A value network development model and implications for innovation and production network management

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Abstract

In managing their value network, firms have to balance current and future value concerns and own and network partners' concerns. Firms generate immediate value through manufacturing and selling the current generation of products together with other firms in their production network. Firms generate future value by developing a new product generation with other firms and research institutes in their innovation network. Product innovation and production often take place simultaneously and recurrently. We take the discernible production and innovation activities to occur in co-evolving layers of the same network. We formulate a biplex value network development model that lays out the temporal pattern of production and innovation activities in the value network. We introduce terminology to pinpoint temporal interactions between the innovation and production activities. We study several exemplary complications in the cross-table of inter- and intragenerational interactions versus interactions within and across network layers.

Keywords: value network, network management, network development, innovation network, production network, temporal complication

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1. Introduction

Firms are embedded in networks in which value is created and appropriated co-opetitively with their suppliers, customers and other organizations (Brandenburger & Nalebuff, 1996; Håkansson & Snehota, 1989; Achrol, 1997). Firms generate *immediate* value through manufacturing and selling the *current* generation of products together with other firms in their *production* network. Firms generate *future* value by developing a *new* product generation with other firms and research institutes in their *innovation* network. From the perspective of production, it is a crucial competence to be able to manage relationships with current network partners to assure low cost/ high quality component supply and high profit product sales. From the perspective of innovation, it is a crucial competence to be able to start and manage relationships with current and also new partners to create new products and thereby create future value (cf. Ritter & Gemünden, 2003; Ritter et al., 2004). So far, the innovation network management literature has considered knowledge creation as its main focus and thus largely dismissed explicit consideration of the actual production. Similarly, the production network management literature has generally reduced product research and development as to tailor operational efficiency. Our perspective is that, in managing their value network, firms have to balance current and future value concerns and own and network partners' concerns. Value networks change due to developments in the industry and interactive (re)actions of firms in the network (cf. Håkansson & Snehota, 1989; Ford & Mouzas, 2008; Halinen & Törnroos, 1998; Allee, 2000; Kothandaraman & Wilson, 2001). Although there are strategic, economic and operational reasons for a firm to manipulate its network, much of the value network development is to accommodate changes in the technology and thereby capabilities that span the value network. The evolution of a value network is technologically interpuncted by technological breakthroughs and tipping of main market segments to certain product technology (cf. Rosenkopf & Tushman, 1998; Halinen et al., 1999; Gilsing, 2005; Oksanen et al., 2010). Following a breakthrough, there is a period of turmoil in which innovation networks investigate and develop competing products based on the new generation of product technology. Production networks manufacture and commercialize the new products, thereby driving technological and market convergence, which leads to consolidation of a particular product-market segment, often even a dominant design. Recent network management theories focus on management of networks during establishment, the actual product research & development and the ultimate production (e.g. Möller & Svahn, 2009; Aarikka-Stenroos & Sandberg, 2012). While the population of the innovation and production networks may differ, future producers are often involved in research and development. Given this overlap, we take the discernible production and innovation activities to take place in *separate layers of the same value network*. In this conceptual paper, we study value network development as outcome of network management activities of individual firms in each of these layers, hereby acknowledging the technologically defined position of firms in and structural features of the network. By studying innovation and production network management in conjunction, we find temporal and interdisciplinary managerial complications.

In Section 2, we formulate our biplex value network development model that lays out the temporal pattern of production and innovation activities in the value network. We introduce terminology to pinpoint temporal interactions of activities in the innovation and production network layers. Members manage the value network to balance production activities for immediate value and innovation activities for future value. In contrast to the various product life-cycle, technology life-cycle and ecological industry life-cycle models, we stress that innovation and production are not *strictly successive* activities, but often take place *simultaneously*. Furthermore, both discontinuous product innovation and changes to the production portfolio generally occur *recurrently*. The topology of and capabilities present in the current value network are *antecedents* to the future value network. In Section 3, we discuss several strategic network management complications present in the cross-table of inter- and intragenerational complications versus within and across the product and innovation network. We hereby take a strategic network management perspective explicitly acknowledging the technological foundation of relationships. In Section 4, we conclude.

