Helsinki University of Technology

Systems Analysis Laboratory Research Reports A100, May 2008

INNOVATION INCENTIVES AND THE DESIGN OF VALUE NETWORKS

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Dissertation for the degree of Doctor of Science in Technology to be presented with due permission of the Faculty of Information and Natural Sciences for public examination and debate in Auditorium E at Helsinki University of Technology (Espoo, Finland) on the 23rd of May, 2008, at 12 noon.

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This report is downloadable at

www.sal.hut.fi/Publications/r-index.html

ISBN 978-951-22-9387-2

ISBN (pdf) 978-951-22-9388-9

ISSN 0782-2030

Multiprint Oy/Otamedia

Espoo 2008

Title: Innovation incentives and the design of value networks

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Date: May 2008

Abstract: Participation in value networks is vital for companies as competition has moved increasingly to the level of company networks. Consequently, the growing complexity of the globally networked business environment necessitates the use of supportive tools in the management of network relations.

This Dissertation studies the value networks from two perspectives. First, as companies expect a return on their contributions to the network, the Dissertation constructs profit-sharing rules that serve as innovation incentives for the network partners. Second, the Dissertation builds models for the identification of network synergies in partner selection. The developments rest on game theory, transaction cost theory, and multi-criteria decision analysis.

The results are normative in that the developed models give insight to decision-makers at three levels: (i) the company decision-maker wants to optimise the company's participation in various networks, (ii) the network decision-maker needs to incentivate the network partners to contribute to the network, and (iii) the policy-maker aims to construct socially optimal instruments for the innovation system. Overall, the use of jointly agreed profit-sharing rules and synergetic partnerships supports the attempts to reduce transaction costs, offering benefits to the firms who participate in value networks.

Keywords: value networks, innovation management, profit sharing, partner selection, game theory, transaction cost theory, multi-criteria decision analysis, mixed-integer linear programming

Otsikko: Innovaatiokannustimet ja arvoverkostojen suunnittelu

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Päiväys: Toukokuu 2008

Tiivistelmä: Yritysten osallistuminen arvoverkostoihin on yhä tärkeämpää kilpailun siirryttyä yksittäisten yritysten tasolta yritysverkostojen tasolle. Tämän seurauksena maailmanlaajuisesti verkottunut liiketoimintaympäristö on tullut niin monimutkaiseksi, että yritysten verkostosuhteiden hallinta edellyttää päätöksentekoa tukevien työkalujen käyttöä.

Tässä väitöskirjassa tarkastellaan arvoverkostoja kahdesta näkökulmasta. Ensiksi, koska yritykset odottavat tuottoja omasta toiminnastaan verkoston hyväksi, väitöskirjassa kehitetään hyödynjakosääntöjä, jotka kannustavat verkostokumppaneita innovoimaan. Toiseksi, väitöskirjassa rakennetaan malleja verkostosynergioiden huomioimiseksi partnerinvalinnassa. Tutkimus perustuu peliteoriaan, transaktiokustannusteoriaan sekä monikriteeriseen päätösanalyysiin.

Väitöskirjassa kehitetyt mallit ovat normatiivisia ja tuovat päätöksentekijälle näkemystä kolmella tasolla: (i) yrityksen päätöksentekijä pyrkii optimoimaan yrityksen osallistumisen eri verkostoissa, (ii) verkostopäätöksentekijä kannustaa verkostokumppaneita toimimaan verkoston hyväksi ja (iii) politiikantekijän tavoitteena on rakentaa sosiaalisesti optimaaliset innovaatiojärjestelmän instrumentit. Ylipäätään verkostokumppaneiden kesken sovitut hyödynjakosäännöt ja synergiset kumppanuudet auttavat vähentämään transaktiokustannuksia ja hyödyntävät täten arvoverkostoihin osallistuvia yrityksiä.

Avainsanat: arvoverkostot, innovaatiojohtaminen, hyödynjako, partnerinvalinta, peliteoria, transaktiokustannusteoria, monikriteerinen päätösanalyysi, lineaarinen sekalukuoptimointi

Academic dissertation

Systems Analysis Laboratory
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Innovation incentives and the design of value networks

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Official opponent:	Professor Srinivas Talluri, Michigan State University

Publications

The Dissertation consists of the present summary article and the following papers:

[I] Jarimo, T., Pulkkinen, U., Salo, A. (2005): Encouraging suppliers to process innovations: A game theory approach. *International Journal of Technology Intelligence and Planning*, 1(4) 403–423.

[II] Jarimo, T., Kulmala, H. I. (2007): Incentive profit-sharing rules joined with open-book accounting in SME networks. *Production Planning & Control* (forthcoming).

[III] Hytönen, H., Jarimo, T., Salo, A., Yli-Juuti, E. (2008): Markets for standardized technologies: Patent licensing with Principle of Proportionality. Helsinki University of Technology, Systems Analysis Laboratory, Research Report E21.

