Design chain visibility: How much information should you share with your partners during new product development projects?

Caridi, M., Pero, M., Sianesi, A. (2017)

Please cite this paper as: Caridi, M., Pero, M., & Sianesi, A. (2017). Design chain visibility: How much information should you share with your partners during new product development projects?. Benchmarking 24(5), pp. 1337-1363

Link: https://www.emerald.com/insight/content/doi/10.1108/BIJ-04-2016-0059/full/html

Design Chain Visibility:
How much information should you share with your partners during New Product Development projects?

Abstract

- **Purpose:** Researchers maintain that the more activities of New Product Development (NPD) process are outsourced to partners, the higher the need for integration. This paper aims at studying: i. to what extent the amount of information shared with the partners during NPD projects (DC visibility) depends on the degree of outsourcing (DC virtuality), ii. what context variables (product features and business relationship features) influence this relationship.
- **Design/methodology/approach:** This paper provides two sets of quantitative indexes to measure: the relevance of the activities outsourced during the NPD project (i.e. virtuality), in terms of the spread of the outsourced technological knowledge, and in terms of outsourced workload; and the amount of information that a focal company shares with product development partners (i.e. visibility). Seven NPD projects in different companies have been analyzed to investigate visibility, virtuality and the implications of contingencies.
- **Findings:** The cross-case analysis shows that the amount of information shared with the partners during the NPD project varies with the relevance of outsourced activities. In particular, the higher the relevance, the higher the amount of information shared with the partner. Partner location and integration, trust, and ICT support have a role in determining the amount of information shared with each single partner.
- **Originality/value**: This study adopts an original network perspective in that the whole set of partners involved in the NPD process is analyzed. New quantitative indexes of visibility and virtuality of NPD projects are proposed, along with original insights about the impact of context variables. The quantitative indexes provide also a useful managerial tool to evaluate whether a focal company has the possibility to build competitive advantages that exploit unique resources beyond the boundaries of the company.

Keywords: Collaborative Product Development, New Product Development, Design Chain, Visibility, Virtuality

1. Introduction

In the recent years, companies have started to refer to external partners for jointly developing new products (Roemer and Ahmadi, 2009). The network of actors involved in the new product development (NPD) process is the so-called Design Chain (DC) (Twigg, 1998). Twigg (1998) defines DC management as ‘the management of the partners both external and internal to the focal firm that contribute to the capabilities (knowledge and expertise) necessary for the design and the development of a product (…)’.

Collaborative NPD is the process including two or more partners with diverse competence, experience, culture, skill and location joining complementary resources to design/develop new/innovative/improved products in order to gain competitive advantage, innovate, explore new markets, share risks and costs and accelerate NPD process (Büyüközkan and Arsenyan, 2012). Supplier involvement in product design stage has become a lever to gain a competitive edge due to a higher productivity and flexibility of the NPD activities and an extended spectrum of technologies and know-how to include in the new product (Howells et al., 2003). Literature has widely studied suppliers' involvement in product design, as highlighted in the literature review by Johnsen (2009). However, Johnsen (2009) points out that researchers have focused on the dyadic relationship client-supplier, not considering the overall network, i.e. the DC. Some recent works have investigated triads, i.e. the buyer-supplier-supplier relationships (Wu et al., 2010; Choi and Wu, 2009), to understand the implications of triads on NPD process. However, they claim that further research is needed in this area, and they advocate to go beyond the dyad client-supplier perspective.

One feature of DCs is, coherently with Li and Qiu (2006), the level of virtuality. This is defined as the amount of activities of the NPD process that are performed by different enterprises so that the results of one or more activities of the NPD process come from different actors. Despite companies rely more and more on external NPD partners, thus increasing the virtuality of DCs (Lai et al., 2009; Caniato et al., 2015; Shen et al., 2016), research in this area lags behind industry practice. As noted by Shen et al. (2016) and Lai et al. (2009), there are few empirical studies on design outsourcing.

In a DC, partners collaborate to develop the product. Collaboration with partners must be carefully designed in order to get the maximum performance and prevent undesired drawbacks. In particular, information sharing is essential for the success of NPD projects (Clark and Wheelwright, 1992; Knudsen, 2007; Sarin and O'Connor, 2009, Kalluri and Kodali, 2014). To this aim, visibility plays an important role. In line with Swaminathan and Tayur (2003), visibility is defined as the ability to access information across the DC and to use them in real time.

The DC literature suggests a link between virtuality and visibility. Managing networks of geographically dispersed operations makes the issue of information sharing with suppliers even more complex (Ghoshal and Bartlett, 1990). When the DC encompasses partners located in different countries, the partners face various communication challenges (Bradfield and Gaob, 2007; Morelli et al., 1995). When DC virtuality is high, organizations tend to collaborate and share information more in order to share risks, reduce costs and time-to-market, improve quality and benefit from the complementary knowledge and competence throughout the NPD process (Littler et al., 1995, Harmancioglu et al., 2007; Büyüközkan and Arsenyan, 2012). In the literature, the link between virtuality and visibility has been measured and its value quantified considering the supply chain processes (Caridi et al., 2010, Caridi et al., 2010a). On the contrary, little is known about this link for NPD process when a DC perspective is adopted.

Therefore, this research aims to address the gaps in the literature regarding virtuality and visibility in DCs, by enlarging the scope of the previous studies to include the network perspective. In particular, the main objective of this work is to study how the information shared within the whole DC , i.e. DC visibility, relates to the degree of outsourcing in the DC, i.e. DC virtuality.

When considering each dyadic relationship, the focal company has to choose the right extent of information shared with each partner of the DC (Brun and Pero, 2011). The literature suggests that, based on certain features relating to product and to the business relationship, the manager must choose the right amount of information to be shared (e.g. Petersen et al., 2005; Yan and Dooley, 2014). How should a company choose the extent of shared information with a partner of the DC? It is quite intuitive and reasonable that, when a long-term relationship links a company to her partner (and vice-versa), the company knows well how the partner is used to organizing her design activities, what is the average quality of her design and her service level. Thus, the company does not need to maintain a strict control on partner's activities over time. Things change when the component outsourced is highly innovative or highly complex: in these cases, even if the relationship is a long-term one, the company may need to have frequent meetings with the partner in order to be sure

that the activities are running according to the plan and that the outcome conforms to the requirements. How do things change when IT systems are set in place? When IT tools support information sharing, the exchange of information should be more accurate and timely and this might offset the lack of trust between the two parties.
This analysis suggests that context variables affecting the choice of the level of information sharing in a design chain cannot be neglected. Therefore in this paper, consistently with the contingency theory (Donaldson, 2001), the role played by context variables (product features and business relationship features) is studied. Context variables might help to interpret the choice of how much information is to be shared across the DC.
The paper is organized as follows. First, the literature background about the topic of visibility and its link with virtuality in the DC will be discussed. Second, the research objective and framework are discussed. Third, the research methodology is described. Finally, the empirical evidence along with the discussion is presented.

2. Literature background

The objective of this section is to support the importance of studying visibility and the link between DC visibility and DC virtuality, with a network perspective.

2.1 The relevance of DC visibility

Swaminathan and Tayur (2003) define visibility as the ability to access information across the DC and to use them in real time. Information sharing is an important pillar of collaboration when developing a product. Büyüközkan and Arsenyan (2012) provide an extensive literature review about collaborative product development, proofing that the infrastructures supporting information-sharing play a relevant role in product development. According to Emden et al. (2006), when partners collaborate in a DC, high levels of transparency, mindfulness, and synergies in participants' interactions are observed, in addition to high levels of integration. Rodriguez and Al-Ashaab (2005) state that collaboration in product development supports the sharing and transferring of knowledge and information of the product lifecycle among geographically distributed companies to aid taking right engineering decisions in a collaborative environment. Wu (2009) shows that trust, commitment, and interdependence have positive impacts on information sharing and that information sharing has a positive impact on product development performance. Hoegle and Wagner (2005) state that communication frequency and intensity has a curvilinear relationship with project performance. Information sharing facilitate the generation of resources and skills essential for NPD (Zsidisin and Ellram, 2001; Lawson et al., 2009). Frohlich and Westbrook (2001) maintain that effective information sharing is crucial to the success of supplier involvement in the new product introduction process. In order to find joint solutions to material problems and design issues, buyers and suppliers must commit a greater amount of information and be willing to share sensitive design information (Giunipero, 1990; Carr and Pearson, 1999). Information and knowledge sharing is a fundamental element of relationship quality, that, in turn, increases NPD process performance (Sjoerdsma and van Weele 2015). Recently, early supplier involvement has been found to positively affect also the environmental and social performance of a company (Saunders et al., 2015). Personnier et al. (2011) utilize the concept of "glitch" by Hoopes and Postrel (1999) to appraise the main costs of a lack of collaboration with suppliers during product development, i.e. the cost of rework, the cost of alignment and mutual understanding, the cost of project delay. Moreover, risks arise from the possible internal loss of design capabilities (Twigg, 1998).

2.2 The link between DC visibility and DC virtuality

In line with Li and Qiu (2006), DC virtuality is defined as the amount of activities of the NPD process that are performed by different enterprises so that the results of one or more activities of the NPD process come from different actors. Researchers suggest that DC virtuality is associated with higher information sharing during NPD process (Littler et al. 1995, Harmancioglu et al. 2007; Büyüközkan and Arsenyan 2012).

The relationship virtuality-visibility has been mainly studied considering the dyad client-supplier: Kim et al. (2015) claim that the kind of dyadic relationship that is in place between client and supplier has implications on how partner firms interact and information sharing. A relationship between virtuality and visibility is also pointed out by the Transaction Costs Theory (Williamson, 1975 and 2008; Coarse, 1937). The theory claims that the choice of "making or buying" an activity depends on the value of the "transaction costs". A transaction is defined as the transfer of a pre-product or semi-manufactured product or service from the upstream stage of a supply or design chain to downstream. Transaction costs are related to e.g. the processes of searching, negotiating, communicating with, and control suppliers. Transaction costs decrease when there is trust among the partners and when the cost of communication decreases, such as thanks to Information Technologies (Singh and Teng, 2016).

Some researchers recognize the implication of network characteristics on visibility. For instance, Noori and Lee (2004) studied the network effects on the product development performance in the telephone industry. They state that NPD complexity increase and magnify when the process involves a network of organizations with different goals, capabilities, and dependencies. Thus, more integrated information accessible by players within the network can enhance collaborative product development. Despite these attempts, little is known about the link visibility – virtuality when a set of different actors is at stake, in particular during the NPD project.

2.3 DC visibility and DC virtuality measurement

The concept of visibility, strongly linked with the one of information sharing, is well established in the extant scientific literature dealing with the complex environment of design and supply chain management (Sun et al., 2013).

In the realm of supply chain management, visibility is defined as the ability of a company to "see" into their supply chain by accessing data (Bradley, 2002). Some authors stress the nature of the shared information with a set of contributions that looks at their proprieties, e.g. accuracy, trustworthiness, timeliness, and usability (e.g. Closs et al., 1997). Most authors focus on information shared within a company-supplier dyad in simple supply chains (e.g. Chen et al., 2000) whereas some authors emphasize that the amount of information shared is affected by the complexity of the network (Kaipia and Hartiala, 2006). Following this stream, Caridi et al. (2010) and Caridi et al. (2010a) suggest a measurement of the amount of visibility in a complex supply chain, focusing on the information shared during supply chain planning and execution. Klueber and O'Keefe (2013) discuss the requisite level of supply chain visibility in regulated industry. Finally, Parry et al. (2016), in the context of the application of Internet of Things and reverse logistics, proposes four generic measurement categories for operationalising the concept of use-visibility: experience, consumption, interaction, and depletion.