2. Biplex network development model

In literature, it is argued that a value network takes a form based on the purpose its serves. Möller & Svahn (2003) distinguish networks that serve production innovation, product innovation, or business renewal. Others distinguish networks that serve exploring new and those that serve exploiting old technology (Rosenkopf & Tushman, 1998; Gilsing, 2005). Kambil (2008) distinguishes networks based on whether the network aims to serve a new or

an existing market and whether the network does so with a new or existing product technology.
In our perspective, there are two main reasons to engage in relationships[2]: firstly, the production and sales of a well-defined product to generate immediate value and, secondly, the research and development of new product technology (and complementary production technology) to generate value in the future[3]. We argue that these two main reasons to engage in relationships shape two elementary network forms: the *innovation* network, which serves research and development of product technology, and the *production* network, which focuses on efficient production of the selected, relatively well-defined product design. We discuss each of the elementary networks separately first, with emphasis on the management concerns. We then discuss their interrelationship in Subsection 2.3 and discuss three theoretical interactions between these two networks in Subsection 2.4. In Section 3, we discuss several concrete cases in which network management copes with these theoretical interactions.

2.1. Innovation network

Under the assumption that Schumpeterian technology competition drives industry developments, firms recurrently look for product innovations to restore profit margins. In developing new products, firms collaborate to tap into alternative knowledge bases and to attune capabilities, at first to explore and later to exploit technological and market opportunities. This notion is widely shared in fields such as industrial purchasing and marketing (cf. Håkansson & Snehota, 1995), social network studies of innovation (cf. Soh & Roberts, 2003; Gilsing, 2005), economic analysis of innovation (cf. Pyka & Küppers, 2002) and strategic management (cf. Dyer & Singh, 1998).
According to the network embeddedness principle (Håkansson & Snehota, 1995), capabilities derive their value from the combination with capabilities owned by others in the network. Furthermore, capabilities can be cross-fertilized to create new capabilities. To create an *innovative* product, firms first explore the capabilities available in their current and adjacent industries, then narrow down innovation targets to pursue, and then -at low level-

[2]We omit super-network activities, like standardization and format establishment.

[3]This is the network counterpart of a firm's exploitative efforts to ensure current viability and, at the same time, explorative efforts to ensure future viability (March, 1991; O'Reilly III & Tushman, 2008).

attune and cross-fertilize capabilities (cf. Chesbrough, 2003). The innovation network takes different forms and develops differently when firms are engaged in flexibly reconfiguring capabilities than when the firms are engaged in creating, absorbing, and cross-fertilizing capabilities (cf. Belussi & Arcangeli, 1998). Clearly, with the challenges and network forms, also the management concerns and activities change (cf. Möller & Svahn, 2009). We distinguish two innovation network stages based on activities in interfirm relationships. The reconnaissance stage is characterized by *monitoring for and reconnaissance of* options in developing technology and market. With gradual (formal) commitment of partners to certain R&D trajectories, the innovation network gets established gradually, relationship by relationship. The recombination stage is characterized by *recombination and synergistic attuning* of capabilities in realizing experimental product and production technology according to an envisaged product design. Despite the linear chronology of the terms, innovation network formation may cycle through pre- and post-establishment while con- and deconstructing (parts of) the innovation network.

Monitoring and reconnaissance occur both at the firm population level, by browsing the population of possible and actual network members, as well as at the level of these firms' knowledge and capability pools. Firms exchange ideas about the product design with different potential component suppliers and potential customers. Firms iteratively select potential vertical partners with whom there is basic consensus. With these, they engage in preliminary recombination of technological knowledge to establish (indications of) feasibility. So, there are technology-based 'generative rules' that govern the formation of relationships (and coordination within those relationships) (Kogut, 2000). As such, there is co-evolution of the technology and the network developing and producing the product[4] (cf. Stolwijk et al., 2013).
However, technology development is a process of trial-and-error (Nelson & Winter, 1982). Upon repeated failures in experimental recombinations, the preliminary product concept is rejected and relationships possibly abandoned. Firms then engage in new rounds of reconnaissance, now communicating also the failures and new product ideas. This process continues until technological feasibility and market viability have been established to a degree such that it is acceptable to all participants to pursue further formal-

[4]This is a widespread observation and found in disciplines like strategic management (cf. Sanchez & Mahoney, 1996) and evolutionary economics (cf. Orsenigo et al., 2001).

ization. Until that time, firms are hesitant to dedicate resources to a single solution.

