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There is a research tradition in the economics of standards which addresses standards wars, antitrust concerns or positive externalities from standards. Recent research has also dealt with the process characteristics of standardisation, de facto standard-setting consortia and intellectual property concerns in the technology specification or implementation phase.

Nonetheless, there are no studies which analyse capabilities, comparative industry dynamics or incentive structures sufficiently in the context of standard-setting. In my study, I address the characteristics of collaborative research and standard-setting as a new mode of deploying assets beyond motivations well-known from R&D consortia or market alliances. On the basis of a case study of a leading user organisation in the market for industrial automation technology, but also a descriptive network analysis of cross-community affiliations, I demonstrate that there must be a paradoxical relationship between cooperation and competition. More precisely, I explain how there can be a dual relationship between value creation and value capture respecting exploration and exploitation.

My case study emphasises the dynamics between knowledge stocks (knowledge alignment, narrowing and deepening) produced by collaborative standard setting and innovation; it also sheds light on an evolutional relationship between the exploration of assets and use cases and each firm's exploitation activities in the market. I derive standard-setting capabilities from an empirical analysis of membership structures, policies and incumbent firm characteristics in selected, but leading, user organisations.

The results are as follows: the market for industrial automation technology is characterised by collaboration on standards, high technology influences of other industries and network effects on standards. Further, system integrators play a decisive role in value creation in the customer-specific business case. Standard-setting activities appear to be loosely coupled to the products offered on the market. Core leaders in world standards in industrial automation own a variety of assets and they are affiliated to many standard-setting communities rather than exclusively committed to a few standards. Furthermore, their R&D ratios outperform those of peripheral members and experience in standard-setting processes can be assumed.

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Standard-setting communities specify common core concepts as the basis for the development of each member's proprietary products, complementary technologies and industrial services. From a knowledge-based perspective, the targeted disclosure of certain knowledge can be used to achieve high innovation returns through systemic products which add proprietary features to open standards. Finally, the interplay between exploitation and exploration respecting the deployment of standard-setting capabilities linked to cooperative, pre-competitive processes leads to an evolution in common technology owned and exploited by the standard-setting community as a particular kind of innovation ecosystem.

Keywords: standard-setting, innovation, industry dynamics and context, industrial automation

JEL: D71, M21, L69, O32

## 1 Introduction

There is a research tradition in the economics of standards which addresses standards wars (particularly see Shapiro/Varian, 1999a, chapter 9, 1999b; on strategic options in standard wars i.e. cf. Hill, 1997; for a case study i.e. cf. Dranove/Gandal, 2003, on Dvd versus Divx), antitrust concerns (Hemphill, 2005; Calderini/Giannaccari, 2006; Economides/Lianos, 2008)[1] or positive externalities/network effects from standards (among others, see Shapiro/Varian, 1999a, chapter 7; Farrell/Saloner, 1985, 1986; Katz/Shapiro, 1985, 1986, 1994; Shy, 2001; Mitchell/Skrzypacz, 2006; for path dependencies in particular, see Arthur, 1989; Liebowitz/Margolis, 1994). Recent research has also dealt with the process characteristics of standardisation,[2] de facto standard-setting consortia (Gerybadze, 2008a; Updegrove, 2008) and intellectual property concerns in the technology specification (i.e. the meaning of (F)RAND, cf. Miller, 2007; Layne-Farrar/Padilla/Schmalensee, 2006; patent pooling, cf. Lerner/Strojwas/Tirole, 2003; or intellectual property issues in standards specification for new technology, cf. Bekkers/Duysters/Verspagen, 2000; for an overview article on intellectual property rights and standards also see Simcoe, 2007). Innovation studies on inter-firm collaboration have dealt with research and development (i.e. in terms of measuring co-patenting or describing joint research between European firms funded by the European Framework Programme), internalisation of costs or some kind of market alliances (i.e. buyer consortia or consortia to share resources such as the Star Alliance in passenger air traffic business). The paradigm of Open Innovation (Chesbrough, 2003; Chesbrough/Vanhaverbeke/West, 2006) has recently created a new field of research into inter-firm activities and firm-STI relationships (triple helix networks, innovation commercialised by universities, etc.). Conversely, the phenomena of collaborative standard-setting and collaboration for open standards[3] require more in-depth studies as well as comparative studies between different industries. The incentives for standard-setting collaboration along the standards lifecycle are conceptualised by, for example, Gipper/Dingee (2007). Technology diffusion in general is taken for a demand-side driven process and typically described by an S-shaped curve (Geroski, 2000; Rogers, 2003).The diffusion rate of an innovation depends on relative technological advantage, but also on social norms and user-related characteristics such as complexity of innovation, compatibility with established user behaviour or, for instance, 'observability' of innovation (Rogers, 2003; Hall, 2004, 2005; also see Thoma, 2006 p. 33). Hall (2005, p. 476f) adds that technology adoption decisions do not necessary depend on users (e.g. this is often not the case in the airline industry), but rather depend on market characteristics which have to be judged from case to case. She particularly points to the role of market concentration in adoption decision. For instance, user-side (few and big global users) and/or supply-side (few dominant technology providers) can be concentrated. Furthermore, Hall (2005, p. 477), argues that "*along with market size and structure, the general regulatory environment will have an influence, tending to slow the rate of adoption in some areas due to the relative sluggishness* *of regulatory change and increasing it in others due to the role of the regulator in mandating a particular technological standard*".

