach the global peak and achieved the highest possible performance.

Table 2 summarizes how the variables included in our conceptual model are operationalized using the NK fitness landscape methodology.

Table 2. Operationalitazion of the conceptual model using the NK fitness landscape.

Conceptual variable	**Modeling variable**
Degree of interdependence	K
Interdependence pattern	Influence matrix
Trust level	Searching procedure
Supply chain performance	Payoff of the supply chain configuration at the end of simulation

4. Simulation analysis

We carried out simulation analysis to test our conceptual model. Accordingly, we designed a plan of experiments made up of 30 diverse types of landscapes (i.e., interdependence structures), each generated by selecting one of the 10 considered interaction patterns (i.e., interdependence patterns) and one of three increasing values of K (i.e., degrees of interdependence). By doing so, we are able to assess the effects of both the degree of the interdependence in the supply chain and the supply chain interdependence patterns.

In all the designed landscapes, N = 12. Notice that each type of landscape (set by K and the interaction pattern) is generated 600 times. This is needed to guarantee statistical significance to our results, because the contributions characterizing the landscape are numbers drawn at random. In all the analyses, the simulation time is equal to 200 periods. Setting the computational parameters in this way allows the dynamics under investigation to be reproduced during the simulation and ensures the statical significance of our results.

On each of the 600 replications of the landscape, the simulation is carried out in both the two considered cases of "*trust*" and "*no trust*" supply chains, which means that two supply chains are released on the landscape, one characterized by the existence of trust across firms (i.e., "*trust*" supply chain) and the other characterized by the absence of trust (i.e., "*no trust*" supply chain). Supply chains employ the searching procedure described in Section 3.3 to discover and occupy the global peak. At the end of simulation supply chain performance is collected for both In total, the data plan consists of 36,000 points (i.e., 600 *iterations* x 10 *interdependence patterns* x 3 *degrees of interdependence* x 2 *levels of trust*).

5. Statistical analysis

We performed a Tobit multiple regression analysis in which supply chain performance is the dependent variable while trust, the degree of interdependence, and the interdependence patterns are the independent variables. The use of Tobit regression was needed because data are right censored (maximum performance equal 1). Trust is conceptualized as a binary variable, where trust = 1 corresponds to the case of "*trust*" supply chain, while trust = 0 means "*no trust*" supply chain. The interdependence patterns are modeled by dummy variables. The degree of interdependence is K. To test our hypotheses involving moderating effects, we considered both the direct and the interaction effects of the independent variables. We also introduced the effect of a control variable.

5.1. Control variable

In complex adaptive systems modeled through NK fitness landscape, the fitness performance of the system is affected by the number of local peaks characterizing the landscape, where a local peak is a system configuration such that none other exists that differs from it in just one decision, having higher system payoff (Kauffman, 1993). Thus, the local peak is a suboptimal configuration in which the system may be blocked during it adaptive walk on the landscape and which impedes the system to reach the global peak (i.e., the optimal performance). The higher the number of local peaks, the lower the likelihood of reaching the global peak, and the lower the system performance (Kauffman, 1993; Siggelkow and Rivkin, 2002; 2003). For this reason, we introduced the number of local peaks as a control variable in our analysis and expected that it would exert a negative impact on supply chain performance. The number of local peaks were then computed for each landscape and the natural logarithmic transformation of the number of local peaks considered as control variable (*Ln Number of local peaks*).

5.2. Results

Table 3. Descriptive statistics and correlation matrix.

		Mean	Std dev	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Performance	0.91	0.072	1													
2	Ln Num Loc Peaks	3.11	1.03	-0.22	1.00												
3	D. of interd.	3	0.82	0.18	0.00	1.00											
4	Trust			-0.23	0.48	0.00	1.00										
5	Centralized			0.08	-0.43	0.00	0.00	1.00									
6	Hierarchical			0.05	-0.25	0.00	0.00	-0.11	1.00								
7	Scale Free			0.04	-0.19	0.00	0.00	-0.11	-0.11	1.00							
8	Random			0.00	0.01	0.00	0.00	-0.11	-0.11	-0.11	1.00						
9	Prefer. Attach.			0.01	-0.06	0.00	0.00	-0.11	-0.11	-0.11	-0.11	1.00					
10	Local			-0.04	0.04	0.00	0.00	-0.11	-0.11	-0.11	-0.11	-0.11	1.00				
11	Small world			-0.02	0.01	0.00	0.00	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	1.00			
12	Block diag.			-0.04	0.03	0.00	0.00	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	1.00		
13	Diagonal			-0.01	0.17	0.00	0.00	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	1.00	
14	Dependent			-0.06	0.65	0.00	0.00	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	-0.11	1.00

Table 4. Results of the Tobit regressions.