These contributions are assessing visibility along a supply chain, thus referring to manufacturing, sourcing, and logistics processes, but they cannot be applied per se to DCs and NPD process. Thus, despite the relevance of visibility when managing a NPD project involving DC partners, a measurement of DC visibility is still lacking.

Also in the case of DC virtuality, a measurement is lacking in the literature. On the contrary, measurements of virtuality are found in the realm of supply chain management. For instance, Caridi et al. (2010) define virtuality as the ability of a company to collaborate with a large set of suppliers and external partners, and propose a quantitative measure of virtuality taking into account suppliers and partners with which the focal company is working in the supply chain related processes. Other measures for supply chain virtuality have been previously proposed by Webster and Sugden (2004). Despite their relevance, these measures cannot be used directly to measure DC virtuality. Therefore, in order to reach the research objectives, an *ad hoc* measure of both DC visibility and DC virtuality have to be defined.

3. Research questions and framework

The main objective of this paper is to investigate how much information is exchanged with partners of the DC (i.e. DC visibility) depending on the extent of DC virtuality. As mentioned in the introduction, the goal of this study is to enlarge the scope of the previous studies to include the network perspective.

To guarantee integration and flexibility, collaborative product development requires a continuous flow of information between partners (Sivadas and Dwyer, 2000). Despite the fact that information exchange has a cost that increases the lower the vertical integration of the company (Williamson, 2008), the benefits associated with high information exchange, in terms of NPD process performance, offset its cost (e.g. Büyüközkan and Arsenyan, 2012). Therefore, the first research question this paper investigates is:
RQ1: How does DC visibility vary depending on the extent of DC virtuality?

In line with the definition provided in the introduction, we model DC Virtuality as a combination of design activities outsourced to external DC partners. The more relevant the outsourced activity, the more relevant the role of the partner within the DC. We call it "NodeRelevance" of the partner.
The characteristics of the involved business units, and people, as well as the structure and the intensity of the network, are important components of information sharing in NPD projects (Sarin and O'Connon, 2009; Tortoriello et al., 2012). Accordingly, we might expect that higher NodeRelevance requires higher visibility on the partners' activities (NodeVisibility). Therefore, the second research question this paper investigates is:
RQ2: How does NodeVisibility vary depending on the NodeRelevance of the partner?

The literature shows that some variables affect the extent of visibility in the design chain. For instance, Lindström et al. (2012) suggest different information should be shared depending on the type of product developed. Thus, virtually being equal, the amount of visibility might be lower or higher depending on some features of the new product and of the partners. According to these insights, the third research question investigates if the features of the product and of the partner affect visibility. Thus the third research question is:
RQ3: How do the product and partner features influence the relationship between virtuality and visibility?

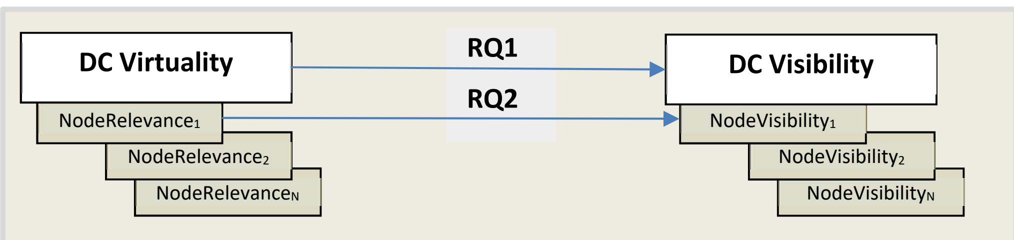


Figure 1. The research framework.

Figure 1 depicts the research framework. The research framework has been built according to the indications of the contingency theory (Sousa & Voss, 2008). Consistently with the research questions, the framework includes five main elements (DC Visibility, DC Virtuality, NodeRelevance, NodeVirtuality, and the context variables), which are described in the following.

3.1 Design Chain Visibility and NodeVisibility

The first element of the research framework is the extent of visibility in the design chain (as a response variable). DC visibility is the visibility that the focal company (i.e. the main contractor of the NPD project; she pays the costs of the project and will receive the benefits of the sale of the project's output) has on the information that product development partners own and that are relevant to manage the project. Literature does not present a proper quantifiable measure of DC Visibility. Few contributions suggest scattered building blocks of visibility in the design chain (e.g. Yong-hui, 2010; Syan and White, 2013). Thus, the proposed index has been developed based on those building blocks and is calculated as a combination of the visibility that the focal company has on each partner, as shown in the following.

The sets of information that the focal company has visibility on during the NPD project are grouped into two categories (Eriksson et al., 2002): project output and project management. The first category encompasses the information about the project output, i.e. the outcome of the partner's work according to the contract. The piece of information about the output depends on the phase of the NPD project in which the partner is involved (Ulrich and Eppinger, 2011; Jepsen, 2013). According to Ulrich and Eppinger (2011), a NPD project encompasses the following phases: (*i*) Planning (P) (*ii*) Concept Development (CD), (*iii*) System-Level Design (SLD), (*iv*) Detail Design (DD), (*v*) Testing and Refinement (TR), (*vi*) Production Ramp-Up (PRU). In line with Jacobs and Chase (2014), the main output of each phase is: project mission statement for phase P; product concept for phase CD; product architecture and final assembly scheme for phase SLD; complete specifications of all the parts for phase DD; physical prototype and its performance for phase TR; small volume of production and solution of any remaining problem for phase PRU.

The second category encompasses the information about project management, i.e. how the partner is managing the project internally. In line with Tonnquist (2008) and Liu and Shih (2009), this information is classified into: project plan (activities, milestones, resources allocated), project organization (team members, and their experience and role), and project status (status of activities, issues, milestones, resources absorption).

The information that a focal company exchanges with its partners has three features: (*i*) quantity, i.e. to what extent the information about the partner is visible to the focal company, (*ii*) accuracy, i.e. the degree of conformity of the shared information to its actual value, and (*iii*) freshness, i.e. the degree of "synchronization" between business partners (Caridi et al., 2010). Each feature is modeled as an interval variable and is assessed by means of a qualitative scale. The qualitative scales are shown in Tables 1, 2, and 3.

Table 1. Qualitative scale to judge the quantity of the exchanged information.

Score	**Description**
1	The company has access to none or a small amount (less than 25%) of information
2	The company has partial access (between 25% and 50%) to the information
3	The company has access to a fairly good amount (between 50% and 75%) of information
4	The company has access to a large part (more than 75%) of the information

Table 2. Qualitative scale to judge the accuracy of the exchanged information.

Score	**Description**
1	The accuracy of the exchanged information is usually very low and unsatisfactory
2	The accuracy of the exchanged information is usually satisfactory, but situations in which the information is incorrect are not uncommon
3	The accuracy of the exchanged information is usually satisfactory, and the information is incorrect only in few situations
4	The accuracy of the exchanged information is always satisfactory (very good accuracy)

Table 3. Qualitative scale to judge the freshness of the exchanged information.

Score	**Project Output (PO)**	**Project Management (PM)**		
		Status	**Organization**	**Plan**
1	At the end of project	Not visible at all	Not visible at all	Not visible at all
2	Information is visible only when the provider is asked to provide data	Information is visible only when the provider is asked to provide data	Information is visible only when the provider is asked to provide data	Information is visible only when the provider is asked to provide data
3	Usually visible in real time, except for some information	Usually visible in real time, except for some information	Project organization is visible in real time, but changes are visible only when the provider is asked	Plans are visible in real time, but changes are visible only when the provider is asked
4	Real-time	Real-time	Project organization and its changes are visible in real time	Project plan and its changes are visible in real time

For each partner *k*, the visibility index is calculated based on the NPD project phases where the partner is involved. $Phase_k$ is the set of phases where partner *k* is involved, and N_k is its cardinality. Notice that a partner *k* involved in a phase $p \in Phase_k$ performs either external activities (the focal company is not involved in the activities; the partner *k* may collaborate with other partners) or

collaborative one (the focal company collaborates with partner *k*; in addition, other partners may be involved) or a combination of collaborative and external activities.
For each partner *k* and for each phase $p \in Phase_k$, $J_{k,p,f,i}$ is the value of the feature $f \in F = \{quantity, accuracy, freshness\}$ of information $i \in \{Output, Status, Organization, Plan\}$ shared with the focal company. $J_{k,p,f,i}$ values are assessed by means of the qualitative scales shown in Table 1, 2, and 3.
The visibility that the focal company has on partner *k* is computed as follows:

$$NodeVisibility_k = \sqrt[3]{\prod_{f \in F} Visibility_{k,f}}$$

where:

$$Visibility_{k,f} = \sqrt[2]{Visibility\_Project\_Management_{k.f} \times Visibility\_Project\_Output_{k.f}} \quad \forall k, \forall f$$

$$Visibility\_Project\_Output_{k,f} = \sqrt[N_k]{\prod_{p \in Phase_k} J_{k,p,f,Output}} \quad \forall k, \forall f$$

$$Visibility\_PM_{k,f,i} = \sqrt[N_k]{\prod_{p \in Phase_k} J_{k,p,f,i}} \quad \forall k, \forall f, \forall i \in \{Status, Organization, Plan\}$$

$$Visibility\_Project\_Management_{k,f} = \sqrt[3]{\prod_{i \in \{Status, Organization, Plan\}} Visibility\_PM_{k,f,i}} \quad \forall k, \forall f$$

Finally, combining the scores of NodeVisibility on the partners, the index of visibility over the whole design chain is found:

$$DC\ Visibility = \sqrt[K]{\prod_{k=1}^{K} NodeVisibility_k}$$

Figure 2 shows an example of Design Chain. The NPD process is carried out by the focal company and two partners. The figure shows that each partner is involved in different phases of the project. Partner 1 collaborates with the Focal Company in the Concept Development phase (activity CD1), whereas is in charge of some activities during the System Level Design (activity SDL1) and the Detail Design phases (activity DD1). Partner 2 contributes to the Detail Design phase, being in charge with the DD2 activity, and collaborates with the focal company during the System Level Design phase (activity SLD2). Testing and refinement phase is managed entirely by Partner 2 (activity TR1). Planning and Production Ramp-up are managed internally.
Thus, in this example: *k* = 1, 2; $Phase_1$ = {Concept Development, System Level Design, Detail Design}; N_1 = 3; $Phase_2$ = {System Level Design, Detail Design, Testing and refinement}; N_2 = 3.

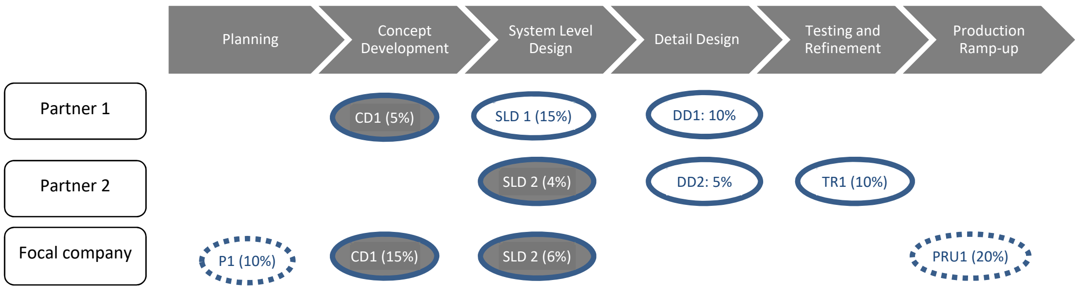


Figure 2. An example of Design chain.
Ovals legend: Gray = collaborative activities; White (Solid line) = external activities; White (Dotted line) = activities performed by the focal company only. The percentages indicate how many resources each activity absorbs out of the resources absorbed by the whole project.