Over the course of time, firms move from monitoring and reconnaissance to recombination and attuning, with which the innovation network of firms crystallizes. By the process just described, the firms in the network, firstly, share the consensus on what product technology is to be developed and, secondly, have already established basic technological feasibility and market viability. Firms come to know which product technology and production capabilities are required. The horizontal and diagonal redundancy in the network that may have been present during reconnaissance reduces (through explicit formal severance or simply dieing out of communication) as the value of information exchange drops. With this, firms generally select one out of possibly multiple potential vertical partners for further recombination. Within this relatively fixed network of capabilities, firms start to synergistically attune the product technology and capabilities (cf. Schilling, 2000). In this, pursuing product modularity may well be a deliberate strategy (cf. Baldwin & Clark, 2000).

The product becomes decomposed into market viable, technologically feasible and manufacturable components. Firms are selected in and out of the innovation network based on their conviction of viability and feasibility, and their production capabilities. So, the network now starts to feature the vertical relationships that reflect the product and production technological dependencies (Kogut, 2000; Hite & Hesterly, 2001; Walker et al., 1997). With phasing in of production, marketing and sales of the new product, the production network takes shape.

2.2. Production network

Apart from those specialized in research exclusively, firms in a manufacturing industry are continuously engaged in production to generate payoff. Firms only engage in (large scale) production if there is a sure market demand and if the product is properly defined such that investments in production technology do not become obsolete by design changes later. Whenever multiple firms are involved in production, the production process must be decomposed and tasks divided. For this, the component specifications must be codified and transferred, and the interface between component and assembly defined (cf. Macher & Mowery, 2004; Sanchez & Mahoney, 1996; Baldwin & Clark, 2000). Generally, given this well-defined nature of interfaces and the profit-based nature of competition in the mature phase of the product life-cycle, firms manage their supplier and customer portfolio based on cost economies. As the production network serves exploitation of existing ideas, the network structure is generally defined by the product technology decomposition. Diseconomies of scope may however limit vertical specialization or promote vertical integration (Hoetker, 2006). Moreover, firms need not comply with emerging product designs and take their vertically specialized production role, but may rather vertically integrate to dedicate themselves to proprietary technology for horizontally differentiated products (cf. Argyres & Bigelow, 2010). So, the production network is shaped by the product technology decomposition, which is mediated by both cost economies and the competitive differentiation strategy.

When producing a dominant product design, technological activities are limited to incremental problem-solving (Rosenkopf & Tushman, 1998) routinized in the production process. As such, communication with innovation network partners is generally limited.

Note that there is a stage in which products in one technology generation are phased out and products in the next technology generation are phased in. In this cross-phasing stage, there is a temporary boom in ties as the production network consists of firms working on either one or both of the product technology generations. Those firms producing old technology exclusively should prepare for a switch or consider an exit.

2.3. Two-layered model

Our contention is that, over the industry evolution, the value network features innovation relationships during particular periods and possibly features changes in production relationships upon cross-phasing product generations. Each value network has a (changing) *mix* of production and innovation activities (cf. Lamming et al., 2000; Möller & Svahn, 2003). In understanding how the value network evolves, however, we need to understand how the innovation network and production network evolve *interactively*. To study the interaction, empirically, it is necessary to establish whether cont(r)acts, communications and transactions pertain to either innovation or production. Luckily, it is generally obvious to both sender as well as receiver which hat is on when communications and transfers take place. So, as depicted in Figure 1, one can hence distinguish the product innovation from the production network layer in the value network. By looking at the considerations in the network formation decisions (who (not) to contact, why (not) to engage in interaction, etc), we also get a clear view *on how the innovation and produc-*

tion network decisions affect one another.