[IV] Jarimo, T., Salo, A. (2008): Multi-criteria partner selection in virtual organisations with transportation costs and other network interdependencies. Helsinki University of Technology, Systems Analysis Laboratory, Research Report E22.

Contributions of the author

Papers [I] and [IV] were initiated and primarily written by Jarimo. Paper [II] was initiated by Kulmala; Jarimo developed the game-theoretic models and was the main author. In Paper [III], the system-dynamics model was developed jointly by Jarimo, Hytönen, and Yli-Juuti. The paper was primarily written by Jarimo and Hytönen; Jarimo was the lead researcher.

Foreword

This Dissertation has benefited from the help of numerous people, whom I have the pleasure to acknowledge, not for the sake of protocol, but for sincere appreciation.

First and foremost I thank Professor Ahti Salo, who always takes the effort of thoroughly reading manuscripts and giving insightful comments. His guidance was essential for the completion of this Dissertation. Equally important, the discussions with my mentor and colleague Urho Pulkkinen, who has now sadly passed away, have been a great source of inspiration. My sincere thanks go to the co-authors of two of the papers; Henri Hytönen, Harri Kulmala, and Erkki Yli-Juuti. It has been a pleasure to collaborate with you.

I thank the official opponent, Professor Srinivas Talluri for his important part in the examination of the Dissertation. I am equally thankful to the preliminary examiners, Professors Vladimír Mařík and Bert De Reyck. They have carefully read through the manuscript and given constructive comments, which considerably helped improve the quality of the Dissertation.

During the course of this research, I worked at VTT Technical Research Centre of Finland, where my colleagues created the most enjoyable working environment. Apart from work, my friends play an important part in bringing the most cheerful events in my life. I thank you all for the shared occasions—in the past and in the future.

I am grateful to my parents Leena and Seppo, who have always encouraged me in my studies. Finally, I thank my own family, Outi and Eevi, for love and care.

Espoo, 4.5.2008

Toni Jarimo

1 Introduction

The dominant view for the optimal level of companies' diversification has evolved during the last century. In the beginning of the 20th century, companies aimed at large-scale vertical integration in order to benefit from economies of scale and a steady supply of raw materials. At the same time, the first scholarly considerations for the optimal size of the firm were published (Coase, 1937). The trend towards integration peaked in the 1960's, when low interest rates tempted the companies to grow through leveraged acquisitions, resulting in large conglomerates.

The conglomerates began to crack in the 1970's with higher inflation, which raised interest rates so that the conglomerates could not afford their debts. Not surprisingly, the financial crisis led to the disintegration of the conglomerates. With the break-up of companies, Williamson (1975) re-raised Coase's (1937) theories of the boundaries of the firm into scientific discussion, now with the well-known name *transaction cost economics*.

The next influential concept was the *value chain*, which categorises the activities of a company into primary and support activities (Porter, 1985). Since its publication, the value chain has been the dominant model for linear supplier-customer relationships. However, several issues caused the need for extensions to the linear model. First, the share of services and other intangibles in business increased. Second, the companies started to focus on their *core competences* (Hamel and Prahalad, 1990). Third, the computer networks improved the efficiency of inter-firm communications. In consequence, *value networks* started to better characterise the multilateral business environment (Normann and Ramírez, 1993; Christensen and Rosenbloom, 1995).

The multilateral nature of value networks implies that their coordination cannot be strictly centralised. Instead, much of the decision-making is decentralised to individual companies, wherefore *game theory* offers well developed concepts for the modelling of the companies' behaviour (Myerson, 1997). Consequently, game theory has been applied widely to the study of supply-chain relationships (Corbett and DeCroix, 2001; Li, 2002; Cachon and Lariviere, 2005). Nevertheless, in the case of value networks, an essential part of the models is that they need to consider the network as a whole. The opposed dyadic supplier-buyer models do not sufficiently address the network phenomena, such as coalition formation.

This Dissertation studies the design of value networks further to the recognition that the network companies seek to gain private benefits, albeit in collaboration with their network partners (Papers [I]-[III]). Since strive for the private benefit may lead to sub-optimal behaviour from the network perspective, the network design needs to be *robust* in that opportunism is not the network partners' privately optimal behaviour. Thus, a robust network design encourages the network partners to contribute to the network. The results of this Dissertation suggest that suitable *ex-ante agreed profit-sharing rules* steer the network partners away from sub-optimal behaviour (Papers [I]-[III]).

The Dissertation contributes to managerial practises in two ways. First, Papers [I] and [II] construct practically feasible profit-sharing rules that offer the network partners the incentive to contribute to the network. Second, Paper [IV] builds models that support partner selection in the presence of inter-organisational dependencies among partner candidates.

Each Paper [I]-[IV] presents a real-life case, highlighting the practical relevance of the network models. Indeed, the management of complex value networks requires tools that support the design of network structures. These tools are particularly valuable in cases which involve both cooperation and competition, such as that of Paper [III], where the companies develop standards in cooperation, but the resulting product markets are competitive.