For each partner *k* and each phase *p* in which the partner is involved, 12 values of the information features are assessed as shown in the following table. For the example depicted in Figure 2, 6 tables will be filled overall: 3 for Partner 1 (activities: CD1, SKD1, DD1) and 3 for Partner 2 (activities: SLD2, DD2, TR1). The $J_{k,p,f,I}$ values are the raw data used to calculate the DC Visibility index.

Table 4. $J_{k,p,f,I}$ values to assess in order to calculate the visibility on partner *k* during phase *i*.

Information features	**Information sets**			
	Output	Status	Organization	Plan
Quantity	$J_{k,p,Quantity,Output}$	$J_{k,p,Quantity,Status}$	$J_{k,p,Quantity,Organization}$	$J_{k,p,Quantity,Plan}$
Accuracy	$J_{k,p,Accuracy,Output}$	$J_{k,p,Accuracy,Status}$	$J_{k,p,Accuracy,Organization}$	$J_{k,p,Accuracy,Plan}$
Freshness	$J_{k,p,Freshness,Output}$	$J_{k,p,Freshness,Status}$	$J_{k,p,Freshness,Organization}$	$J_{k,p,Freshness,Plan}$

3.2 DC Virtuality and NodeRelevance

DC virtuality is measured based on the amount of outsourced NPD activities (Li and Qiu, 2006). The higher the amount of workload performed by the product development partners, the more virtual the design chain. Thus, a design chain whose partners perform 95% design activities and the focal company performs 5% only, is more virtual than a 50%-50% design chain.

However, the kind of outsourced activities also matters. For instance, let's consider two design chains where the amount of outsourced workload is the same. In one design chain, the reason for outsourcing is mainly cost savings, being the required technological knowledge a commodity. In the second design chain, the reason is to have access to the partner's exclusive technological knowledge. In this example, the second design chain is more virtual because the technological knowledge directly owned by the focal company is lower. Thus, the higher the know-how required to perform the outsourced activities, in terms of experience, commitment and certified competencies, the higher the DC virtuality.

Recalling Ulrich and Eppinger (2011) NPD phases, each phase *i* (*i* = 1, …6) is either performed completely outside the focal company by one or more partners, or entirely performed by the focal company, or performed by the focal company in collaboration with at least one partner (Gerwin, 2004).

In the example shown in Figure 2, the Focal Company performs the whole Planning phase and the whole Production Ramp-up phase, thus they are "internal". These phases absorb respectively the 10% and 20% of the resources of the whole project. During the Concept Development phase, the focal company collaborates with Partner 1. This phase accounts for the 20% of resources: 5% are Partner 1's resources, 15% are focal company's ones. The System Level Design phase encompasses two sets of activities. One of them (SLD1) is completely outsourced to Partner 1. Thus, it is an "external" activity. It absorbs 15% of the resources of the whole project. The second set of activities (SLD2) accounts for 10% and is performed by the focal company in collaboration with Partner 2. In particular, the partner provides 4% of the resources. All the activities of the Detail Design phase and of the Testing and Refinement phase are external. The former involves Partner 1 (activity DD1) and Partner 2 (activity DD2); the latter involves Partner 2 only.

For each activity *i* of the NPD process, the following attributes are defined:

$X_i \in [0;1]$ is the exclusivity of the know-how required by the activity *i*. X is the opposite of the spread of technological knowledge across the industry (Nelson, 1980). X equals 100% when the activity requires leading technological knowledge owned by one sole company (exclusive patent). It equals 0% when every single company in the industry owns the technological knowledge. Notice that, dealing with NPD projects, the occurrence of X = 0% is very limited. However, the lower X, the wider the spread of the technological knowledge across the industry: this means that the required technology knowledge is a commodity; if the activity is outsourced, the reason might be cost saving or a lack of internal design capacity (Rundquist and Halila, 2010).

- $Y_{i,a} \in (0;1)$ is the degree of importance of the amount of tasks performed by the actor *a* during activity *i*; it is the percentage of actor *a*'s resources during activity *i* out of the total amount of resources absorbed by the whole NPD process. Notice that both the focal company and her partners are actors of NPD process. In the case of an external or collaborative activity, two or more actors are involved in the activity (Gerwin, 2004). Notice that the sum over *i* and *a* of $Y_{i,a}$ is 100%.

Each NPD actor performs a set of activities within the NPD project. The higher the amount of workload the actor performs and the higher the capabilities required by those activities, the more relevant the actor is. Therefore, the measure of the NodeRelevance of actor *a* is provided by the following index:

$$NodeRelevance_a = \frac{\sum_{i=1}^{N}(X_i * Y_{i,a})}{\sum_{i=1}^{N}\sum_a(X_i * Y_{i,a})}$$

where *i* is an activity of the NPD process (*i* = 1, …, N).

DC Virtuality is the ratio between a proxy of the know-how employed by actors external to the company and the amount of know-how committed in the NPD project. Be *EA* the set of external actors (notice that the whole set of actors is *EA* U {Focal Company}). DC virtuality is calculated as follows:

$$DC\ Virtuality = \frac{\sum_{i=1}^{N}\sum_{a\in EA}(X_i * Y_{i,a})}{\sum_{i=1}^{N}\sum_a(X_i * Y_{i,a})} = \sum_{a\in EA} NodeRelevance_a$$

DC Virtuality is high when either the % of resources absorbed by the partners (Y) is high, or the capability degree of activities performed by the partners (X) is high, or a combination of both applies.

For example, the DC Virtuality of the design chain depicted in Figure 2 is calculated as shown in Table 5.

Table 5. DC Virtuality and NodeRelevance calculation.

		Activities								% Resources	Node Relevance	DC Virtuality
		P1	CD1	SLD1	SLD2	DD1	DD2	TR1	PRU1			
Y	Partner 1		5%	15%		10%				30.0%	39.2%	55.8%
	Partner 2				4%		5%	10%		19.0%	16.7%	
	Focal company	10%	15%		6%				20%	51.0%	44.2%	
X			80%	50%	80%	50%	90%	80%	40%	40%		

Table 5 shows that the DC Virtuality is 55.8%. Moreover, the percentage of resources managed by the two partners is 49% (30% + 19%), whereas the focal company manages 51% of the resources. The technological knowledge needed to perform partners' activities is higher than the one of focal company's activities.

3.3 Context variables

According to contingency theory (Donaldson, 2001; Sousa and Voss, 2008), a list of context variables that might affect the relationship between visibility and virtuality has been defined based on the literature review:

- NPD project innovativeness. According to Wheelwright and Clark (1992), NPD projects' innovativeness increases when shifting from derivatives to platforms, to breakthrough. The higher the innovativeness, the higher the need for collaboration (Pero et al., 2010), and the need for the company to involve external partners having new or complementary know-how (Engardino and Einhorn, 2005; Quinn, 2000), especially relating to critical technology embedded in the new product (Hakansson, 1987; Bonaccorsi and Lipparini, 1994; Nishiguchi and Ikeda, 1996). In breakthrough projects, partners are strongly involved in the initial phases of NPD project (Wagner and Hoegl, 2006; Afuah, 2000).
- Partner location (local, regional, global). The higher the distance between the focal company and its partners, the more difficult coordination (Wagner and Hoegl, 2006), and the stronger the need of exchanging good quality information. Moreover, Frigant and Lung (2002) state that face-to-face meetings with local partners are more frequent and less costly.
- Partner size (revenues, number of employees). Compared to small partners, large partners (>50 Mln euros; 250 employees) tend to have more rationalized operations based on their experience and tend to retain routines that have proved to be previously successful (Myers et al., 1997). Therefore, the focal company and large partners can easily set up a process of information sharing. On the other hand, when the partner is a small company (<10 Mln euros; 50 employees), her decision processes are usually lean and the bargaining power of the buyer (focal company) is stronger: these conditions set the base for a rapid roll-out of projects aiming at increasing focal company's visibility on partners. Therefore, the role of this context variable is controversial and needs more investigation.
- Partner integration. Information sharing is the major vehicle that allows the involved NPD actors to become integrated (Moenaert and Souder, 1990; Sivadas and Dwyer, 2000). Partner integration is classified in line with Petersen et al. (2005) as white box, gray box, and black

box. Under a white box integration, the focal company designs the product, whereas the partner works as a consultant supporting the development. Gray box means that the project activities are performed jointly: focal company and partners share technology and make joint decisions regarding design specifications. Black box means that the partner designs the product based on focal company's design requirements; the partners takes the full responsibility for the design process. In the case of gray box integration, a much richer and more formal relationship is created; here, collaboration is much higher as well as closer (Arikan and Enginoglu, 2016).

- Mutual trust. Trust is important in order to gain a real competitive advantage from collaboration with partners (Freeman et al., 2009; Brun and Pero, 2011). The higher the degree of trust, the higher the tendency to share information and know-how with business partners (Dyer and Ouchi,1993; Cheng et al., 2009; Bstieler et al., 2004; Talke and Hultink, 2010). Trust is measured as the length of the relationship between the focal company and the partner: "low" means less than 5-year relationship; "medium" means more than 5-year long relationship; "high" means more than 10-year relationship.
- ICT support. It is classified in line with Welker et al. (2008) as extensive, moderate, low or null use of ICT. Extensive use of ICT means that information is shared between two actors from different companies through an information system (e.g. the availability of product information through an online catalog). Moderate use of ICT means that actors share information by fax or phone, and sometimes by email or EDI. Low or null use of ICT means that the actors share information through direct contact, e.g. by phone or in face-to-face meetings.

4. Research methodology

In order to study DC Virtuality, DC Visibility, and the relationship between them a multiple case study approach was adopted (Yin, 2003; Voss *et al*., 2002). The case study methodology is appropriate when the research is exploratory and the phenomenon under investigation is still poorly studied, as it offers the opportunity to achieve in-depth results through direct experience (Voss *et al*., 2002).

Coherently with the research framework, a purposive sample was selected to include only NPD projects where the focal company involved a set of heterogeneous partners to carry on some activities of the NPD project, thus a Design Chain exists (Patton, 2002).

Based on the replication logic (Yin, 2003), the sample size was chosen so as to obtain both convergent (literal replication) and contrasting results (theoretical replication). Yin (2003) proposes the usage of around 6-10 cases arranged effectively by selecting 2-3 cases for literal replication and 4-6 cases for theoretical replication. Eisenhardt (1989) claims that "a number between 4 and 10 cases usually works well". The sample is made of seven case studies and is depicted in Table 6.

The unit of analysis is an NPD project that the focal company carried out relying on a Design Chain. During the case studies, information was collected by means of semi-structured interviews and documentary analysis.