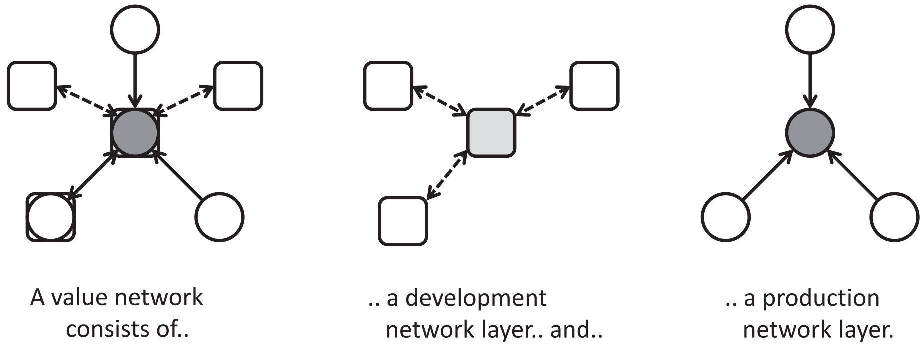

Figure 1: A graphical illustration how a value network is made up of a product innovation and a production network layer each consisting of firms and their interactions.

We propose our biplex network development model for this 'disentangled' evolution of both networks[5] and their interaction. Explicit in this biplex network development model is that the innovation and production network co-exist during particular intervals of the industry evolution, that value networks must conduct both activities proficiently (Benner & Tushman (2003) call this 'ambidexterity') to assure continuity and hereto adapt the capabilities to changes in technology and market demand. The biplex model serves as a conceptual framework to reflect on the complications in organizing both regular production as well as R&D of new product technology.
We contend that firms are *continuously* producing products to sell, while they *intermittently* (but generally recurrently) generate *radically new* products. The development of product technology of generation $g + 1$ and production of the products based on technology generation g occur simultaneously. In the production phase (and hence network), there is also incremental product and process innovation that fine-tunes technology locally.
We thus propose the biplex network development model depicted in Figure 2, which is an abstract temporal layout of both activities.

[5]We use 'network' rather than 'network layer' whenever confusion between the value network as a whole and a separate layer is unlikely.

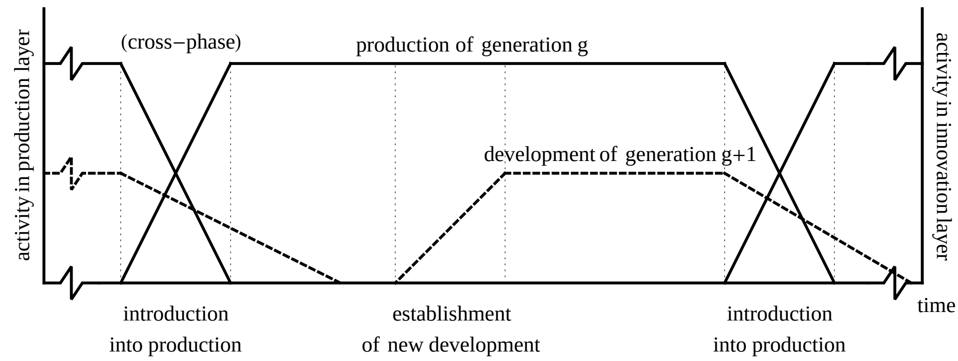

Figure 2: A graphical impression of the biplex network development model with production (innovation) activity plotted in the continuous (dashed) line.

While innovation and production may have their own autonomous organizational rationales, there are two phases (labeled 'introduction' and 'establishment') during which there is definitely close interaction between the two networks.

During the *introduction* phase, firms arrange production facilities to manufacture the product based on the new technology generation. Firms draw up contracts for delivery with suppliers and customers, thereby formalizing the new production network. The old product is also phased out, such that contracts may be discontinued. We thus see a cross-phasing from the old generation production network into the new generation production network. Furthermore, facilities, communication structures, and contacts in place for radical innovation research are discontinued, such that the value network is rid of the innovation partners that do not coincide with production partners.

During the *establishment* phase, firms start radical research by engaging in reconnaissance and early recombination with a wide variety of firms. The contacted firms may belong to the pool of current production partners, previous innovation partners (e.g. universities), and also firms yet external to the value network or even current industry. As described before, firms move and are moved in and out of the innovation network. The firms in the network gradually reach consensus on the product definition, establish market viability, and prove technological feasibility.

As particular firms may be member of both the innovation and production network, network management actions like (dis)integration or switches in one

network may have an immediate impact on the other network.
Figure 3 contains an illustration of how the two layers of the value network develop over time. By signing contracts, fixing production schedules and placing orders with suppliers, the switch from innovation to production is relatively clear-cut. The coming into existence of the next generation innovation network may well be more gradual.