Besides unique structural characteristics of standard-setting and standardisation in particular industries, dynamics & evolutionary economics studies on technical standards are also a fascinating new subfield. Standard-setting capabilities and incentive structures with respect to standards evolution should be researched in more depth. Furthermore, contemporary research on de facto standards only focuses on high technologies such as telecommunications or information technologies, but seldom provides in-depth studies on low/medium-technologies. In my study, I address the characteristics of collaborative research and standard-setting as a new mode of deploying assets beyond motivations well-known from R&D consortia or market alliances in high-technology domains. Note that the case of industrial automation discussed here is best described as medium technology (cf. also Hatzichronoglou, 1997). On the basis of a case study of a leading user organisation in the market for industrial automation technology, but also a descriptive network analysis of cross-community affiliations, I demonstrate that there must be a paradoxical relationship between cooperation and competition. More precisely, I explain how there can be a dual relationship between value creation and value capture with regard to exploration and exploitation.

In strategic management, capabilities are inter alia defined as "*repeatable patterns of action in the use of assets to create, produce and/or offer products to a market*" (Sanchez, 2004, p. 519; also cf. Sanchez, 2001). Capabilities in general and in this paper are best described as 'ability to'. A comprehensive survey on dynamic capability as a concept is provided by Menon (2008). Forthcoming studies on technological competencies at our Centre for International Management and Innovation, Hohenheim, indicate that such abilities are based on *accessible resources*, experience and *knowledge dynamics*, *intellectual property regimes* and managerial *competence*. According to Slowak (2008), standard-setting capability is related to the ability to create and control a strong business system.[4] More precisely:

> Standard-setting communities … create a simplified frame of reference which turns [industry] problems into standards for attractive, new product offers ... The purpose of a standard-setting community is both to embed strong technology as regards innovation into the standard's new vintage '$s_{iv}$' (exploration of technology) and to achieve a fast rate of technology diffusion (i.e. achieve strong open standards which can be exploited by the value added strategies of each member firm).
>
> (Slowak, 2008, p. 149).[5]

Gerybadze describes how firms apply wise tactics and techniques in order to influence global standards. The ability to apply and advance such tactics and techniques for de facto standard-setting represents a crucial standard-setting capability (cf. Gerybadze, 2008a). Gerybadze argues that standard-setting success depends on a forceful, convincing innovation strategy; the ability to appropriate intellectual property; and finally, the early exertion of influence on evolving de facto standards and *high-norm* activities (Gerybadze, 2008b, p. 166). He observes 'novel dynamics of standard-setting and innovation' which are evolving from complexity in products, systems and technologies. Among other factors, it is then crucial on which level of the value chain standards are set, and who drives innovation in industry (cf. Gerybadze, 2008a, pp. 113 and 117).