Direct interviews were conducted in the focal company, with product managers, project managers, design managers, NPD managers. Each interview was two to three hour long. The interviewed managers were asked to pick an NPD project in which his/her company had acted as the focal company of the Design Chain. The managers described the project and the Design Chain: what product was developed, what partners have been involved, what activities were in charge of each partner, what information the partners had to share with the focal company, how often, and what accuracy and freshness the shared information had. Moreover, during the field trip, archival data about the NPD project were also accessed in order to corroborate information from the interviews and to collect relevant information about the involvement of each partner into the project. Company website was also consulted before the field trip in order to get prepared for the interview. After the field trip, online information about the project was consulted, if available, with the aim of corroborating the information gathered during the interviews and add more qualitative information if possible.

Beside the qualitative information about the project and the Design Chain, each manager was asked to assess the amount and the quality of the information exchanged with the partners during the project. In order to collect the value of quantity/accuracy/freshness of the exchanged information, the qualitative scales shown in Tables 1, 2, and 3 were used. Each manager was asked to fill in a table similar to Table 4 for each partner and each NPD phase in which the partner was involved. Moreover, the interviewed managers were asked to provide information about the building blocks of the virtuality index. To this purpose, a table similar to Table 5 was filled in. The X values and the Y values were assessed based on the knowledge of the managers and based on archival data (mainly, the contract signed with the partners). During the interviews, information relating the context variables was collected as well.

Data were triangulated using multiple sources of evidence, namely direct interviews, direct observation in the company, documents provided by the company, and available online information about the product under study. Two to three researchers conducted each interview. In most cases, upon permission by the interviewee, interviews were recorded to prevent information loss.

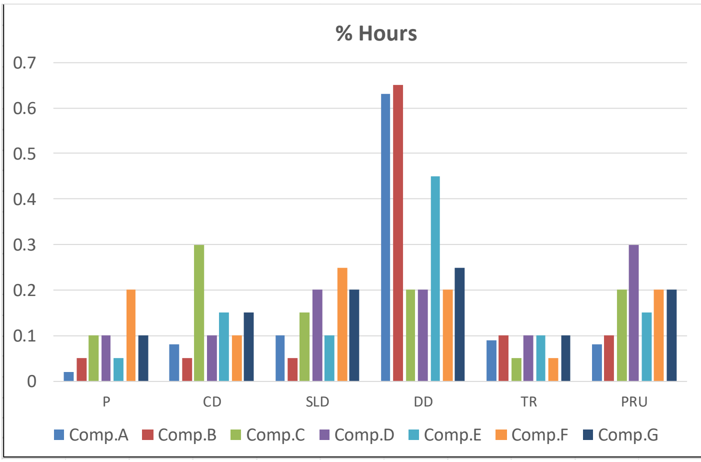
Data collected through the case studies were used to realize a cross-case analysis. NodeRelevance, NodeVisibility, DC Visibility and DC Virtuality indexes were calculated for each Design Chain. Thus, it was possible to analyze how the NodeVisibility changes according to the NodeRelevance of the partners and to the context variables value. Moreover, DC Visibility was studied across the case studies and the impact of DC Virtuality on DC Visibility was studied depending on the values of the context variables. The qualitative information gathered during the field trips (mainly, about the product, the NPD project, the content of NPD activities outsourced to the partners) was extremely useful in order to interpret and discuss the findings.

Company	**Main business**	**Size**	**NPD project (unit of analysis)**
A	Baby products	€200 million of revenues (2013)	Car seat
B	Consumer goods	More than €50 billion of revenues (2012)	Dishwashing soap
C	Mobile phones	n.a.	Mini mobile phone
D	Electronic cigarettes	n.a.	Lady cigarette
E	Plastic furniture	More than €100 million of revenues (2012)	Plastic chair
F	Engineering and contracting	€2.2 billion of revenues (2012)	Subway viaduct
G	Led Lighting	n.a.	Led component

Table 6. Sample description.

5. Empirical evidences

Based on the data collected, a first analysis of the sample was carried out. The following chart depicts the percentage distribution of the hours across the six phases of each NPD project under study (Planning, P; Concept Development, CD; System-Level Design, SLD; Detail Design, DD; Testing and Refinement, TR; Production Ramp-Up, PRU). Moreover, for each NPD phase, the table shows the percentage distribution of the hours across different kinds of activities: internal (%int), external (%ext), and collaborative (%coll).



Company	%	P	CD	SLD	DD	TR	PRU	Total
A	% coll	-	-	-	0.5	-	-	0.5
	% ext	-	-	-	0.03	0.02	-	0.05
	% int	0.02	0.08	0.1	0.1	0.07	0.08	0.45
B	% coll	-	-	-	0.55	0.1	-	0.65
	% ext	-	-	-	-	-	-	-
	% int	0.05	0.05	0.05	0.1	-	0.1	0.35
C	% coll	-	0.3	-	-	-	-	0.3
	% ext	-	-	0.15	0.2	0.05	0.2	0.6
	% int	0.1	-	-	-	-	-	0.1
D	% coll	-	-	-	0.2	-	-	0.2
	% ext	-	-	-	-	0.1	0.3	0.4
	% int	0.1	0.1	0.2	-	-	-	0.4
E	% coll	-	0.15	0.1	0.45	0.06	-	0.76
	% ext	-	-	-	-	-	0.15	0.15
	% int	0.05	-	-	-	0.04	-	0.09
F	% coll	-	0.1	0.25	-	-	0.2	0.55
	% ext	-	-	-	0.2	0.05	-	0.25
	% int	0.2	-	-	-	-	-	0.2
G	% coll	-	-	0.2	0.25	0.1	-	0.55
	% ext	-	-	-	-	-	-	0
	% int	0.1	0.15	-	-	-	0.2	0.45

Figure 3. Analysis of the phases of each NPD project under study.

Figure 3 shows that Planning (P) is managed always internally. In most of the projects, Detail Design (DD) phase absorbs most of the hours of the NPD project. Moreover, the table shows that, in most of the cases, each NPD phase is either internal, external, or collaborative and it is seldom a mix of them. Mixed activities are found rarely in the sample: for instance, during the Detail Design of her car seat project, Company A managed some activities internally, few activities were external, and most activities were collaborative.

It's interesting to highlight that in every NPD project the total of external and collaborative percentage hours (last column of the table) represents more the half of the hours of the project (it ranges from 55% to 91%). This confirms that design chain played a relevant role in every NPD project under study.

Table 7 summarizes the main features of the design chains under study. For each design chain, the list of partners involved in each NPD phase is provided. Each Design Chain involves few partners (2 to 8). For each partner, the table shows the score of NodeRelevance and NodeVisibility.

The NodeRelevance of each partner has been calculated using the formula in Section 3.2. For each activity (*i*) and each partner (*a*) the values of the variables X_i and $Y_{i,a}$ (Section 3.2) are reported in Annex 1. DC Virtuality has been determined summing up the NodeRelevance of the partners of the Design Chain.

As far as NodeVisibility is concerned, the scores of visibility have been calculated using the formulas in Section 3.1. One $J_{k,p,f,I}$ value has been assessed during the interviews for each partner k , each NPD phase p, each feature f (quantity, accuracy, freshness), and each information i (output, status, organization, plan). For instance, for Case A, 4x6x3x4 = 288 distinct values of $J_{k,p,f,I}$ have been assessed during the interview. By combining the $J_{k,p,f,I}$ values, NodeVisibility has been calculated, as shown in Annex 2. By combining NodeVisibility values, DC Visibility has been determined.

Figure 4 plots the scores of DC Visibility and DC Virtuality across the seven case studies. An interesting result is that more virtual the design chain, the higher the visibility focal company has on its partners.

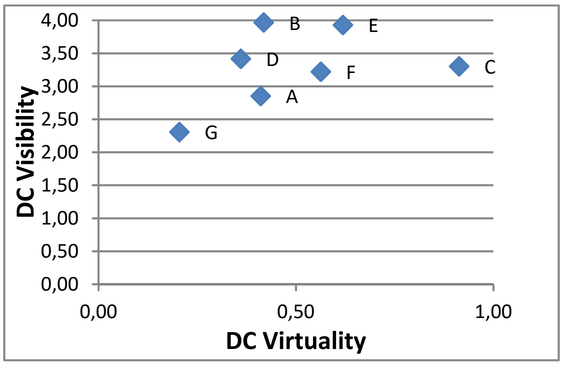


Figure 4. DCVisibility and DCVirtuality in the sample.

Table 7. Main features and indexes value of the design chains under study.

Company	Innovativeness		NPD phases						Context variables					Node	Node	DC	DC
		Partner	P	CD	SLD	DD	TR	PRU	Location	Size	Trust	ICT	Integration	Relevance	Visibility	Virtuality	Visibility
A	Platform	A1				X			Local	large	low	medium	gray	0.239	3.05	0.41	2.85
		A2				X			Local	medium	low	medium	gray	0.120	3.63		
		A3				X			Local	large	high	medium	black	0.036	2.20		
		A4					X		Local	large	high	medium	black	0.016	2.71		
B	Platform	B1				X	X		Local	large	high	medium	gray	0.098	3.94	0.42	3.97
		B2				X			Local	large	high	medium	gray	0.092	3.94		
		B3				X	X		Local	large	high	high	gray	0.065	4.00		
		B4				X	X		Local	large	high	medium	gray	0.163	4.00		
C	Derivative	C1		X	X				Global	large	low	medium	black	0.216	3.41	0.91	3.30
		C2		X	X				Global	medium	medium	medium	black	0.216	3.41		
		C3				X	X		Global	medium	low	medium	black	0.273	3.32		
		C4						X	Global	large	medium	medium	black	0.208	3.09		
D	Derivative	D1				X	X	X	Global	large	low	high	gray	0.302	3.54	0.36	3.42
		D2				X			Local	small	low	medium	gray	0.058	3.30		
E	Breakthrough	E1		X	X	X			Regional	small	high	medium	gray	0.154	4.00	0.62	3.93
		E2				X	X		Regional	large	high	medium	gray	0.021	3.81		
		E3				X	X	X	Local	small	high	medium	gray	0.444	3.98		
F	Platform	F1		X	X	X	X	X	Local	medium	low	high	gray	0.223	3.19	0.56	3.22
		F2		X	X				Global	medium	high	high	gray	0.041	3.25		
		F3		X	X	X	X	X	Local	large	low	high	gray	0.223	3.42		
		F4		X	X			X	Local	large	low	high	black	0.077	3.04		
G	Breakthrough	G1			X	X	X		Local	small	high	medium	white	0.026	2.37	0.20	2.31
		G2			X	X	X		Regional	large	medium	medium	black	0.026	2.55		
		G3			X	X	X		Regional	large	high	high	white	0.026	2.87		
		G4			X	X	X		Local	large	low	medium	black	0.026	1.77		
		G5			X	X	X		Local	medium	medium	medium	gray	0.026	1.99		
		G6			X	X	X		Local	small	medium	medium	black	0.026	2.22		
		G7			X	X	X		Local	medium	low	medium	black	0.026	2.30		
		G8			X	X	X		Global	large	low	medium	white	0.026	2.61		