The rest of this summary article is organised as follows. Section 2 reviews the theoretical background and summarises the contributions of the Dissertation. Section 3 presents the main results of the Dissertation, and Section 4 discusses the implications of the results and the modelling of value-networks in general. Finally, Section 5 concludes with topics for future research.

2 Theoretical background and contributions

2.1 Game theory

The concepts of game theory are readily applicable to the analysis of value networks: companies are the *players*, who make *decisions* so as to maximise their own pay-off according to a *utility function*. The utility functions cater for the interdependencies between the players in that the utility function of Player x maps the decisions of x and the decisions of the other players to x's utility scale. (Myerson, 1997)

In value networks, the participating companies strive for collaboration rather than competition. Although the companies might not directly compete against each other, opportunistic behaviour may still exist within partners whose commitment to the network is low. Typically, opportunism occurs as ‘free riding’, which refers to collecting benefits without contribution, or misuse of confidential information, for instance (Axelrod, 1984; Nooteboom, 1999).

To escape the partners’ sub-optimal behaviour, the structure of the network needs to be such that the partners’ local optimisation drives the network towards global value creation. In essence, value creation requires the network to (i) reveal and prevent the possibilities of cheating, and (ii) construct benefit-sharing mechanisms that encourage the companies to contribute to the network.

A number of game theoretic developments can be employed to analyse and design incentive network structures. In his seminal papers, Nash (1950, 1953) axiomatised the bilateral utility-sharing problem and formulated a corresponding unique rule for cooperative utility sharing. The original idea is that the players’ outcomes in both disagreement and agreement have an impact on the share. Alternatively, Kalai and Smorodinsky (1975) suggested replacing the Nash’s (1950) Axiom of Independence of Irrelevant Alternatives by the Axiom of Monotonicity. This replacement yields another unique solution for two-player utility sharing. Nonetheless, in the case of transferable utility, such as money, and assuming that both players have similar utility functions, the solutions of Nash (1950) and Kalai and Smorodinsky (1975) coincide.

In games with several players, a subset of players can form a coalition, which complicates the analysis. Shapley (1953) showed that there exists a unique rule—the *Shapley value*—that allocates benefits among n players with respect to three widely accepted axioms. Furthermore, Harsanyi (1963) included threats in the Shapley value. Kalai (1977), in turn, axiomatised the broad class of proportional rules for n-player games. A common property for the above rules is that they seek *Pareto efficient* solutions, which implies that the increase of benefit for one player implies a decrease in another player’s payoff.

The above rules consider the static case of one-shot benefit sharing. Business, however, is dynamic, whereupon the benefit-sharing rules need to account for future collaboration, too. For the dynamic cases, a useful concept is *Stackelberg games*, where a leading player acts first, followed by a player who reacts to the leader’s action (Başar and Olsder, 1982). For instance, in the context of value networks, the *leader’s* problem is to construct benefit-sharing rules that encourage the *followers* to contribute to the network.

In contrast to cooperation, all games that involve competition have at least one equilibrium, from which no player wants to depart unilaterally (Nash, 1951). This equilibrium is the outcome of a non-cooperative game with rational decision makers (DM). Since network relations often involve both a cooperative and a competitive component, the identification of non-cooperative outcomes is relevant, too.

In cases where benefits accrue in the future, or which require the commitment of resources or trust between the partners, the concept of *repeated games* has proven useful (Axelrod, 1984). The idea of repetition is that although one-shot collaboration may be dominated by opportunism, the repetition and accumulation of benefits makes long-term collaboration optimal to all players. In game-theoretic terms, collaboration becomes the *sub-game perfect Nash equilibrium* (Myerson, 1997).

2.2 Transaction cost economics

Transaction cost theory explains the companies' behaviour through the extra costs incurred from inter-organisational activity (Williamson, 1975). Two categories for transaction costs are, first, *ex-ante* information collection, partner search, bargaining for prices, and contracting; and second, *ex-post* adaptation of operations, monitoring, and contract enforcement, for instance (Williamson, 1985). Although the measurement of transaction costs is not accurate, *activity based costing* (Cooper and Kaplan, 1988) offers a practical approach for the measurement (Degraeve and Roodhooft, 2000).

While transaction costs are inherent in all value networks, some network characteristics are likely to reduce them. First, the size of the network impacts the total costs; the marginal value of new network partners often turns negative after a certain point (Bakos and Brynjolfsson, 1993a,b; Nooteboom, 1999). Second, since the possibility for opportunism increases transaction costs, young relations are often characterised by strong governance and high transaction costs, but as the collaboration grows older, trust and informality instead of contracts reduces transaction costs (Parkhe, 1993; Woolthuis et al., 2005).

A relevant question is whether there exist structures that reduce the transaction costs of young value networks. Interestingly, Parkhe (1993) concludes that game theoretic analysis of network relations performed by managers contributes to the stability of the network. Indeed, game theory forces the managers think of possible unwanted outcomes, which helps foresee and minimise the impact of conflicts.