This paper emphasises the dynamics between knowledge stocks produced by collaborative standard setting and innovation, not the firm tactics behind those dynamics; it also sheds light on an evolutional relationship between the exploration of assets and use cases and each firm's exploitation activities in the market. The section which follows introduces the industrial automation industry and major system integrators in the segment of field bus technology. It will also describe the methodology of my empirical industry analysis. In sections three and four, I provide a descriptive network analysis for leading field bus user organisations. The analysis also shows how dynamics and variety in technology are shaped by cross-community affiliations. Conceptually, first I characterise standard-setting communities as part of a *sectoral innovation system*; second, I illustrate the means of industry structure for market velocity whereas 'structure' from an evolutionary standpoint might be taken for replication channels within the innovation process. Section five lists the different industry-specific network effects. Finally, section six includes limitations of the model and conclusions; it also provides a formalised model to resolve the modelling challenges discussed in sections three to five. The theoretic model of standard-setting follows West (2007) and Slowak (2008). West (2007) distinguishes four phases of technology diffusion: specification of a technology, implementation, complement phase, and use phase. Standard-setting primarily addresses technology specification and implementation, although the anticipation of the use cases and complementary goods and services separates a well-designed standards proposal from a weak one. Slowak argues that knowledge dynamics in industrial automation can be described by evolutionary economics theory. More precisely, there is an evolutionary relationship between exploration and exploitation of knowledge.[6] If that is the case, collaborative standard-setting can also be conceptualised by replication patterns:

> How can we understand the knowledge dynamics which moderate standard-setting capability? It seems that PROFIBUS knowledge dynamics can be described as a virtuous cycle of exploration and exploitation respecting some trade-off between the deployment of current know-how and experimentation with new alternatives from the external environment or else an interplay between variety generation, selection and replication.
>
> (Slowak, 2008, p. 159).

> Collaborative standard-setting can be thought of as alignment against challenges from the market field. Standard-setting communities provide an institutional frame for replication of success by new, innovative but backward-compatible standard vintages.
>
> (Slowak, 2008, p. 162).

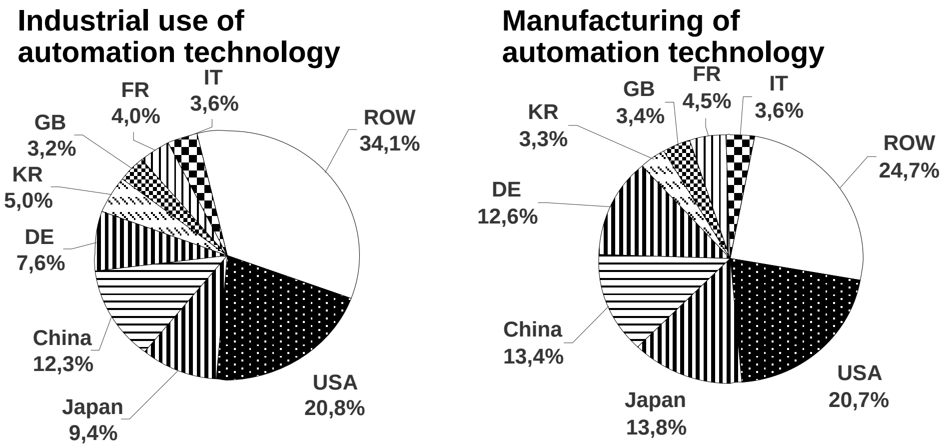
Such a dynamics perspective poses several questions on the characteristics of the *market field*, best analysed in terms of a dynamic industry study. My paper undertakes this challenge, although it cannot quantify the concept outlined below. In particular, who defines the *market field* and what are its rents? How far can the dynamics be initiated or controlled?