In the following, a discussion of the scores of DC Virtuality and DC Visibility is provided.
Company A's visibility on the design chain is below the average of the sample. Both partner A1 and A2 work jointly with the focal company to develop the detail design of two different components of the car seat (skeleton and fabric respectively), whereas A3 is in charge of the detail design of the seat belt. A4 is in charge of the Test and Refinement phase. A3 and A4 are black box, and they exchange few data with the focal company. The company does not use IT platforms to exchange data. Also DC virtuality is below average: most of the competencies needed to develop the new car seat are available inside the company. Only a few competences have been involved from outside the company, with the aim to reach the time to market as fastest as possible. A2 is a critical partner since she develops jointly with the focal company the detail design of the seat's skeleton: on one hand, A2 partner has access to Company A's information system; on the other hand, Company A has visibility on partner's project output and project management.
Company B has a high score of DC visibility. All the partners develop their activities jointly with the focal company (gray integration). An established long-term relationship with her partners (more than 20 years) allows Company B to exchange continuously information with them, especially about project management. Company B collaborates with external partners for Detail Design, and Testing and Refinement, because she has few internal competencies of package designing. Partner B4 is in charge of mold design and testing; it operates inside Company B's manufacturing plant: for this reason company's visibility on project output (PO) and project management (PM) data is very high. Partner B3 is in charge of the soap's perfume design. She communicates with Company B by means of an IT technology platform, supporting fresh and accurate information exchange.
When it comes to Company C, all manufacturing and design activities are performed externally, except for the Planning phase. For this reason, the company needs to maintain a high visibility on the design chain. Having access to partners' planning and status information, Company C can prevent a delay of the product launch. A long-term relationship (since 2008) links partner C4 to Company C, and Company C trusts this partner more than the others. Therefore, Company C does not control C4's project management data, although the partner would be willing to share the data.
The information that Company D exchanges with her partners is above average. The exchanged information is mainly related to product output and less to project management and organization. Partner D2 is a small and local partner, with whom Company D collaborates in order to develop the formula of the liquid inside electronic cigarettes. Company D keeps a strict control of D2 activities. However, visibility is higher on partner D1 because information sharing is supported by the IT system, so providing high freshness and accuracy.
Company E continuously exchanges information with its partners about both project output and management. In four out of six phases of NPD process (namely Concept Development, System Level Design, Detail Design, and Testing and Refinement) Company E collaborates with external partners, whereas Production Ramp-up is fully outsourced. A long-term relationship between Company E and her partners allows the intense exchange of information. Partner E3 is a small company that produces molds. E3 is extensively involved in the project: she collaborates with the focal company during Detail Design, and Testing and Refinement and is in charge of Production Ramp-up. Although the high trust, Company E has required accessing data about the management of activities (PM) in order to better control the project.
Company F keeps a continuous control on the activities carried out by the partners involved in the NPD project. The information about both project output and project management are visible to the focal company. Partner F4 is in charge with the viaduct feasibility study and is a "black-box" partner.

Visibility on partner F4 is lower compared to the partners. Partner F3 is involved in all the NPD phases (except for Planning) and is in charge of the viaduct's architectural design, which is critical to bid successfully for a contract. For this reason, the visibility on partner F3 is higher than on other partners, both in terms of PO and PM data.

Company G's design chain is not as virtual as the others in the sample are. External partners are involved in three NPD phases (System design, Detail Design, and Testing and Refinement) but the relevance of outsourced activities is limited. No phase is completely outsourced. The visibility is limited as well: the quantity of information exchanged is low; accuracy and freshness are scarce, especially when information is exchanged with small partners. The highest scores of visibility are related to partners G2 (lenses), G3 (electronic board), and G8 (aluminum parts). They are located in Finland, Switzerland, and China respectively, whereas Company G is located in Italy. They are large companies and this facilitates the exchange of information. An ICT platform supports the visibility of Company G on partner G3; thus, the visibility score is higher than for other partners.

Comparing the partners' scores of NodeVisibility and NodeRelevance (Figure 5), the NodeVisibility is higher on the partners that are more involved in the NPD project (high NodeRelevance). However, given a certain NodeRelevance, the score of NodeVisibility assumes diverse values. This is true in particular for low values of NodeRelevance. The analysis of context variables helps to interpret this result.

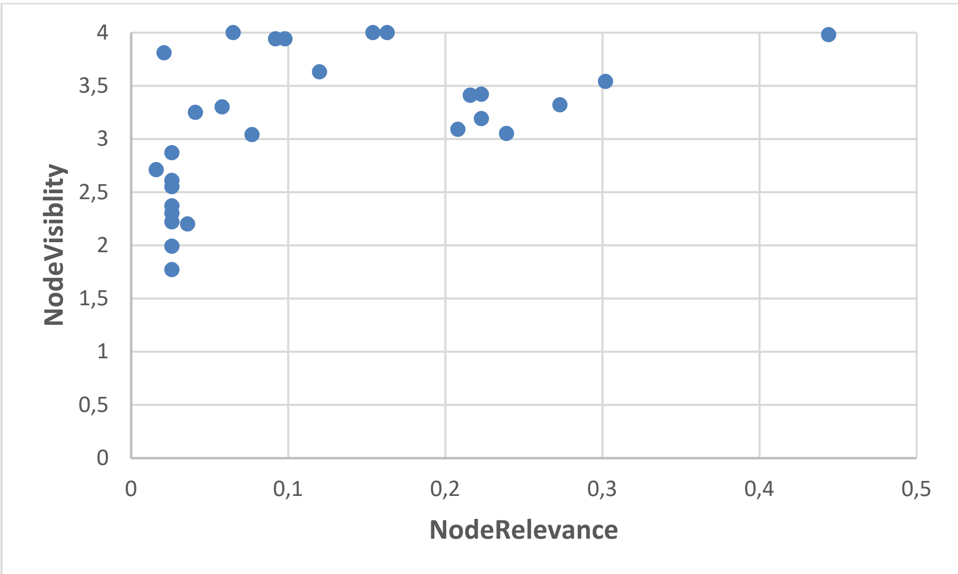


Figure 5. NodeVisibility and NodeRelevance of the partners in the sample.

5.1 The role of the context variables

For each case study, the values of context variables are reported in Table 7. It is worth understanding how the relationship between visibility and virtuality varies with the context variables. Based on the empirical research, it can be observed that a subset of context variables plays a major role in determining visibility. They are partner location, partner integration, mutual trust and ICT support. With regard to the other context variables, no interesting results emerge.

Companies B and E have the highest score of DC Visibility. Both companies use gray box integration with their partners, so they need to monitor partners' activities in order to be sure that they act properly. Both of them develop Detail Design in collaboration with external partners. This phase is the most complex and involves the highest number of external actors. Moreover, both companies have established a long-term relationship with their partners. Trust and risk sharing make collaboration with partners effective: the partners are willing to give focal company visibility on single activities and the focal company is kept informed about the project plan, team composition, and project status.

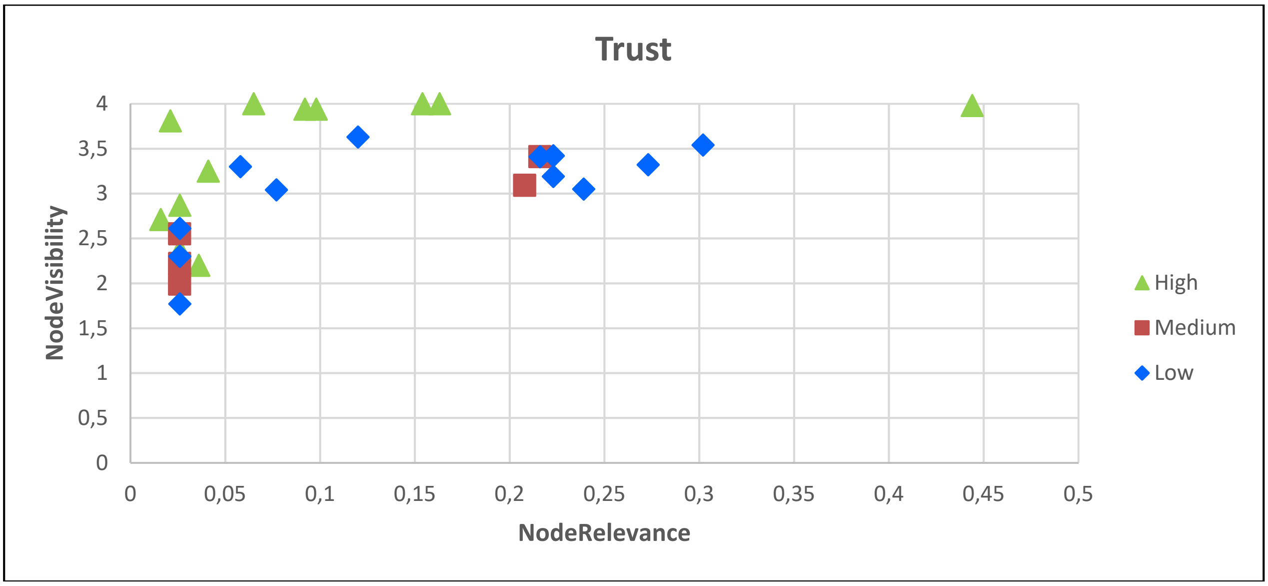


Figure 6. NodeVisibility and NodeRelevance depending on trust.

Figure 6 shows the NodeVisibility-NodeRelevance chart depending on the trust between focal company and partners. It can be noticed that the high visibility on a partner implies high trust. However, having high trust is not necessarily implying high visibility. As for the case of C4 discussed above, focal companies do not always want the visibility on the partner, since visibility has a cost.
As far as the variable Partner Integration is concerned, in the case of gray box integration the quantity of exchange data is high as well as their freshness and accuracy. In the case of black box, the overall visibility is low. Nevertheless, by analyzing the components of visibility (i.e. quantity, freshness, and accuracy) it can be noticed that in the case of black box integration the quantity of exchanged information is low but accuracy and freshness are high. The following figure shows how NodeVisibility and NoreRelevance vary depending on the value of partner integration.

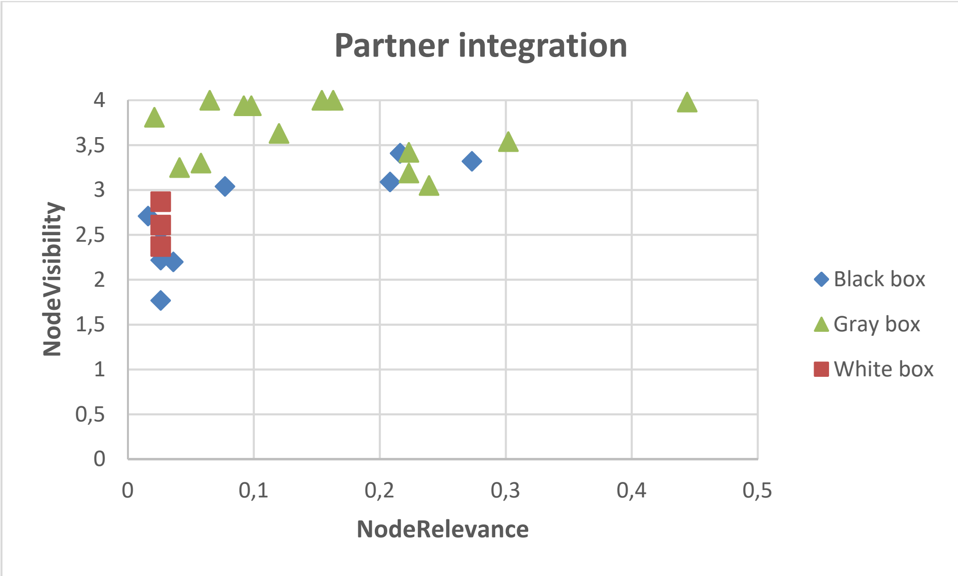


Figure 7. NodeVisibility and NodeRelevance depending on partner integration.