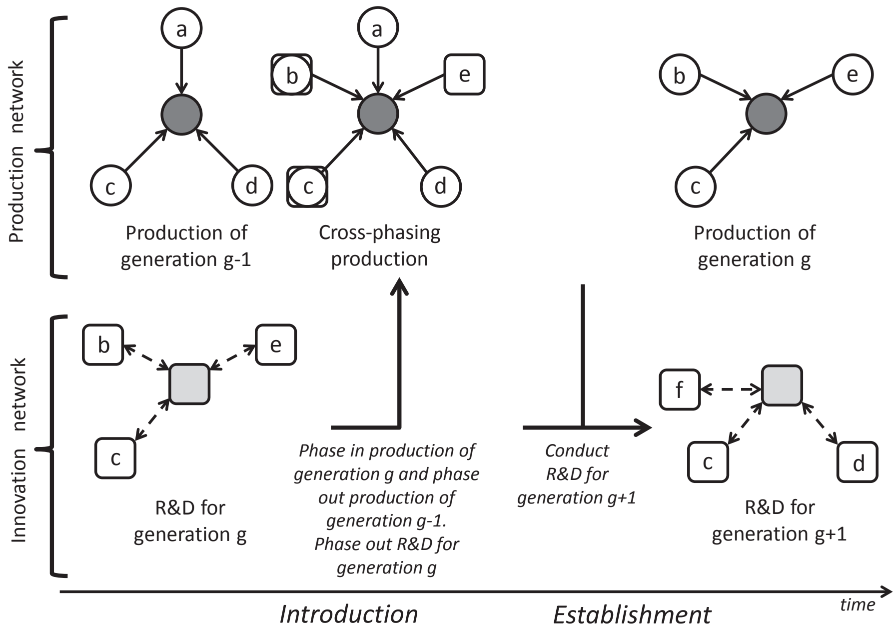

Figure 3: A simple illustration how the (two layers of the) value network change(s) over time.

2.4. Temporal interactions

By adopting an explicit distinction between the innovation and the production network (as layers in the value network) and studying the temporal layout of innovation and production activities, we find several temporal interactions of innovation and production activities: recurrence, simultaneity, and antecedence.

Firstly, there is *recurrence*. Over the lifespan of an industry, there generally are several generations of product technology, where each generation goes through its product life-cycle. Technological breakthroughs may enable the development of a new generation of product technology and thus extend the industry life-cycle. So, firms active in an industry are faced with recurrent product development activities and recurrent phasing-in of new products into production (and phasing-out of outdated products out of production).

Secondly, there is *simultaneity*. In striving for continuity, firms should be engaged both in exploiting existing capabilities efficiently to generate current value, as well as developing new capabilities to assure future value creation. Our contention is that innovation and production activities do not occur clear-cut successively and there hence is also no clear temporal interleaving in the membership of the production and the innovation network. Firms may well be involved in both activities at the same time, such that the firm is member of a production as well as an innovation network simultaneously. The two value network layers co-exist and co-evolve. Regardless of whether the production and innovation network are working on the same or different generation of product technology, network management decision in one network are well likely to affect the other network.

Thirdly, there is *antecedence* in the formation of the innovation network (cf. Halinen & Törnroos, 1998; Kogut, 2000; Rosenkopf & Tushman, 1998; Zirpoli & Camuffo, 2009). In the formation of the innovation network, firms rely on current production partners and use existing transaction and communication infrastructures. Firms elaborate on the existing technology paradigm or prefer to rely on firms with critical resources (like a physical network) (cf. Fleury & Fleury, 2007). Innovativeness is served if firms in the innovation network are not restricted in their partner or product technology choices by future production facilities. Furthermore, there also is antecedence in the formation of the production network as firms in the innovation network take into account future production performance. This does not mean they should stick to manufacturers in the current production network. However, collaboratively developing particular product technology with one supplier or customer and then switching to another as soon as actual production starts may be opportunistic and have unfavorable social consequences for future innovation projects. Hence, the current innovation network structure and population carries over to the production network structure and population as well, to some extend.

The three temporal interaction concepts are related in a graphical model in Figure 4. In the next section, we study complications in network management arising from these temporal features of network development.