2.3 Decision analysis

Companies typically make their decisions so as to maximise profits. The profits are the result of incoming and outgoing cash-flows, which depend on the market success, on one hand, and e.g. transaction, operation, and capital costs, on the other. Hence, the future cash-flows determine the success of the decisions, as long as the time-value of money has been accounted for (McLean, 1958). However, the accurate estimation of future cash-flows at the time of decision-making is normally unrealistic; the uncertainties in e.g. market development, competitors' decisions, and even future costs yield high uncertainties in the future cash-flows.

In cases where the estimation of future cash-flows at sufficient accuracy is practically impossible, the DM can try to identify other, more accurately measurable *attributes* or *criteria*, which he/she deems to influence the cash-flows. The DM then estimates the performance of the *decision alternatives* with respect to the attributes, thus trying to identify the most preferred alternative (Churchman and Ackoff, 1954). Various multi-criteria methods have been used for centuries. For instance, Benjamin Franklin describes the method of "moral or prudential algebra" in his 1772 letter to Joseph Priestly (Hammond et al., 1998).

It is imperative for a network DM to make *rational decisions*. The rational decision-making was axiomatised by von Neumann and Morgenstern (1947) in their expected utility theory. Furthermore, multi-attribute value theory (MAVT) suggests that a rational DM can identify the most preferred alternative by (i) normalising the performance *scores*, (ii) weighting the attributes by non-negative *weights* that sum up to one, and (iii) calculating the weighted sum of the scores for each decision alternative. The resulting *additive value function* ranks the alternatives in the DM's preference order, assuming certain independencies between the attributes (Debreu, 1960). The additive model is practical because it leads to linear functions, which are computationally easier to handle than for instance non-linear multiplicative models. (Keeney and Raiffa, 1993)

The DM cannot necessarily give perfect information on the relative importance of the criteria (Steuer, 1976). Thus, several decision alternatives may be preferred, depending on the criteria weights. In such cases it is useful to identify the Pareto-efficient alternatives, in which the improvement of one criterion implies a trade-off with another criterion. It is worth noting that this demonstrates the connection between multi-criteria decision analysis and game theory; the criteria correspond to the various players' payoffs.

The outside world gives rise to numerous exogenous uncertainties, of which the rational DM identifies the most influential ones. The exogenous uncertainties often provide the DM with *real options*, which are decisions that need to be made only after the DM has more information on the prevailing conditions (Myers, 1977). The value of the real options lies in that they yield flexibility to the DM allowing him/her react to new information. (Dixit and Pindyck, 1994)

The formulation of decision-making cases as optimisation problems is often beneficial. The benefit of such formulations is that numerous solution techniques exist for various categories of optimisation problems. Thus, much of the routine calculations can be computerised, and the DM can focus on interpreting the results. Mixed-integer linear programming (MILP) formulations in particular have proven to be useful in many realistic cases, partially because of their flexibility for modifications and computational tractability.

2.4 Contributions of the Dissertation

This Dissertation constructs normative models for the company DM to make better decisions in value networks, when the aim is at efficient and structurally robust collaboration. The models exploit game-theoretic concepts for multilateral decision-making, which involves both cooperation and competition. Moreover, transaction cost theory is particularly useful in the study of inter-organisational efficiency. Decision analysis and optimisation, in turn, are applicable in situations that are best characterised by a centralised DM.

The empirical cases and the theoretical developments of Papers [I]-[IV] are in relation to two Postulates. First, Papers [I] and [II] describe two value networks—a ship-building network and a roof-assembly network—where the explicit determination of incentive profit-sharing rules became a prerequisite for continuous cost-reduction. Paper [III] studies the impact of profit sharing in a setting where companies participate in standard-setting organisations. Since standards are open also to companies who have not contributed to their development, the profit-sharing rules in standardisation context need to provide the incentive to develop technology. The research of Papers [I]-[III] relate to the first Postulate:

Postulate 1 There is no altruism in networks; companies aim to maximise own profits. Therefore, structurally robust value networks have incentive, ex-ante agreed profit-sharing rules, which steer the network towards global value creation.

Second, Paper [IV] describes a production network, where trust and collaboration history were used as criteria in partner selection. The case highlights the importance of inter-organisational synergies in partner selection, following the second Postulate:

Postulate 2 Inter-organisational factors influence the success of the network. Thus, besides organisational competencies, partner selection needs to account for the interdependencies between partner candidates, too. Examples are collaboration history, inter-firm trust, and geographical distance.

The above Postulates are connected in that the design of *robust value networks* requires: (i) the employment of incentive profit-sharing rules and (ii) the selection of synergetic partner configurations that minimise transaction costs. (Jarillo, 1988; Gulati et al., 2000; Zaheer and Bell, 2005)

Motivated by the empirical observations, this Dissertation contributes, first, by analysing and developing profit-sharing rules that can be used as incentives for innovation in value networks, and second, by constructing multi-criteria partner-selection models, which incorporate the interdependencies between the partner candidates. Table 1 lists the research settings and particular contributions of Papers [I]-[IV].