When it comes to ICT support, in some design chains (namely Company B, D, and G) ICT support ranges from medium to high depending on the partner. This means that the focal company is integrated with some partners by means of medium ICT support and with some others by means of high ICT support. In all these cases, the NodeVisibility is higher the higher the ICT support is. For instance, Company G's visibility on partner G3 is positively affected by the higher ICT tools compared to the other partners.

Finally, partner location does not affect the overall score of NodeVisibility but it affects its features. In particular, the information exchanged with global partners is much more accurate than that exchanged with local and regional partners. When working with overseas partners, there is a high need of formalization due to e.g. different language and time zones. Table 8 summarizes the impact of the above-stated context variables on visibility.

Table 8. The impact of context variables on visibility.

	Impact of the context variables on visibility
Mutual trust	The highest the length of business relationship the higher trust and visibility.
Partner integration	In black box integration, visibility is low, it is intermediate for white box, and high for gray box integration. The quantity of exchange information is particularly affected by the kind of partner integration.
Partner location	The accuracy of information exchanged with global partners is higher than that with local partners.
ICT support	When information exchange is supported by ICT tools, visibility on partners is higher. In particular, accuracy and freshness of exchanged information increase.

6. Conclusions and future remarks

In this paper, we investigated how much information focal companies exchange with the partners of the design chain (i.e. DC Visibility) depending on the degree of the virtuality of the design chain (i.e. DC Virtuality). In the literature many contributions maintain that information sharing is essential for the success of NPD projects (e.g. Kalluri and Kodali, 2014; Hoegle and Wagner, 2005, Lawson et al. 2009). Despite the relevance of this topic, the extant research lacks a network perspective and it is mainly focused on dyadic relationship (Johnsen, 2009). Therefore, the main objective of this paper was to enlarge the scope of research to include the network perspective when studying the relationship between DC Virtuality and DC Visibility. To this purpose, the paper proposes an original measurement approach of DC Visibility and DC Virtuality. The proposed approach has been successfully applied to seven NPD projects. Each case study per se represents an important contribution to the empirical research about design chains: it provides an example of a design chain, showing its structure (actors involved, relevance of each of them) and the way the design chain is managed (what visibility on what actors). The relevance of providing empirical examples about design chains should be evaluated in the light of the extant lack of empirical studies, as recently suggested by Shen et al. (2016).
An interesting result of the cross-case analysis is that the more virtual the design chain, the higher the visibility the focal company has on her partners. This result is in line with the previous findings about collaborative product development (Sivadas and Dwyer, 2000). Moreover, this result confirms that when the DC Virtuality is high, more integrated information accessible by players within the network can enhance collaborative product development, as already found in the literature (among the others, Noori and Lee, 2004).

Another relevant result of the paper is that the amount of shared information varies as both the relevance of the partner (NodeRelevance) and certain features relating to product and to the business relationship change. This general result is in line with Petersen et al. (2005), and Yan and Dooley (2014). More specifically, we found that trust, partner integration, partner location and ICT support play a relevant role. Table 8 shows the impact of the context variables on the visibility that the focal company has on the DC partner. In the empirical analysis, we found that high visibility is associated with high trust and high ICT support. Moreover, when working with global partners, focal companies have higher visibility and ask for a higher formalization of the exchanged information. Partner integration affects visibility, which is higher in case of gray box integration, intermediate for white box, and low for black box integration. These results suggest that when dealing with the topic of DC visibility one size does not fit all, and managers should choose the right amount of information to be shared with the partners depending on NodeRelevance, trust, partner integration and location, and ICT support.

As far as the relevance for practitioners is concerned, the paper provides a measurement approach that managers can use to analyze the design chain in order to discover the opportunities provided by information sharing. The visibility and virtuality indexes provide a useful managerial tool to evaluate whether a focal company has the possibility to build competitive advantages that exploit unique resources beyond the boundaries of the company. By measuring the indexes proposed in this paper, a focal company can compare its visibility to that of the best-in-the-class, thereby gathering useful hints to improve visibility inside the design chain. For instance, if two companies have similar visibility on their design chains, it may happen that one of them shares a huge quantity of low-quality information, whereas the other one has access to a low quantity of high-quality information. Therefore, the first company should invest in information accuracy and freshness, whereas the second one should increase the amount of shared information. Moreover, the proposed indexes might help to compare visibility and virtuality across different design chains (i.e. different NPD projects within the same company or different companies). In fact, DC virtuality (and context variables) being equal, a lower score of DC visibility might suggest a possible weak area to work on in order to improve the performance (time, quality, and cost) of the NPD project. The indexes can be used to benchmark a company's performance against the competitors, to set priorities to improve visibility (e.g. what partners are worth working first), to measure the value of information sharing projects (e.g. investments in ICT tools).

The main limitation of this study is the sample, which was chosen to test the applicability of the model to different contexts, but it is small and heterogeneous. A larger sample is needed in order to generalize the impact of context variables. Moreover, a larger sample would allow carrying out a statistical analysis and benchmarking different design chains. Different samples should be chosen for different industries since some industry features (e.g. product complexity) may influence visibility and virtuality level and blunt cross-industry evaluation. Finally, the analysis of the impact of context variables on the level of visibility and virtuality carried out in this paper suggests some research questions that should be further investigated in a future empirical analysis.

References

Afuah, A.N. (2000), " How much do your competitors' capabilities matter in the face of a technological change?", *Strategic Management Journal,* Vol.21, pp. 387–404.

Arikan, C. L. and Enginoglu, D. (2016), "A qualitative study on supplier relationship management in new product development process", *Journal of Research In Social Sciences*, Vol. 6. No. 5, pp. pg 1-10.

Bonaccorsi A. and Lipparini A. (1994), "Strategic partnerships in new product development: an Italian case study", *Journal of Product Innovation Management,* Vol. 11, pp. 134–145.

Bradfield, D. J. and Gaob, J. X. (2007), "A methodology to facilitate knowledge sharing in the new product development process", *International Journal of Production Research,* Vol. 45, pp. 1489-1504.

Bradley, P. (2002), "How far can you see", *Logistics Management*, Vol. 41 No. 9, pp. 27-34.

Brun, A. and Pero., M. (2011), "Assessing suppliers for strategic integration: a portfolio approach", *International Journal of Business Excellence*, Vol.4 No. 3, pp. 346-370.

Bstieler, L. and Hemmert, M. (2004), "Increasing Learning and Time Efficiency in Interorganizational New Product Development Teams", *Journal of Product Innovation Management*, Vol. 27, pp. 485-499.

Büyüközkan, G. and Arsenyan, J. (2012), "Collaborative product development: a literature overview", *Production Planning & Control*, Vol. 23 No.1, pp. 47-66.

Caniato, F., Crippa, L., Pero, M., Sianesi, A. and Spina, G. (2015). "Internationalisation and outsourcing of operations and product development in the fashion industry", *Production Planning and Control*, Vol. 26 No. 9, pp.706-722.

Caridi, M., Crippa, L., Perego, A., Sianesi, A. and Tumino, A. (2010), "Do virtuality and complexity affect supply chain visibility?". *International Journal of Production Economics*, Vol. 127 No. 2, pp. 372-383.

Caridi, M., Crippa, L., Perego, A., Sianesi, A. and Tumino, A. (2010a), "Measuring visibility to improve supply chain performance: a quantitative approach", *Benchmarking: an International Journal*, Vol. 17 No. 4, pp. 593-615.

Carr, A.S. and Pearson, J.N. (1999), "Strategically managed buyer-seller relationships and performance outcomes", *Journal of Operations Management*, Vol. 17 No. 5, pp. 497–519.

Chen, F., Drezner, Z., Ryan, J.K. and Simchi-Levi, D. (2000), "Quantifying the bullwhip effect in a simple supply chain: the impact of forecasting, lead-times and information", *Management Science*, Vol. 46 No. 3, pp. 436-43.

Cheng, J., Law K., Bjornsson H., Jones A. and Sriram, R. (2009), "A service oriented framework for construction supply chain integration", *Automation in Construction*, Vol. 19 No. 2, pp. 245-260.

Choi, T.Y. and Wu, Z. (2009), "Taking the leap from dyads to triads: Buyer–supplier relationships in supply networks", *Journal of Purchasing and Supply Management*, Vol. 15 No. 4, pp. 263-266.

Clark, K. B. and Wheelwright, S. C. (1992), **"**Organizing and leading "heavyweight" development teams" *California Management Review*, Vol. 34 No. 3, pp. 9–28.

Closs, D.J., Goldsby, T.J. and Clinton, S.R. (1997), "Information technology influences on world class logistics capability", *International Journal of Physical Distribution and Logistics Management*, Vol. 27 No. 1, pp. 4-17.

Coase, R. H. (1937), "The Nature of the Firm," *Economica*, Vol. 4, pp. 386-405.

Donaldson, L. (2001), *The Contingency Theory of Organizations*. Sage Publications

Dyer, J.H. and Ouchi, W.G. (1993), "Japanese-Style Partnerships: Giving Companies a Competitive Edge", *Sloan Management Review*, Vol. 35 No. 1, pp. 51-63.

Eisenhardt, K.M. (1989), " Theories from Case Study Research", *The Academy of Management Review*, Vol. 14 No. 4, pp. 532-550.

Emden, Z., Calantone, R.J. and Droge, C. (2006), "Collaborating for new product development: selecting the partner with maximum potential to create value", *Journal of Product Innovation Management*, Vol. 23 No. 4, pp. 330–341.

Engardino, P. and Einhorn, B. (2005), "Special report: Outsourcing innovation", *Business Week*, Vol. 3925, pp. 46−53.

Eriksson, M., Lilliesköld, J., Jonsson, N. and Novosel, D. (2002), "How to manage complex, multinational R & D projects successfully", *Engineering Management Journal*, Vol. 14 No. 2, pp. 53-60.

Freeman, S., Hutchings, K., Lazaris M. and Zyngier S. (2009), "A model of rapid knowledge development: The smaller born-global firm", *International Business Review*, Vol. 19 No. 1, pp. 70-84

Frigant, V. and Lung, Y. (2002), "Geographical proximity and supplying relationship in modular production", *International Journal of Urban and Regional Research*, Vol. 26, pp. 742-755.

Frohlich, M. and Westbrook, R. (2001), "Arcs of integration: an international study of supply chain strategies", *Journal of Operations Management* , Vol. 19 No. 2, pp. 185–200.

Gerwin, D. (2004), "Coordinating new product development in strategic alliances", *Academy of Management Review*, Vol. 29 No. 2, pp. 241-257.

Ghoshal, S. and Bartlett, C.A. (1990), “The multinational corporation as an interorganisational network”, *Academy of Management Review*, Vol. 15, pp. 603–623.

Giunipero, L.C. (1990), “Motivating and monitoring JIT supplier performance”, *Journal of Purchasing and Materials Management* , Vol. 26 No.3, pp. 19–24.

Håkansson, H. (1987), “Industrial Technological Development” London. Croom Helm.

Harmancioglu, N., McNally, R.C., Calantone, R.J. and Durmusoglu, S.S. (2007), “Your new product development (NPD) is only as good as your process: An exploratory analysis of new NPD process design and implementation”, *R&D Management*, Vol. 37 No.5, pp. 399-424.

Hoegl, M. and Wagner, S.M. (2005), “Buyer-supplier collaboration in product development projects”, *Journal of Management*, Vol. 31 No. 4, pp. 530-548.