Parameters	***Model 1***	***Model 2***	***Model 3***	***Model 4***
Constant	0.972996***	0.958365***	0.988157***	1.06645***
	(0.0013623)	(0.001398)	(0.002124)	(0.003957)
Ln Number local peaks	-0.019197***	-0.019176***	-0.013096***	-0.033149***
	(0.000413)	(0.000406)	(0.000456)	(0.000692)
Trust		0.029094***	0.026794***	-0.000721
		(0.000829)	(0.002629)	(0.002424)
Degree of interdependence			-0.016247***	
			(0.000704)	
Trust x Degree of interdependence			0.000775	
			(0.000843)	
Centralized				-0.083185***
				(0.003408)
Hierarchical				-0.065747***
				(0.003153)
Scale free				-0.063091***
				(0.003100)
Random				-0.074427***
				(0.002864)
Preferential Attachment				-0.072766***
				(0.002920)
Local				-0.082451***
				(0.002832)
Small world				-0.080172***
				(0.002866)
Block diagonal				-0.076448***
				(0.002828)
Diagonal				-0.047758***
				(0.002718)
Trust x Centralized				0.026851***
				(0.003548)
Trust x Hierarchical				0.011136**
				(0.003527)
Trust x Scale free				0.007365*
				(0.003544)
Trust x Random				0.048228***
				(0.003532)
Trust x Preferential attachment				0.039297***
				(0.003518)
Trust x Local				0.051838***
				(0.003526)
Trust x Small world				0.049374***
				(0.003528)
Trust x Block diagonal				0.040037***
				(0.003510)
Trust x Diagonal				0.024682***
				(0.003525)

Number of observations	36000	36000	36000	36000
LR Chi-square	2130.15	3342.69	4107.07	4663.33
Log likelihood Full Model	30140.911	30747.179	31129.371	31407.501
Pseudo R^2	-0.0366	-0.0575	-0.00706	-0.0802

*p< 0.05; **p<0.005; ***p<0.0001. Standard errors are indicated in brackets.

We run four models, whose results are presented in Table 4 (in Table 3 descriptive statistics and correlation matrix are shown). In *Model 1* we regressed supply chain performance on the control variable, i.e., the natural logarithm of the number of local peaks. Results confirm that the natural logarithm of the number of local peaks impacts supply chain performance negatively and significantly (β= -0.019197; p<0.0001).

In *Model 2* we tested the effect of trust on supply chain performance, that we found to be positive and significant (β=0.029094; p<0.0001). This offers statistical support to our hypothesis H0.

In *Model 3* we tested our hypothesis H1 by introducing both the main effect of the degree of interdependence on supply chain performance and its interaction effect with trust. Results indicate that the main effect of the degree of interdependence on supply chain performance is negative and significant (β=-0.016247; p<0.0001), while the moderating effect of the degree of interdependence on the relationship between trust and performance is positive but not significant (β=0.000775; p<0.3). Thus, we did not find statistical support for our hypothesis that the degree of interdependence that characterizes the supply chain moderates positively the relationship between trust and supply chain performance.

In *Model 4* we finally included the direct and the interaction effect of the interdependence patterns on supply chain performance, so as to test our hypothesis H2. In particular, we introduced nine dummy variables, one for each interdependence pattern considered, except for the dependent[1] chosen as the baseline and other nine variables that operationalize the

[1] Dependent was chosen as the baseline as it is the most complex pattern among the ten examined here (Siggelkow and Rivkin, 2007).

interactions of trust with each considered pattern. Results confirm both the direct and the moderating impact of the interdependence pattern on supply chain performance. In particular, the direct impact is negative for all the interdependence patterns, except for the dependent (baseline), which positively and significantly impacts supply chain performance. As to the interaction effects between trust and the interdependence pattern dummies, results show that all patterns positively and significantly moderate the relationship between trust and supply chain performance, except for the dependent pattern whose interaction effect with trust on supply chain performance is negative but not significant (see the coefficient of trust). Ranking the interdependence patterns on the basis of the moderating effect, we find that the scale free pattern shows the lowest positive effect ($\beta=0.007365$; $p<0.0001$), while the local pattern shows the highest one ($\beta= 0.051838$; $p<0.0001$). Based on these results, we then statistically confirm our hypothesis H2, i.e., that the overall pattern of interdependencies that characterizes the supply chain positively moderates the relationships between trust and performance and that the performance benefits associated with trust vary across the interdependence patterns.

6. Discussion

Moving from the widely acknowledged hypothesis that trust is beneficial for supply chain performance, our study, investigating into the factors moderating this relationship, confirmed some results of literature and also adds some interesting contributions. Given that supply chains are framed as complex adaptive systems, we argued that the interdependence structure characterizing the supply chain, mapping the interactions occurring among supply chain firms and described in terms of the degree of interdependence and the overall supply chain interdependence pattern, affects the beneficial impact of trust on the overall performance of the entire supply chain.