Table 1: Contributions of Papers [I]-[IV]

Paper	Research objective	Methodology	Results
[I]	Construct profit-sharing rules that encourage network partners to process innovations.	Stackelberg game: principal sets the incentive so that it is optimal for the network partners to innovate.	Suggests three different profit-sharing rules based on theoretical analysis.
[II]	Construct profit-sharing rules that incentivate network partners to cost reduction and dynamically account for the network's competitive position.	Real-option approach caters for the dynamics of the business environment. Otherwise similar to the Stackelberg game of Paper [I].	Profit-sharing rule needs to reward the innovator similarly in different competitive positions.
[III]	Study the applicability of proportional sharing of benefits from patent licensing in the context of technological standards.	System dynamics modelling for describing the business environment. Non-cooperative game theory for determining the competitors' optimal market-entry times.	Proportional sharing of benefits is applicable from the perspectives of technology development and market growth.
[IV]	Construct a multi-criteria partner selection model, which accounts for the interdependencies between partner candidates.	MAVT to cope with the multiple criteria, and MILP to identify the Pareto-efficient network configurations.	New models for the incorporation of network interdependencies in partner selection.

3 Robust structures for value networks

3.1 Ex-ante agreed profit-sharing rules

Collaboration in value networks typically requires some sort of commitment or contribution to the network. Examples of such contributions are the re-organisation of workload (Paper [I]), the revelation of cost information (Paper [II]), and the investments in technology development (Paper [III]).

However, in compliance with Postulate 1, the companies expect a return on their contributions. If the company assesses that the expected return does not compensate the contributions, defective participation, or 'free riding' becomes the dominant alternative (Axelrod, 1984). The fear of low compensation is particularly present in value networks with young partnerships, low trust, and possibilities for opportunism (Parkhe, 1993; Nooteboom et al., 1997).

The network can reduce the partners' uncertainty on the compensations through *ex-ante agreed profit-sharing rules*. Thus, Papers [I]-[III] develop and analyse profit-sharing rules that, firstly, encourage the network partners to contribute, and secondly, are practically feasible. The development of the profit-sharing rules relies strongly on game-theoretic concepts.

As a result, not all profit-sharing rules are eligible. The rules need to be such that innovation is rewarded, and the opportunity for unmerited rewards is minimised. Thus, the responsible construction of profit-sharing rules accounts for the following considerations:

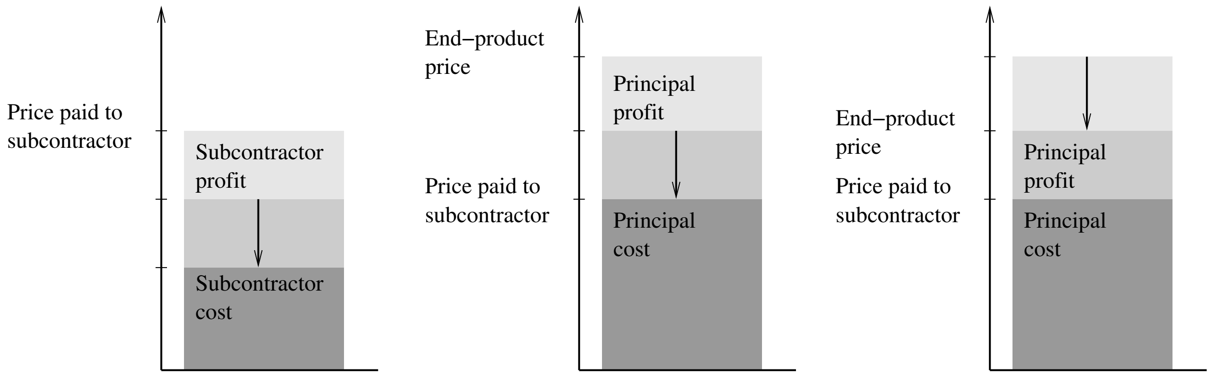
- Theoretically sound rules measure the contribution and reward the partners respectively. In contrast, if profit-sharing is based on costs plus profit margin, there is a risk that the network partners show higher costs than what is appropriate. This risk is particularly present when the partners belong to several networks.
- The measurement of the parameters needs to be practically feasible so that the effort does not drain the benefits of innovation. Nonetheless, the strive for practicality may not lead to the use of poor measures.
- Transparent and jointly agreed rules help foster trust between the partners, which in long-term collaboration reduces transaction costs.
- The profit-sharing rules need to account for the dynamics of the value network and the surrounding business world. Thus, profit-sharing cannot be seen as a static one-shot problem, but instead as a continuous process throughout the life-cycle of the value network.

There are indeed practically feasible rules that meet the requirements. Papers [I] and [II] consider the case where the profit-sharing rule is an incentive for cost-reduction in networks with a principal and several subcontractors. Here, the profit to be shared is the amount of cost reduction, in which case there are three parties among whom the benefit is shared: (i) the subcontractors (Figure 1a), (ii) the principal (Figure 1b), and (iii) the customer (Figure 1c).