Taking a ‘virtuous cycle of exploration and exploitation’ as a given, what does industry structure mean to this interplay? I assume that depending on the number of cross-memberships, community size and pooled technology portfolios, a standard-setting community stimulates competing communities to increase innovative standards output. Note that standards and technology are not isolated from routines and competencies which devalue or stretch a firm’s resources. Therefore, a description of the population of agents ascribed to a *sectoral innovation system* allows for preliminary assumptions about which interdependencies underlie the sector’s standard-setting dynamics; it takes account of the context in which exploration or exploitation activities are practised.

## 2 Case context and methodology of research

Basically, world market shares in automation technology are distributed nearly equally between the United States, Western Europe and Asia (for details, see Figure 1). Recently, the field bus market has been dominated by three standard-setting user organisations: *ODVA*, *CLPA* and *PROFIBUS*. Each has about one-third of the world market share in the global *PLC market*.[7, 8 and 9] ZVEI (2008) estimates German growth rates for 2009 plus 1-2% in factory automation, and plus 4-5% in process automation.

**Figure 1: World market for automation technologies in 2005**




**Source: ZVEI (2007). ROW: rest of world.**

The market for industrial automation can be technically separated into factory, process and building automation because each segment has its own requirements with regard to safety, reaction times and functionality. Whereas factory automation requires real-time motion (i.e. robots, drives), process industry needs to ensure stable processes / requires reliable process monitoring functionality (i.e. safety in explosive chemical processes, measurement of liquids, measurement of pressures). Today, process automation promotes innovation – more and more monitoring functions are installed in factories and the application sectors where factory and process automation technology converge. Influences from consumer markets and logistics particularly accelerate this convergence process. Building automation rather represents a low-technology domain. Here, it is crucial to provide maximal interoperability of heterogeneous devices, but also to allow for the integration of consumer market high-technology standards (i.e. Ethernet, WiFi, pervasive connectivity in home automation). Standards in factory and process automation seem to be over-engineered for building automation and the majority of functions do not need to run in real time. In building automation, Siemens is heavily involved in one of the leading standards as well. The firm has two seats on the executive board of the KNX Association; among these is the President's function.

The history of 'control and automation technologies' begins with simple measurement devices such as the thermostat, and the invention of the transistor in 1947. Then, there were several inventions which introduced electronics into industrial controls/automation, for instance the inventions of electronic drives and programmable controls. In 2004, a programmable logic controller is capable of implementing full SPS functionality on one microchip. Around 1997, digital factories technology & simulation software are integrated into automation solution sotware (A&D Kompendium 2007/2008; Thoma, 2006, p. 7ff and p. 9 Table 1). Ethernet field busses ('Industrial Ethernet') represent the next generation of busses in industrial automation which will displace conventional field bus technology in future plant or factory solutions. Recently, Industrial Ethernet technology is diffusing into automation technologies and component prices are declining. There are several technologies which offer 'web in automation' and protocols based on XML or other web standards. Nonetheless, figures on Industrial Ethernet's market share of automation are rare. As described by Thoma (2006), field busses are *General Purpose Technology (GPT)*. Such technology is characterised by 'technological cumulativeness', 'complementary innovations' and "*a vicious circle relationship between the GPT producers and its application sectors*" (Thoma, 2006, p. 3). *General Purpose Technologies* have been particularly analysed for their effect on economic growth (for instance, see Bresnahan/Trajtenberg, 1995; Helpman, 1998; or Petsas, 2003), although the previously quoted 'vicious circle relationship' also requires a standard-setting process analysis separate from the one for technologies in downstream or typical consumer markets.

The leading user organisations *PROFIBUS*, *ODVA* and *CLPA* will be described in brief.[10] These standard-setting communities will be taken as an example of how standard-setting capabilities and industry contexts are interrelated in medium-technology markets. Each of the three communities is governed by big multinational firms in automation or industrial electronics such as Siemens (*PROFIBUS User Organisation*, European market leader), Rockwell Automation, Omron, Schneider Electric and Cisco (*ODVA*, US market leader) and Mitsubishi Electric (*CLPA*, Asian market leader), hereafter referred to as 'integrators'.