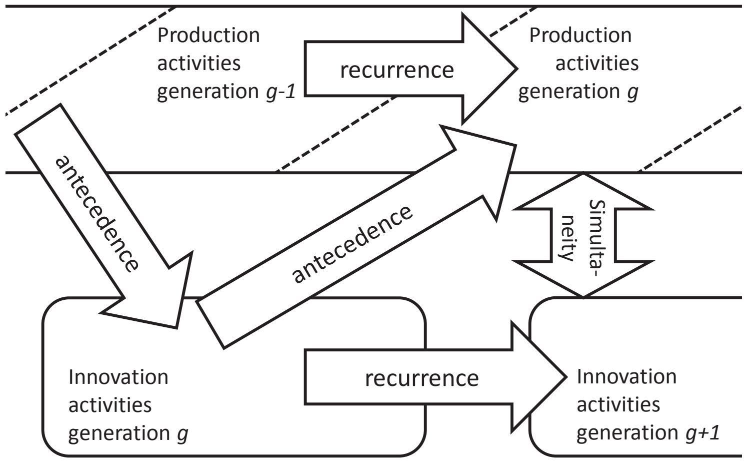

Figure 4: Graphical model of the temporal interaction concepts.

3. Biplex network management complications

Current innovation and production management literature provides regular management strategies concerned with the network for the *current* product technology generation and either innovation or production respectively. However, given the development of the two value network layers and given the various temporal complications (simultaneity, recurrence, and antecedence), when and how should a firm manage (a particular layer in) its value network? Simultaneity calls for network management strategies that attend to both the innovation *and* production concerns. Recurrence and antecedence call for network management strategies that take into account the effect of changes to the current network on future options and how to overcome the effects of past choices on current options. In the present section, we provide a non-exhaustive list of network management issues that become apparent by looking at temporal interactions between the two network layers at the same time or from one to the next generation (between different and within the same layer). Table 1 contains the exemplary network management issues we discuss in this paper.

3.1. Conflicting concerns

Whenever a firm changes its value network, e.g. by altering the members or changing the governance over capabilities, this may affect both the

	intra-generational	inter-generational
within innovation network		**recurrence**: anticipating feed-forward (3.3)
within production network		**recurrence**: production flexibility (3.4)
across network layers	**simultaneity**: conflicting concerns (3.1)	**antecedence**: technological role (3.2), **recurrence**: separate facilities (3.5)

Table 1: The exemplary temporal network management issues per combination and between parentheses the number of the subsection in which we discuss the particular issue.

production and the innovation network when both activities occur simultaneously. Whenever concerns are aligned in both network layers, e.g. removal of a subpar supplier, this may not be a problem. However, the concerns in the innovation and production network may be opposed. Whenever R&D and production are conducted simultaneously, the cost-based view dominant in management of the production network and the capability-based view dominant in management of the innovation network may arrive at conflicting recommendations for the value network change.

An obvious situation in which there is conflict of concerns is that of supplier management. On the one hand, cost and efficiency concerns in the production network may call for squeezing suppliers or pure transaction cost economic governance forms, but, on the other hand, the financial health, willingness to share knowledge and collaborative stance of suppliers may be needed in the innovation network (now or in the future) (cf. Macher & Mowery, 2004). In this case, firms better maintain a co-opetitive attitude towards (potential) network partners as it is beneficial for long term competitiveness of the value network and its members.

Another situation in which there is a conflict of concerns is in deciding on the governance over certain capabilities. Due to simultaneity, there may be *ambiguity* as to what governance form to pick. This is the case, for instance, when there is high asset specificity (which calls for integration according to the TCE) and high technological uncertainty (which calls for flexibility according to the capability-based view). Consequently, in changing the governance over capabilities up- or downstream in the value network, firms have to give priority to static efficiency and cost-based rationales in the production layer over dynamic efficiency and capability-based rationales in the innovation layer or vice versa.

While this ambiguity calls for giving the concerns in one layer the priority over those in the other layer, the governance decision is also *conditional*, i.e. depending on the current status and conditions (cf. Cacciatori & Jacobides, 2005). For example: when a firm is vertically specialized, it may seek alliances to tap into certain knowledge bases, but when already vertically integrated, that same firm may not divest the internal capabilities and vertically specialize to engage in the same alliances.