We confirmed that, as the degree of interdependence increases (for example where there is a high specialization of the firms in a few phases of the production process, or where the firms share a high number of critical resources) supply chain performance decreases because of the increasing complexity associated with higher degrees of interaction among firms (Bozarth et al., 2009; Nair et al., 2009). Although our analysis found a positive moderating effect of the degree of interdependence on the relationship between trust and performance, it also showed that it is not statistically significant. This leads to the supposition that degree of interdependence plays a more complex effect on the examined variables, i.e., trust and performance, than we advanced. In particular, as the degree of interdependence increases, it becomes more difficult to develop trust among supply chain partners, because the more interconnected are the firms participating in a supply chain, the greater is the risk that they will behave opportunistically (McCarter and Northcraft, 2000). Thus, there is a negative impact of the degree of interdependence on trust and, consequently, decreasing trust determines a negative effect on supply chain performance. The existence of this opposite effect may contribute to explaining why we found that increasing the degree of interdependence, performance does not significantly improve.

Similarly to the findings of other studies, we also confirmed that the interdependence pattern of the supply chain plays a direct role in affecting supply chain performance (Ernst and Kamrad, 2000; Mahapatra et al., 2010). In particular, we found that the dependent pattern (characterized by several firms who influence a small number of other firms, who in turn do not influence any others, as happens in supply chains using postponement strategy or in the case of distribution channels consisting of few large central depots supplying a great number of independent retailers) positively influences supply chain performance, while all the other examined patterns exert a negative influence. The explanation is that this pattern is associated with the highest alignment between the global and the local interests, which in turn determines a low risk of opportunism by firms with a positive impact for the performance of the supply chain as a whole, while for all the other patterns the alignment between the global and the local interests is significantly lower thus inducing greater likelihood that firms will adopt opportunistic behaviors having a negative effect on supply chain performance (Capaldo and Giannoccaro, 2010).

However, our results go beyond validating the impact of the interdependence pattern on trust and show that the interdependence pattern moderates the relationship between trust and supply chain performance. In particular, we found that for all the examined interdependence patterns the moderating effect is negative, except for the dependent one, whose moderating impact is positive but not significant. We found that the performance benefits associated with trust significantly vary across the interdependence patterns. Our results showed that the scale free pattern occurring in hub-and-spoke supply networks is associated with the lowest beneficial impact on supply chain performance. This result contributes to explaining why the empirical observations in previous studies have not credited hub-and-spoke networks with high levels of trust (Gray et al., 1996; Lazerson and Lorenzoni, 1999).

Moreover, we found that the local pattern, typically resulting from the adoption of just in time strategy, is associated with the highest beneficial effect of trust on supply chain performance. Such a pattern is in fact characterized by high risk of opportunism by supply chain firms (Capaldo and Giannoccaro 2010), which negatively impacts supply chain performance and therefore considerable levels of trust are required if it is to be improved (e.g., Frazier, Spekman, and O'Neal, 1988). A similar result also holds for the small world pattern, which is a variant of the local pattern occurring when most interactions among firms are 'local' (i.e., adjacent), but a few interactions exist between firms that are 'distant' (i.e., not adjacent) from each other.

7. Conclusions

In the present paper we have investigated trust as a fundamental predictor of positive supply chain performance. In particular, framing supply chains as complex adaptive systems, we have advanced that the performance benefits associated with trust are significantly influenced by both the degree of interdependence and the overall interdependence pattern of the supply chain. We tested our conceptual model by using simulation based on NK fitness landscape, a methodology particularly suited to studying the influence of the network of interactions on complex system behaviors and very popular in management studies which analyze the behaviors of both single firms and (although to a lesser extent) networks of firms. The results statistically confirm that the interdependence pattern positively moderates supply chain performance and that the benefits associated with trust vary across the ten examined interdependent patterns.

Our findings have implications for managers interested in exploiting the benefits associated with a pervasive climate of trust in the supply chain. First, we suggest they should identify and take into consideration the overall pattern of interdependencies that characterizes their supply chains, as it is a major determinant of the extent to which trust is beneficial to supply chain performance. In particular, since we found that performance improvement varies across the range of interdependence patterns, and since developing and nurturing trust in supply chains is an expensive task entailing substantial costs, we argue that the need for trust varies depending on supply chain interdependence pattern. We suggest to managers that the need for trust is high in those supply chains where the interdependence pattern resembles the local, the small world, and the random ones, while in the case of the scale-free pattern the need for trust is considerably lower.

Future research should thus be devoted to further investigation into some of these main outcomes, both theoretically and empirically. In particular, we believe that a promising direction for further investigation could be the development of a theory explaining whether, why, and under which conditions trust can be detrimental for supply chain performance, as our results seems to suggest is the case with the dependent pattern.

A further research development could also address a limit of the present study, in which trust is considered as a dichotomous concept. We in fact model just two opposite scenarios of trust assuming that supply chain can be characterized only by complete presence or absence of trust. Both empirical evidence and recent studies suggest conversely that moderate levels of trust can exist, implying a need for better modeling of the trust variable, treating it as a continuum.

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