A practically feasible profit-sharing rule accounts for the network's competitive position (Porter, 1996) as follows. First, if the network is uncompetitive against its competitors, then a large share is allocated for end-product price-reduction. Second, if the network already has a better price-value position than its competitors, then the network partners can allocate profits among themselves. Regardless of the competitive position, the innovating sub-contractors always receive the same share, which eliminates their chances to benefit from the hold-up of cost-reduction (Figure 2).

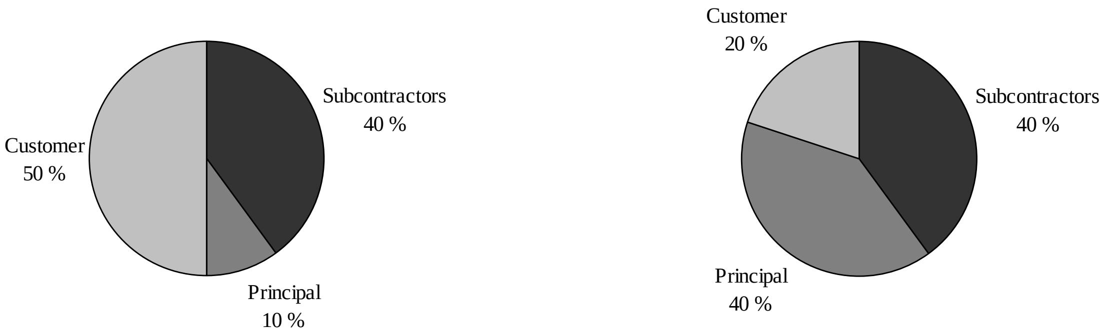
In cases where the contribution is measurable, a practical rule is to share the benefits in proportion to the contribution. The proportional rule is generally used in e.g. joint ventures, where the financial investment is the measure of contribution. Paper [III] studies the case where the network partners contribute to standard setting by investing into technology development. Here, the contribution is measured as the number of the standard-related essential patents the companies accumulate. An essential patent is a patent that is inevitably infringed if the standard is implemented. Since the number of patents reflects the results of technology development, the proportional share according to essential-patent numbers approximates the companies' contributions.

Papers [II] and [III] in particular address the dynamic aspects of benefit sharing; the former presents how real options need to be taken into account in profit-sharing rules, whereas the latter incorporates the companies' market-entry decisions in the study of benefit sharing.



a) Increase subcontractor profit b) Increase principal profit c) Decrease end-product price

Figure 1: Three objects of profit sharing



a) Uncompetitive position b) Competitive position

Figure 2: Profit sharing related to position against competitors' prices

Overall, the more transparent the value network, the easier it is to construct feasible profit-sharing rules. In principal-subcontractor networks, open-book practises are a good way towards transparency.

3.2 Synergetic network configurations

Selecting the right partners can be crucial for the success of the value network. Often, partner selection cannot be made purely based on financial indicators, such as cash-flow estimates, because the differences in the partner candidates' performances are impossible to measure in monetary terms. In the case example of Paper [IV], monetary criteria were the least important, because the continuity of an important customership rests rather on successful project performance.

Thus, partners are often selected with respect to multiple criteria (Dean and Schniederjans, 1991; Meade et al., 1997; Talluri and Narasimhan, 2003). There exist numerous criteria, according to which partners are typically selected (for 183 evaluation criteria of individual companies, see Lin and Chen, 2004). The most typical ones include quality, punctuality, learning capabilities, corporate image, and financial stability, for instance.

Further to Postulate 2, the sole use of partner-specific criteria neglects the possible gains from synergetic effects. Nevertheless, synergy benefits due to for instance collaboration history, interfirm trust, geographic location, cultural compatibility, etc. can reduce transaction costs and promote openness and innovation in the value network. Therefore, taking into account additional criteria