*PROFIBUS User Organisation* – Karlsruhe, Germany – maintains and develops the standard *PROFIBUS* (conventional field bus technology) and *PROFINET* (Ethernet field bus). *PROFIBUS* was created between 1987 and 1990, initiated by Fraunhofer-Gesellschaft, Research Centre for Information Technology Karlsruhe, RWTH Aachen, TU Munich, Bosch, Honeywell and Siemens. It was supported by big German specialist associations for electrical and mechanical engineering, namely the Association of German Engineers (VDI) and Association for Electrical, Electronic and Information Technologies (VDE). *PROFIBUS* consists of *PROFIBUS User Organisation* and *PROFIBUS & PROFINET International*. Whereas *PROFIBUS User Organisation* (which is the German regional association within *PROFIBUS & PROFINET International*) holds exclusively the innovation mandate for PROFIBUS and PROFINET, *PROFIBUS & PROFINET International* distributes and implements the standard.[11]

The American standard *DeviceNet* respecting underlying technology was developed by Allen-Bradley (a Rockwell company)[12] and introduced between 1993 and 1994. It is a specific implementation of the *CAN* protocol where the physical and application layer has been modified. Technology was transferred to *ODVA* in 1995 (Caro, 2007; http://www.rockwellautomation.com/ about_us/history.html, Rockwell Automation). The *ODVA* was established in April 1995. Ethernet/IP was developed by ControlNet International, the Industrial Ethernet Association and the Open DeviceNet Vendor Association. It was released in March 1998 and adopted by the Open DeviceNet Vendor Association in July 2000 (for a time chart, see www.isd.mel.nist.gov/projects/openarch/Jan_2002/What%20Is%20EtherNet-IP.ppt, NIST, Open Architecture Control).

*CC-Link Partner Association (CLPA)* was established in November 2000 by six Foundation Partner companies to promote and to advance the field bus CC-Link. The standard was developed by Mitsubishi Electric in 1996 and released in 2000. Global organisational structures respecting six additional global offices were founded in 2001 (http://www.meau.com/eprise/main/sites/CC-Link/Partner_Association/2._Organization_History, CLPA, History).

Standard-setting collaboration concerns pre-competitive but crucial-to-competition technology. Nonetheless, regularly there are standardisation projects within standard-setting communities which can be best described as both competitive and crucial-to-competition projects. Those projects or also de facto standards industry consortia[13] have developed sophisticated policies and routines in order to handle intellectual property concerns and exclusion rights. Examples, for instance, are *IO-Link* and *WirelessHART*. *High-norm* activities[14] are either about formal standardisation of such technology for the entire *sectoral innovation system*, or about quality and other standards which are not crucial-to-competition. Note that not only standard wars and standard-setting collaboration but also *high-norm* activities may be subject to firm ‘tactics’. Note further that *high-norm* activities are increasingly addressing innovation and shortened technology life cycles through new deliverables such as i.e. *IEC* or *DIN Publicly Available Specifications, IEC Industry Technical Agreements* or *CENELEC Workshop Agreements*. These pre-norm documents have evolved and become sophisticated in their use over time; the idea is to shorten a standard’s time-to-market through the early provision of preliminary documents on the final future standards specification.