Hoopes, D.G. and Postrel, S. (1999), “Shared knowledge, “glitches”, and product development performance”, *Strategic Management Journal,* Vol. 20, pp. 837-865.

Howells, J., James, A. and Malik, K. (2003), “The sourcing of technological knowledge: Distributed innovation processes and dynamic change”, *R&D Management*, Vol. 33 No.4, pp. 395–414.

Jacobs, F.R. and Chase, R.B. (2014), *Operations and Supply Chain Management*, New York : McGraw-Hill/Irwin, 14th ed.

Jepsen, L.B. (2013), “Complex new product development projects: How the project manager's information sharing with core actors changes over time”, *Project Management Journal*, Vol. 44 No. 6, pp. 20-35.

Johnsen, T. E. (2009), “Supplier involvement in new product development and innovation: Taking stock and looking to the future”, *Journal of Purchasing and Supply Management*, Vol. 15 No. 3, pp. 187-197.

Kaipia, R. and Hartiala, H. (2006), “Information-sharing in supply chains: proposals on how to proceed”, *The International Journal of Logistics Management*, Vol. 17 No. 3, pp. 377-393.

Kalluri, V. and Kodali, R. (2014), “Analysis of new product development research: 1998-2009", *Benchmarking: An International Journal*, Vol. 21 No. 4, pp. 527 – 618.

Kim, Y., Choi, T.Y. and Skilton, P.F (2015), "Buyer-supplier embeddedness and patterns of innovation", *International Journal of Operations & Production Management*, Vol. 35 No. 3, pp.318 – 345.

Klueber, R. and O’Keefe, R.M. (2013), “Defining and assessing requisite supply chain visibility in regulated industries”, *Journal of Enterprise Information Management* , Vol. 26 No. 3, pp. 295-315.

Knudsen, M.P. (2007), **“**The relative importance of interfirm relationships and knowledge transfer for new product development success”, *Journal of Product Innovation Management*, Vol. 24 No. 2, pp. 117–138.

Lai, E.L.C., Riezman, R. and Wang P. (2009). “Outsourcing of innovation”. *Economic Theory*, Vol. 38 No. 3, pp. 485–515.

Lawson, B., Petersen, K.J., Cousins, P.D. and Handfield, R.B. (2009), “Knowledge sharing in interorganizational product development teams: The effect of formal and informal socialization mechanisms”, *Journal of Product Innovation Management*, Vol. 26 No. 2, pp. 156-172.

Li, W.D. and Qiu, Z.M. (2006), “State-of-the-art technologies and methodologies for collaborative product development systems”, *International Journal of Production Research*, Vol. 44 No. 13, pp. 2525–2559.

Lindström, J., Löfstrand, M., Karlberg, M. and Karlsson L. (2012), “Functional product development: what information should be shared during the development process?”, *International Journal of Product Development* , Vol. 16 No. 2, pp. 95-111.

Littler, D., Leverick, F. and Bruce, M. (1995). “Factors affecting the process of collaborative product development: a study of UK manufacturers of information and communications technology products”, *Journal of Product Innovation Management*, Vol. 12 No. 1, pp. 16–32.

Liu, S.-S. and Shih, K.-C. (2009), “Construction rescheduling based on a manufacturing rescheduling framework”, *Automation in Construction*, Vol. 18 No. 6, pp. 715-723.

Moenaert, R. K. and Souder, W.E. (1990), “An information transfer model for integrating marketing and R&D personnel in new product development projects”. *Journal of Product Innovation Management*, Vol. 7 No. 2, pp. 91-107.

Morelli, M.D., Eppinger, S.D. and Gulati, R.K. (1995), “Predicting technical communication in product development organisations” *IEEE Transactions on Engineering Management*, Vol. 42, pp. 215–222.

Myers, C., Hall, T. and Pitt, D. (1997), *The Responsible Software Engineer: Selected Readings in IT Professionalism*, Springer London, London.

Nelson, R.R. (1980), “Production Sets, Technological Knowledge, and R & D: Fragile and Overworked Constructs for Analysis of Productivity Growth?”, *The American Economic Review*, Vol. 70 No. 2, pp. 62- 67

Nishiguchi, T. and Ikeda, M. (1996) “Suppliers' innovation: Understated aspects of Japanese industrial sourcing”, in Nishiguchi, T.(Ed.), *Managing Product Development*, Oxford University Press, pp. 206-232

Noori, H. and Lee, W. B. (2004), “Collaborative design in a networked enterprise: the case of the telecommunications industry”, *International Journal of Production Research*, Vol. 42 No. 15, pp. 3041-3054.

Parry, G.C., Brax, S.A., Maull, R.S. and Ng, I.C.L. (2016), “Operationalising IoT for reverse supply: the development of use-visibility measures”, *Supply Chain Management*, Vol. 21 No. 2, pp. 228-244.

Patton, M. Q. (2002), *Qualitative Research & Evaluation Methods*, Sage, Thousand Oaks, CA.

Pero M., Abdelkafi N., Sianesi A. and Blecker, T. (2010), “A framework for the alignment of new product development and supply chains”, *Supply Chain Management: An International Journal*, Vol. 15 No. 2, pp. 115-128.

Personnier, H., Le Dain, M.-A. and Calvi, R. (2011), “Collaborative glitches in design chain: Case study of an unsuccessful product development with a supplier”, *in 18th International Conference on Engineering Design - Impacting Society Through Engineering Design proceedings*, Vol. 3, pp. 176-186.

Petersen, K.J, Handfield, R.B. and Ragatz, G.L. (2005), “ Supplier integration into new product development: coordinating product, process and supply chain design”, *Journal of Operations Management,* Vol. 23, pp. 371– 388.

Quinn, J. B. (2000), "Outsourcing innovation: The new engine of growth", *Sloan Management Review*, Vol. 41 No. 4, pp. 13−28.

Rodriguez, K. and Al-Ashaab, A. (2005), "Knowledge web-based system architecture for collaborative product development", *Computers in Industry*, Vol. 56, pp. 125–140.

Roemer T.A. and Ahmadi R. (2009), "Models for concurrent product and process design", *European Journal of Operational Research*, Vol. 203 No. 3, pp. 601-613.

Rundquist, J. and Halila, F. (2010), "Outsourcing of NPD activities: A best practice approach", *European Journal of Innovation Management*, Vol. 13 No. 1, pp. 5-23.

Sarin, S. and O'Connon, G. (2009), "First among Equals: The Effect of Team Leader Characteristics on the Internal Dynamics of Cross-Functional Product Development Teams", *Journal of Product Innovation Management*, Vol. 26 No. 2, pp. 188–205.

Sarin, S. and O'Connor, G. C., (2009), "First among equals: The effect of team leader characteristics on the internal dynamics of cross-functional product development teams", *Journal of Product Innovation Management*, Vol. 26 No. 2, pp. 188–205.

Saunders, L.W., Kleiner, B.M., McCoy, A.P., Lingard, H., Mills, T., Blismas, N. and Wakefield, R. (2015), "The effect of early supplier engagement on social sustainability outcomes in project-based supply chains", *Journal of Purchasing and Supply Management*, Vol. 21 No. 4, pp. 285-295.

Shen, B., Li, Q., Dong, C. and Quan, V. (2016), "Design outsourcing in the fashion supply chain: OEM versus ODM", *Journal of the Operational Research Society*, Vol. 67 No. 2, pp. 259-268.

Singh, A. and Teng, J.T.C. (2016), "Enhancing supply chain outcomes through Information Technology and Trust", *Computers in Human Behavior*, Vol. 54, pp. 290-300.

Sivadas, E. and Dwyer, F.R. (2000) "An Examination of Organizational Factors Influencing New Product Success in Internal and Alliance-Based Processes". *Journal of Marketing*, Vol. 64 No. 1, pp. 31–49.

Sivadas, E. and Dwyer, F.R. (2000). "An Examination of Organizational Factors Influencing New Product Success in Internal and Alliance-Based Processes". *Journal of Marketing*, Vol. 64 No. 1, pp. 31–49.

Sjoerdsma, M. and Van Weele, A. (2015), "Managing supplier relationships in a new product development context", *Journal of Purchasing and Supply Management*, Vol. 21 No. 3, pp. 192–203.

Sousa, R. and Voss, C.A. (2008), " Contingency research in operations management practices", *Journal of Operations Management*, Vol. 26 No. 6, pp. 697–713.

Sun, X., Zeng, Y. and Liu, W. (2013), "Formalization of design chain management using environment-based design (EBD) theory", *Journal of Intelligent Manufacturing*, Vol. 24 No. 3, pp. 597-612.

Swaminathan, J.M. and Tayur, S.R. (2003), "Models for supply chains in e-business", *Management Science*, Vol. 49 No. 10, pp. 1387-1406.

Syan, C.S. and White, A.S. (2013), "Role of European automotive supplier integration in new product development", in Eid R. (Ed.), In *Managing Customer Trust, Satisfaction, and Loyalty through Information Communication Technologies*, Business Science Reference, Hershey, PA: IGI Global, pp. 178-201.

Talke K. and Hultink, E. J. (2010). Managing Diffusion Barriers When Launching New Products. *Journal of Product Innovation Management*, Vol. 27, pp. 537-553.

Tonnquist, B. (2008), *Project Management- A guide to the Theory and Practice of Project, Program and Portfolio Management, A Business Change*, Bonnier Utbildning AB, Stockholm.

Tortoriello, M., Reagans, R. and McEvily, B. (2012), “Bridging the Knowledge Gap: The Influence of Strong Ties, Network Cohesion, and Network Range on the Transfer of Knowledge Between Organizational Units”, *Organization Science*, Vol. 23 No. 4, pp. 1024-1039.

Twigg, D. (1998), “Managing product development within a design chain”, *International Journal of Operations and Production Management*, Vol. 18 No. 15, pp. 508-524.

Ulrich, K.T. and Eppinger, S.D. (2011), *Product design and development*, Boston: McGraw-Hill Higher Education.

Voss, C., Tsikriktsis, N. and Frohlich, M. (2002), “Case research in operations management”, *International Journal* of Operations *& Production Management*, Vol. 22 No.2, pp. 195–219.

Wagner, S.M., and Hoegl M. (2006), “Involving suppliers in product development: insights from R&D directors and project managers”, *Industrial Marketing Management,* Vol. 35, pp. 936-943.

Webster, M. and Sugden, D.M. (2004). “The measurement of manufacturing virtuality”, *International Journal of Operations and Production Management*, Vol. 24 No. 7, pp. 721–742.

Welker, G. A., Van der Vaart, T. and Van Donk, D. P. (2008), “The influence of business conditions on supply chain information sharing mechanisms: A study among supply chain links of SMEs”, *International Journal of Production Economics*, Vol. 113 No. 2, pp. 706-720.

Wheelwright, S. and Clark, K. (1992), “Creating Plans to focus product development”, *Harvard Business Review,* Vol. Mar-Apr, pp. 70-82.

Williamson, O. E. (2008), “Outsourcing: transaction cost economics and supply chain management”, *Journal of Supply Chain Management*, Vol. 44 No. 2, pp. 5–16.

Williamson, O.E. (1975), *Markets and hierarchies: Analysis and antitrust implications: a study in the economics of internal organization*. New York: The Free Press.

Wu, J. (2009), “The impact of inter-organizational relationship on new product development performance with the intermediate role of information sharing”, *in 4th International Conference on Cooperation and Promotion of Information Resources in Science and Technology proceeding*, pp. 285-289.