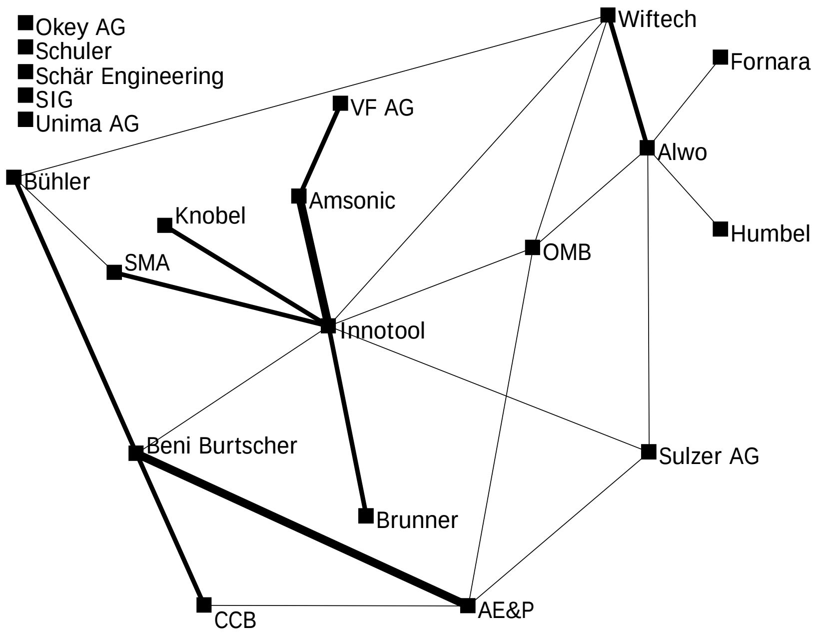


Figure 3: Collaboration history of twenty-one case companies (line thickness corresponds to intensity of past collaboration)

that are measured for a set of companies helps identify network configurations that work better as a whole.

To account for the network criteria, Paper [IV] develops models that incorporate these criteria in MILP formulations for partner selection. An illustrative way to present the data on network relations is a graph where the vertices and edges represent the companies and their interrelations, respectively. For example, Figure 3 depicts the collaboration history of twenty-one case-companies of Paper [IV].

The developed models can generally use graph representations as inputs for network criteria. Moreover, the models enable the use of the total number of partners as a selection criterion. The total number may be relevant if one partner can contribute with multiple competencies, and a smaller total number of partners is preferred. The incorporation of these criterion-categories in partner selection helps capture many of the success factors identified in transaction cost theoretical studies.

MILP models allow the DM to identify Pareto-efficient network configurations using common algorithms and solver libraries. Knowing the Pareto-frontier, the DM can focus the cost-benefit-risk and sensitivity analyses on the most potential network configurations, and thereby make the final decisions manually. MILP models are also flexible to modifications and extensions, since they accommodate well to linear constraints and objective functions. In general, the developments of Paper [IV] are useful in portfolio-selection problems, where a subset of elements needs to be identified from a larger set with respect to multiple objectives and constraints.

4 Discussion

The models of this Dissertation are useful for network decision-making at three levels. First, the models help an individual company optimise its participation in various networks. Second, the models support network decision-makers steer their network partners towards global value creation. Third, the results give insight to policy-makers at the innovation-system level. Table 2 summarises the implications of this Dissertation.

Value-network models increase the understanding of complex network relations and open the way for the optimal design of network structure. Formal optimisation, however, requires the estimation of model parameters, which in some cases may turn out very difficult or overly expensive. In such cases, the most important benefit of modelling is the conceptualisation and increased knowledge of the business environment.

Besides parameter estimates, the other source of inaccuracy follows from the models' limited capability to describe the real world. The modeller needs to balance between the model's comprehensiveness and amount of details, on one hand, and the clarity and computational tractability, on the other. In any case, the responsible modeller firstly focuses on model validity; secondly, the level of details determines the use of the model—whether it is sheer conceptualisation, or whether it includes numerical calculations and optimisation, too.

If the main purpose of models is decision support, several issues are worth noting. First, the effort of parameter elicitation must not be too burdensome. It is typically the experts of the organisation who are solicited for this work, and there are demands for their time also in other activities than filling forms. Second, responsible use of numerical models does not seek unique optimum, although the models may tempt towards narrow-sighted optimisation. Instead, it is more robust to identify several good alternatives, on which the DM can focus his/her further assessment effort. Third, the results of the models should undergo critical qualitative scrutiny that contrasts them with practical experiences.

Table 2: Implications of the Dissertation at three levels

Level of analysis	Postulate 1: Innovation incentives and profit sharing	Postulate 2: Synergetic partner selection
Company	A rational company DM finds out the profit-sharing mechanisms of its networks and tries to restructure partnerships where the other companies can benefit without appropriate contributions to the network.	Anticipatory companies look beyond their own partners. The partners' partners and their interrelationships yield a more holistic view on the other companies' intentions.
Network	A robust network sets incentives that encourage the partners to contribute to the network. The optimal incentives for long-term relationships are jointly agreed, transparent, and account for the dynamics of the business environment.	Besides the partners' competences, the success of the network depends on the efficiency of collaboration. Hence, optimal partner selection addresses the inter-organisational dependencies between the partner candidates.
Innovation system	Transparent profit-sharing rules related to the systemic instruments decrease the companies' contracting and litigation costs. Responsible policies encourage risky research and development and reward for factual results instead of empty rhetoric.	Networking with everyone is not valuable per se. Thus, the incentives for synergetic collaboration between universities, research institutes, and companies leave space for self-organisation, too.

The network topology has an impact on the suitability of models. In very large networks computational tractability may restrict the use of combinatorial models (De Reyck and Herroelen, 1996). Moreover, heterogeneity within the network partners complicates the modelling process, since various partners need to be modelled one by one. Besides the increased complexity, the topological issues do not invalidate the results of this Dissertation.