*IO-link* is a standard to add active functions to the sensor level in factory automation. The project consortium is affiliated to the *PROFIBUS User Organisation*, namely it represents the Working Group 16. Standards development started in 2001 and 2002 as the initiative of Siemens and SICK. The working group was founded to facilitate the programming and diagnosis of sensors with modern engineering tools, as the combination of physical standard sensor connections and recent field bus protocols significantly limited sensor functionality. New functionalities, for instance, concern sensor self-configuration, active status report or replacement and automatic reconfiguration of broken sensors.[15] Prior to the project, Siemens had developed a solution to this issue which, however, would have changed the physics characteristics of the sensor interface. The functional advantages of IQ-sense are similar to those achieved by *IO-link* a few years later. They also offer better access through programming tools, active diagnosis and sensor substitution with self-reconfiguration of a new sensor. Siemens IQ-sense specification, however, uses two-conductor cable, whereas conventional sensors use three-conductor cable (as *IO-link* also does). Furthermore, IQ-sense was designed to work seamlessly with *SIMATIC STEP*, which is proprietary Siemens technology. The Siemens value added with regard to *PROFIBUS/PROFINET* standards relies – *inter alia* – on *SIMATIC* specification. As *IQ-sense* did not win a critical mass of adopters, *IO-Link* emerged as the technical winner of status negotiations between Siemens and the incumbent sensor companies. In order to mature, the technology had to be negotiated successfully over several years; IEC standardisation activities (namely IEC 60947-5-2 / IO-link proposal by DKE, DKE K956) was completed in 2007. Recent *high-norms* specify the 'ports' so that the standard can also be used in other field busses apart from *PROFIBUS* (IEC 61131). *IO-link* products have been available on the market since 2008; leading sensor firms like SICK presented their first products at the Hannover Messe 2007. Note that the consortium has been granted a temporary monopoly for the use of relevant patents and the trade mark '*IO-link*'. The working group established entry fees and exclusion mechanisms beyond the regular terms of the *PROFIBUS User Organisation* Guidelines. *IO-link* trademarks were owned by the firms Balluff (figurative elements) and ifm electronic (name), (see WIPO Trademarks 876152 and 913389) (http://www.wipo.int/ipdl/en/madrid/ key.jsp?KEY=876152 and http://www.wipo.int/ipdl/en/ madrid/key.jsp?KEY=876152), and they have now been transferred to the *PROFIBUS User Organisation*. *IO-link* represents a case where a standard has been developed which is fully backward-compatible in hardware although it provides innovative features; standards design is close to proprietary value added strategies at the market.

*WirelessHART* is a wireless standard in process automation which has been established by the HART Communication Foundation. It replaces wired HART-communication. The standard allows for safe wireless data transfer in compliance with the US Advanced Encryption Standard (AES 128). It is part of the HART specification release 7 and backward-compatible with releases 5 and 6. Furthermore, there are adapters which allow for an upgrading of HART 5/6-devices for the running of *WirelessHART*. Note that *WirelessHART* uses the open standard ZigBee at the physical layer in compliance with IEEE 802.15.4. The

HART protocol merely controls the application layer. Wireless technology discovers new application fields in the process industry, for instance, the monitoring of maintenance of battery-driven field devices or the gathering of new process data owing to decreased installation costs. More generally, the ‘economics of industrial automation’ builds on a reduction of cabling and a decentralisation of factory/plant-wide integrated motion and process control. This increases functionality without increasing costs of ownership.

The methodology of this paper is as follows. My perception of the *market field* of ‘industrial automation’ is based on informal talks at the trade fairs *SPS/IPC/DRIVES 2007* and *2008* and on a series of interviews with industry experts and selected consultants in 2008. These qualitative studies allow for the identification of leading field bus user organisations, but they also provide a basic understanding on how cooperation and competition are interrelated. The applied explorative and qualitative case study method follows Yin (2003). The paper presented is the third piece of the puzzle in a concept on standard-setting capability. First, Gerybadze/Slowak (2008) explain how standard-setting can be taken for a race between challengers and incumbents; second, Slowak (2008) demonstrates that the interplay between cooperation in user organisations and competition through proprietary value added strategies at the market solve a trade-off between value creation and value capture respecting exploration and exploitation; and third, this paper looks at the means of industry dynamics for standard-setting capability. Additionally, a model on standard-setting in innovation clusters has been presented by Christ/Slowak (2008). The qualitative analysis of this paper is enriched by a network chart of membership affiliations / some kind of descriptive network analysis for selected leading field bus organisations and market-near standard-setting project consortia. The circular network graph in Figure 3, page 16, illustrates the firms’ affiliations with the standard-setting communities *CLPA*, *ODVA* and *PROFIBUS* or project consortia *IO-Link* and *WirelessHART*. The list of member firms for the standard-setting communities and project consortia is provided in Appendix B. It consists of members at the home-base of the standard-setting communities with regard to known early and founding members of the project consortia. It does not include the global population of members in the case of standard-setting communities; nor does it include all recent memberships in the case of project consortia. I assume that members must be present at a standard-setting community’s home-base in order to influence the innovation agenda and standards specification. Furthermore, project agendas are driven by incumbent, early members, not late followers.