Wu, Z., Choi, T. Y. and Rungtusanatham, M. J. (2010), “Supplier–supplier relationships in buyer–supplier–supplier triads: Implications for supplier performance”, *Journal of Operations Management*, Vol. 28 No. 2, pp. 115-123.

Yan, T. and Dooley, K. (2014), “Buyer-supplier collaboration quality in new product development projects”, *Journal of Supply Chain Management*, Vol. 50 No. 2, pp. 59-83.

Yin, R.K. (2003), *Case study research: design and methods*. Third Edition, Sage Publications.

Yong-hui, G. (2010), “Modeling for design chain optimization based on information flow”, *in IEEE 17Th International Conference on Industrial Engineering and Engineering Management proceedings*, pp. 1551-1554.

Zsidisin, G.A. and Ellram, L.M. (2001), “Activities related to purchasing and supply management involved in supplier alliances”, *International Journal of Physical Distribution & Logistics Management*, Vol. 31 No. 9, pp. 629–646.

Annex 1 – DC Virtuality Calculation

The calculation of DC Virtuality for the seven case studies is reported here. The grey cells contain data that were collected during interviews and/or by means of archival data. The numbers in the white cells have been calculated using the formulas reported in Section 3.2.

Table 1.1. DC Virtuality calculation.

Case study A		**Actor *a***	**NPD phase *i*: P**	**CD**	**SLD**	**DD**	**TR**	**PRU**	$\sum_{i=1}^{N}(X_i * Y_{i,a})$	**Node Relevance**	**DC Virtuality**
	$Y_{i,a}$	A1				*0.2*			0.200	0.239	0.410
		A2				*0.1*			0.100	0.120	
		A3				*0.03*			0.030	0.036	
		A4					*0.02*		0.013	0.016	
		Focal company	*0.02*	*0.08*	*0.10*	*0.30*	*0.07*	*0.08*			
	X_i		*0.50*	*0.33*	*0.83*	*1.00*	*0.67*	*0.33*			
	$\sum_a(X_i * Y_{i,a})$		0.01	0.03	0.08	0.63	0.06	0.03			

Case study B		**Actor *a***	**NPD phase *i*: P**	**CD**	**SLD**	**DD**	**TR**	**PRU**	$\sum_{i=1}^{N}(X_i * Y_{i,a})$	**Node Relevance**	**DC Virtuality**
	$Y_{i,a}$	B1				0.08	0.02		0.080	0.098	0.418
		B2				0.08			0.075	0.092	
		B3				0.05	0.01		0.053	0.065	
		B4				0.12	0.04		0.133	0.163	
		Focal company	0.05	0.05	0.05	0.33	0.04	0.10			
	X_i		0.17	0.67	0.83	1.00	0.33	0.50			
	$\sum_a(X_i * Y_{i,a})$		0.01	0.03	0.04	0.65	0.03	0.05			

Case study C		**Actor *a***	**NPD phase *i*: P**	**CD**	**SLD**	**DD**	**TR**	**PRU**	$\sum_{i=1}^{N}(X_i * Y_{i,a})$	**Node Relevance**	**DC Virtuality**
	$Y_{i,a}$	A1		0.13	0.08				0.139	0.216	0.913
		A2		0.13	0.08				0.139	0.216	
		A3				0.2	0.05		0.175	0.273	
		A4						0.2	0.133	0.208	
		Focal company	0.10	0.05							
	X_i		0.33	0.50	1.00	0.83	0.17	0.67			
	$\sum_a(X_i * Y_{i,a})$		0.03	0.15	0.15	0.17	0.01	0.13			

Case study D		**Actor *a***	**NPD phase *i*: P**	**CD**	**SLD**	**DD**	**TR**	**PRU**	$\sum_{i=1}^{N}(X_i * Y_{i,a})$	**Node Relevance**	**DC Virtuality**
	$Y_{i,a}$	D1				0.02	0.10	0.30	0.217	0.302	0.360
		D2				0.05			0.042	0.058	
		Focal company	0.10	0.10	0.20	0.13	0.10	0.10			
	X_i		0.67	0.83	1.00	0.83	0.50	0.50			
	$\sum_a(X_i * Y_{i,a})$		0.07	0.08	0.20	0.17	0.05	0.15			

Table 1.1 (continued). DC Virtuality calculation.

Case study		Actor a	NPD phase i						$\sum_{i=1}^{N}(X_i * Y_{i,a})$	Node Relevance	DC Virtuality
			P	CD	SLD	DD	TR	PRU			
Case study E	$Y_{i,a}$	A1		0.12	0.04	0.03			0.117	0.154	0.619
		A2				0.01	0.02		0.016	0.021	
		A3				0.2	0.04	0.15	0.337	0.444	
		Focal company	0.05	0.03	0.06	0.21	0.05				
	X_i		0.17	0.50	0.67	1.00	0.33	0.83			
	$\sum_{a}(X_i * Y_{i,a})$		0.01	0.08	0.07	0.45	0.03	0.13			

Case study		Actor a	NPD phase i						$\sum_{i=1}^{N}(X_i * Y_{i,a})$	Node Relevance	DC Virtuality
			P	CD	SLD	DD	TR	PRU			
Case study F	$Y_{i,a}$	F1		0.01	0.03	0.10	0.03	0.04	0.165	0.223	0.563
		F2		0.01	0.03				0.030	0.041	
		F3		0.01	0.03	0.1	0.03	0.04	0.165	0.223	
		F4		0.01	0.03			0.04	0.057	0.077	
		Focal company	0.20	0.08	0.13			0.08			
	X_i		0.50	0.83	0.83	1.00	0.33	0.67			
	$\sum_{a}(X_i * Y_{i,a})$		0.10	0.08	0.21	0.20	0.02	0.13			

Case study		Actor a	NPD phase i						$\sum_{i=1}^{N}(X_i * Y_{i,a})$	Node Relevance	DC Virtuality
			P	CD	SLD	DD	TR	PRU			
Case study G	$Y_{i,a}$	G1			0.01	0.01	0.004		0.018	0.026	0.205
		G2			0.01	0.01	0.004		0.018	0.026	
		G3			0.01	0.01	0.004		0.018	0.026	
		G4			0.01	0.01	0.004		0.018	0.026	
		G5			0.01	0.01	0.004		0.018	0.026	
		G6			0.01	0.01	0.004		0.018	0.026	
		G7			0.01	0.01	0.004		0.018	0.026	
		G8			0.01	0.01	0.004		0.018	0.026	
		Focal company	0.10	0.15	0.10	0.20	0.07	0.20			
	X_i		0.50	0.50	0.67	1.00	0.83	0.50			
	$\sum_{a}(X_i * Y_{i,a})$		0.05	0.08	0.13	0.25	0.08	0.10			

Annex 2 – DC Visibility Calculation

The calculation of DC Visibility for the seven case studies is reported here.
For each partner k and each feature f (Quantity, Accuracy, Freshness), the column "Output" shows the values of $Visibility\_Project\_Output_{k,f}$, the column "Prj. Mng." shows the values of $Visibility\_Project\_Management_{k,f}$, and the column "Total" shows the values of $Visibility_{k,f}$. All the numbers have been calculated using the formulas reported in Section 3.1, based on the $J_{k,p,f,l}$ values collected during field trips.

Table 2.1. DC Visibility calculation.

Case	Partner	Quantity			Accuracy			Freshness			Node Visibility	DC Visibility
		Output	**Prj.Mng.**	**Total**	***Output***	***Prj.Mng.***	***Total***	***Output***	***Prj.Mng.***	***Total***		
A	*A1*	3.00	3.30	**3.15**	3.00	3.00	**3.00**	3.00	3.00	**3.00**	***3.05***	**2.85**
	A2	3.00	3.00	**3.00**	4.00	4.00	**4.00**	4.00	4.00	**4.00**	***3.63***	
	A3	2.00	1.59	**1.78**	3.00	3.00	**3.00**	2.00	2.00	**2.00**	***2.20***	
	A4	1.00	2.29	**1.51**	4.00	3.30	**3.63**	4.00	3.30	**3.63**	***2.71***	
B	B1	4.00	3.63	**3.81**	4.00	4.00	**4.00**	4.00	4.00	**4.00**	***3.94***	**3.97**
	B2	4.00	3.63	**3.81**	4.00	4.00	**4.00**	4.00	4.00	**4.00**	***3.94***	
	B3	4.00	4.00	**4.00**	4.00	4.00	**4.00**	4.00	4.00	**4.00**	***4.00***	
	B4	4.00	4.00	**4.00**	4.00	4.00	**4.00**	4.00	4.00	**4.00**	***4.00***	
C	C1	3.00	3.30	**3.15**	3.00	3.30	**3.15**	4.00	4.00	**4.00**	***3.41***	**3.30**
	C2	3.00	3.30	**3.15**	3.00	3.30	**3.15**	4.00	4.00	**4.00**	***3.41***	
	C3	4.00	4.00	**4.00**	2.00	2.62	**2.29**	4.00	4.00	**4.00**	***3.32***	
	C4	3.00	3.30	**3.15**	2.00	3.30	**2.57**	4.00	3.30	**3.63**	***3.09***	
D	D1	4.00	2.52	**3.18**	4.00	3.56	**3.78**	4.00	3.41	**3.69**	***3.54***	**3.42**
	D2	4.00	3.00	**3.46**	4.00	3.00	**3.46**	3.00	3.00	**3.00**	***3.30***	
E	E1	4.00	4.00	**4.00**	4.00	4.00	**4.00**	4.00	4.00	**4.00**	***4.00***	**3.93**
	E2	4.00	3.30	**3.63**	4.00	4.00	**4.00**	4.00	3.63	**3.81**	***3.81***	
	E3	4.00	3.87	**3.94**	4.00	4.00	**4.00**	4.00	4.00	**4.00**	***3.98***	
F	F1	3.18	3.37	**3.27**	2.55	3.30	**2.90**	3.37	3.50	**3.43**	***3.19***	**3.22**
	F2	3.00	3.46	**3.22**	3.00	3.63	**3.30**	3.00	3.46	**3.22**	***3.25***	
	F3	3.37	3.43	**3.40**	3.10	3.57	**3.33**	3.37	3.72	**3.54**	***3.42***	
	F4	2.62	3.20	**2.90**	2.62	3.10	**2.85**	3.30	3.52	**3.41**	***3.04***	
G	G1	3.00	1.82	**2.34**	3.63	1.88	**2.61**	2.62	1.82	**2.18**	***2.37***	**2.31**
	G2	4.00	2.29	**3.03**	3.00	1.66	**2.23**	3.18	1.88	**2.44**	***2.55***	
	G3	3.30	2.83	**3.06**	3.30	2.40	**2.81**	2.62	2.87	**2.74**	***2.87***	
	G4	3.30	1.96	**2.55**	2.00	1.26	**1.59**	1.59	1.17	**1.36**	***1.77***	
	G5	2.00	1.26	**1.59**	3.30	1.54	**2.25**	3.00	1.61	**2.20**	***1.99***	
	G6	3.30	1.61	**2.30**	2.88	1.49	**2.07**	2.88	1.82	**2.29**	***2.22***	
	G7	2.52	1.96	**2.22**	2.52	1.82	**2.14**	3.30	1.96	**2.55**	***2.30***	
	G8	3.00	2.03	**2.47**	3.63	2.36	**2.93**	2.62	2.29	**2.45**	***2.61***	