Evidently, while ambiguity and conditionality are evident complications in the governance decision within the biplex network development model, this is not an exhaustive list. Furthermore, ambiguity and conditionality (and several other types of general management complications) in fact also occur *within* individual layers.

3.2. Technological role and comprehension

Antecedence refers to how the production network emerges out of the innovation network, or how an innovation network for new R&D is formed out of the current production network by relying on existing partners and infrastructure. An example of how such antecedence affects network development is found in the case that the technological foundation of the value network may persist. After all, in value network management decisions, a firm is influenced by the technological role it fulfills and the comprehension of technological developments it has (cf. Harland et al., 2001). Furthermore, firms are contacted on the basis of this role and existing capabilities, also while establishing an innovation network for the next generation of technology, so this role may persist over successive life-cycles. Consequently, previously existing technological and organizational capabilities determine the newly established innovation network (Zirpoli & Camuffo, 2009).

Particularly problematic is that antecedence may in fact limit a value network's chances of survival. With specialization in a technological role, firms narrow their scope of capabilities and thereby forfeit the ability to create new knowledge through further internal recombination (e.g. Leonard-Barton, 1992; Brusoni, 2003; Rosenkopf & Almeida, 2003; Cacciatori & Jacobides, 2005) or to adjust to system changes (which is known as the 'modularity trap', see Chesbrough & Kusunoki (2001)). Apart from giving up on internal recombination options and absorptive capacity, with specialization comes also selective perception and corporate filters (Henderson & Clark, 1990). Both the lack of being able to escape the technological role and the limited comprehension decreases the absorptive capacity and locks in firms. So, the current value network constrains the technology that can be absorbed (Christensen & Rosenbloom, 1995; Orsenigo et al., 2001; Jacobides & Winter, 2005) and, under extensive vertical specialization, incumbents are likely to fail to make the transition to a new industry after a technological discontinuity (cf. Soh & Roberts, 2003; Henderson & Clark, 1990; Afuah, 2001; Belussi & Arcangeli, 1998).

Consequently, firms need to review effects of (intended) adjustments to own component technology (and related capabilities) to product technology developed and produced elsewhere in the value network. The greater the scope of firms taken into account, the more extensive the 'network horizon' (Anderson et al., 1994), and the more power is (to be) exerted in reorganizing and possibly reorienting the value network. Firms in the network have different levels of power in orchestration, mobilization, and persuasion. This also relates to the aforementioned technological role: system integrators or specialized component suppliers have more (bargain) power than commodity suppliers. However, while integrators of system technologies like cars and lithography equipment have considerable oversight and orchestration power, a value network is, in general, not under control of an individual firm. Value networks, arguably those developing and producing low-tech and highly modular product technology, are loosely coupled and thereby mostly self-organizing through attempts of individual firms to manage and manipulate the network (Ritter et al., 2004; Harland et al., 2001). While power to orchestrate a value network facilitates a timely response, alignment of strategies of partners and attuning of product technology, this power may be used to coerce firms to comply with certain system standards and is thereby a liability for key players in the network. After all, whenever technological discontinuities are recurrent, the value network needs to adopt new capabilities and needs to adjust to the capability topology of the new technological system. In anticipation of technological discontinuities, a value network may possibly best disintegrate to facilitate decentralized technology search in a loosely coupled innovation network. A system integrator (or other key component manufacturer) may refuse to relegate technological decisions to other firms and is thereby effectively limiting the technology search space. Employing a wide network horizon and exercising orchestration power may hamper the value network from adopting new capabilities and from morphing to accommodate new product technologies. As such, establishing the appropriate horizon and managing firms across this horizon is a strategically crucial competence (Holmen & Pedersen, 2003; Möller & Halinen, 1999). Conclusively, taking a technologically specialized scope and narrow network horizon may cause overlooking potential technological incompatibilities as well as miss technological opportunities, but taking a broad horizon and a technological integrative perspective may be a source of lock-in.

3.3. Anticipating feed-forward in product-market strategy

Ultimately, the product that is developed in the innovation network needs to be produced. As such, there is a feed-forward of the design choices made during innovation into the future production network. Anticipating this feed-forward, firms have to align the product-market strategy. An innovation network targeting the main market segment with price competition (focused price competition strategy) may work towards a modular design and a vertically specialized production network that facilitates outsourcing for scale and scope economies. An innovation network targeting a specialized high-quality-high-price niche (focused niche strategy), should work towards a superiorly performing, synergistically integrated solution (cf. Argyres & Bigelow, 2010) that provides a tenable position given the substitution by mainstream products. To achieve such synergistic optimization, tight vertical governance or even vertical integration in the innovation network may be required.