Although this Dissertation focuses on centralised optimisation, largely heterogeneous or non-hierarchical networks can be alternatively modelled with a decentralised approach (Lesser and Corkill, 1981). In this regard, the field of *multi-agent systems* (MAS) deals with autonomous entities—the agents—that have private objectives and problem-solving skills and that share common protocols for interaction (Sycara, 1998). The MAS models can offer solutions whose identification is difficult for the centralised decision maker, particularly when the frequency of change or the complexity of the systems increase (Mařík and McFarlane, 2005). The profit-sharing and partner-selection models of this Dissertation can be useful in MAS models where the agents strive to maximise their own benefit, while the socially optimal solution would be commonly desired.

Towards this end, several authors have approached coalition formation with MAS techniques. Sandholm and Lesser (1997) study coalition formation in a setting where the agents' rationality is bounded by the performance of their algorithms and the cost of computational resources. In such cases the DM faces a trade-off between the optimality of the solution and the cost of computation, thus the solutions are typically sub-optimal with respect to the total value. Shehory and Kraus (1998), in turn, take a MAS approach to task allocation where each task is to be performed by a coalition of agents. Again, the presented any-time algorithms aim to maximise the total value of the system, but the final solution is likely to be sub-optimal.

In recent years, also the European research community has been active in the study of network phenomena with MAS models. Norman et al. (2004) consider holistic virtual organisation (VO) management, which includes both VO formation and VO operation. First, the formation of the VO follows a process where the agents bid for participation in a specific VO, taking into account the quality of service. Second, the operation accounts for situations where reconfiguration of the VO may be necessary. Furthermore, the MAS models of Hodík et al. (2005) distinguish between the intra-enterprise and extra-enterprise levels in network-relations management. They propose several use cases—including dynamic production planning, supply chain management, simulation, and extra-enterprise information access—where MAS models can be beneficial.

This Dissertation is closely related to some recent results of the European research community. First, the holistic VO creation framework of Camarinha-Matos et al. (2007) includes four tools, namely (i) collaboration opportunity identification, (ii) collaboration opportunity characterisation and VO rough planning, (iii) partners search and suggestion, and (iv) agreement negotiation. In particular, Tool (iii) utilises the partner selection models of Paper [IV]. Second, Paper [IV] itself is influenced by Lavrač et al. (2007), who use collaboration history as a measure of inter-organisational trust.

A managerial prerequisite for value-network modelling is the management's willingness to consider the network relations at the aggregate level. Exploiting models in decision support requires the time and desire to understand the motives of model-building and to fine-tune the models into the proper context. Therefore, model-based decision-making often requires the presence of the modelling experts at least in the very first implementations.

Finally, the managerial relevance and usefulness of the models can be enhanced by gathering data on the companies' decision-making processes. The benefits of storing data derive from more accurate model validation and parameter estimation. Particularly in repeated decision-making processes, data gathering for computer-assisted decision-making is likely to be beneficial. Besides collecting data, the identification of future opportunities encourages the elicitation of scenarios and the related real options, which can considerably improve the quality of decision-making (Myers, 1977).

5 Concluding remarks

The results of this Dissertation are summarised as follows. First, the construction and implementation of ex-ante agreed profit-sharing rules reduce the network partners' uncertainty of the returns on their contributions. The resulting increased transparency motivates the network partners to contribute more, which results in higher potential for innovation (Postulate 1). Second, accounting for inter-organisational dependencies in partner selection helps obtain a holistic view on the possible network synergies. In contrast, these synergies are ignored in partner-selection models that only account for the performance of individual organisations (Postulate 2).

In any case, the value of networking derives from *appropriate combination of competences*, as long as the relevant partners have been identified, and the structure of the network is such that the partners have the incentive to contribute. If either of these conditions is violated, there is a high risk of inefficiency and free-riding in the network. The implications for innovation policies are similar; socially optimal innovation systems reward for contribution and encourage risky research and development, which is carried out in collaboration between universities, research institutes, and companies. Nevertheless, the instruments of the innovation system should emphasise self-organisation in partner selection instead of top-down network configuration.

The ever more rapid research and development and the globalisation of the networks calls for tools that prevent the excessive increase of transaction costs and, besides the macro level, increase the understanding of managers at the company level, too. When networks grow larger, they lose efficiency because of increased number of network relations. Moreover, combining complementary competences to meet customer needs requires very broad knowledge; in large networks it is costly to train people for such broad knowledge. This Dissertation is a contribution towards the better management of network relations.

This Dissertation suggests several avenues for future research. First, since partnerships involve the risk of inefficiency, a relevant question is when it is optimal to control the network through competition, and when it is more beneficial to strive for partnership. Answering this question requires more research in terms of both empirical and theoretical studies. Second, more empirical case-studies are needed to study the operationalisation of the theoretical results of this Dissertation. Third, in knowledge-based networks the competences of various partners is intangible, in which case it may be more efficient to transfer knowledge rather than money. More research is needed to study the prerequisites for transferring intangibles within the network. Fourth, networks that offer services need methods for service valuation and the further sharing of the service value among the customer and the network partners.

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