Our contention is that firms in the innovation network should explicitly communicate the future product-market strategy and anticipate the feed-forward of technological choices in the product-market strategy (cf. Ford & Mouzas, 2010).

However, while the future production network, facilities and activities should be anticipated, firms should transcend their current technological role and decomposition of production tasks so as to overcome antecedence. Failing to rid oneself of the current role may lock-in the value network in current technology and insufficiently leverage the opportunities of breakthrough technology.

3.4. Production flexibility

In managing purely the production network, there still is inter-generational interaction. The choices in the arrangement for the production of one generation propagates into the production of the next generation. If the two generations of products are technologically different, either the transition in production arrangement is dynamically inefficient or production of at least of generation is statically inefficient. While cost economies and production efficiencies are managerial priorities in production network management, a 'focused factory' (Skinner, 1974) -i.e. a dedicated production network in our perspective- is dynamically inefficient with recurring disruptive product innovation. The switching time in production then forms a liability (cf. Langlois & Robertson, 1989). Moreover, sticking too much to current production facilities forms a definite source of lock in. On the other hand, maintaining a 'strategic flexibility' (Hayes & Pisano, 1994; Gerwin, 1993) to absorb undefined turmoil or preparing for a wide range of products to produce hurts static efficiency during technological stable periods. We argue that, in order to be cost competitive, production networks need to be able to make timely switches from producing one to the next generation of products, i.e. the production network needs to have a *cross-generational flexibility.* One immediate implication for network management is that firms may need to unsentimentally switch production partners in cross-phasing.

3.5. Separate facilities per layer

We argued that value networks should be dynamically efficient in innovation and statically efficient with cross-generational flexibility in production. However, is that even possible, *given the interactions due to simultaneity?*. If the current production network is also used for experimentation and manufacturing of early designs of the next generation, the static efficiency of production decreases. Moreover, one is already involving the current producers, such that the current production network is an antecedent of the innovation network (see Subsection 3.2). As products may then be designed for the production facilities at hand, innovative product development is hampered.

One possible way to overcome the adverse effects of the recurrence and simultaneity on network efficiency is to have two relatively independent production arrangements. On the one side, the value network needs a relatively independent research and development infrastructure with flexible production facilities with freedom to adjust the partner pool, and, on the other side, a relatively statically efficient network of interconnected mass-scale production facilities with 'merely' *cross-generational* manufacturing flexibility.

4. Conclusions

In this paper, we started from the notion that firms manage their value network and thereby balance current and future value generation concerns (i.e. production versus innovation) and balance own and network partners' concerns. Current value is generated and appropriated in the production network layer and future value is generated in the innovation network layer. We then formulated a biplex value network development model that basically is a temporal layout of innovation and production network activities, given that industries evolve by recurring radical product technology breakthroughs. From this network development model it is obvious that there are several temporal complications that firms encounter in managing their innovation and production network layers. We then studied several evident issues in the cross-table of inter- and intragenerational complications versus within versus across network layers. Interesting first implications are that recurrence calls for the installation of merely cross-generational production flexibility and separate innovation experimentation facilities. Furthermore, simultaneity gives rise to ambiguity in governance. Antecedence calls for strategic alignment already in the innovation network. We know that the list of issues discussed is by no means exhaustive, but is a clear indication that network management of a firm would benefit from taking explicitly into account the two value network layers and the simultaneity and recurrence/ antecedence of its innovation and production activities.

Each of the cells in the cross-table, Table 1, provides topics for further research. Moreover, the biplex development model itself may be further refined with different phases in innovation and production network development. We already hinted on the reconnaissance and recombination phases in the innovation network development.
An interesting avenue for further research is to relate the activities in the biplex model to technological events and (anticipated) activities of competing networks, to be more explicit about managerial options and priorities. Innovation network management may, for instance, be different when an innovation network is the inventor of a radically new technology from when it is merely established in response to an invention by a competing network.

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