## 3 Capability as the ability to control

Within this section of the paper, first the concept of standard-setting communities is defined; second, I introduce selected success cases of standard-setting projects in industrial automation, and third, I derive a model of *community dynamics within the sectoral innovation system of industrial automation*. It takes account of empirical observation from standard-setting community cases introduced in section two.

Previously, I have described the dominant standard-setting communities. Standard-setting takes place within layered organisational settings where firms collaboratively try to place a new de facto standard on the market, and to maintain it in future vintages. These settings or structured and cooperating populations of firms are best described as standard-setting communities. In such communities, firms collaborate on standards, and implicitly on standards diffusion. Standard-setting communities compete for firm members, but at the same time a community's members compete in the market-place. The communities *PROFIBUS*, *ODVA* and *CLPA* can be characterised as layered organisations in the terminology of Gerybadze (2008a, b). There are many examples showing that layered organisation structures have become more usual in high-technology industries, e.g.. see *FlexRay* in automotive electronics (described in Gerybadze 2008b; König, 2008); IT-consortia such as the Open Source Development Lab in telecommunication, now part of the *Linux Foundation*; or *WiMAX Forum*, *ZigBee Alliance* and other wireless standards consortia.[16] The *Open Source Automation Development Lab (OSADL)* is an example for how layered standard-setting communities in non-HT industries may function as integrators of high-technology; here, the community adapts Embedded Linux to the requirements of the machine tool industry's real-time applications. The core of standard-setting communities is represented by big industry leaders capable of exerting conceptions of control on complementers and member firms in other community layers; they are characterised by status hierarchies which separate core from peripheral members. I will refer to those in control as *incumbents*, and to the community that they control/strongly influence as their *primary standard-setting community*. Note that big, multinational incumbents may have several 'primary standard-setting communities', as they often use different standards for different business segments. *Conceptions of control* are to be read as follows; for a more detailed description applied to industrial automation see Gerybadze/Slowak (2008):

> A stable 'market as field' means that the main players in a given market are able to reproduce their firms. … Incumbent firms are those that dominate a particular market by creating stable relationships with other producers, important suppliers, customers, and the government. They exploit their position by reacting to what other dominant firms are doing. Challenger firms fit into the dominant logic of a stable market, either by finding a spot in the market (i.e. a niche) or imitating dominant firms.
>
> (Fligstein, 2001, p. 17).

> A stable market is defined as a situation in which the identities and status hierarchy of producer firms … are well known, and a conception of control that guides actors who lead firms is shared. Firms resemble one another in tactics and organizational structure. Politics reproduce the position of the advantaged groups.
>
> (Fligstein, 2001, p. 76).

If the situation can be summarised in one sentence, conceptions of control are the logics behind politics capable of reproducing the structure and thus hierarchies of a *market field*.

In physics and chemistry atom models, researchers analyse binding energies/bond within reactions. Similarities to standard-setting are as follows. Any atom core is separated into protons and neutrons. Protons attract the electrons in the different atom layers. In industrial automation, incumbent firms at a standard-setting community's core attract technology providers, complementers and other amplifiers of standards implementation and advancement. Conversely, competitors may be neutral to the standard because their prior-ranking commitment is to another standard-setting community. Nonetheless, competitors and passive members increase the number of a community's memberships; they add inertia to the community. Community alliances can be modelled as 'molecules' which attract 'atoms' in order to create strong business systems for incumbent firms. This is to say that industry context determines dynamics within standard-setting communities and vice versa.[17]

> There is a chemical *bond* between two atoms or groups of atoms in the case that the forces acting between them are such as to lead to the formation of an aggregate with sufficient stability to make it convenient for the chemist to consider it as an independent 'molecular species'.
> (IUPAC Compendium of Chemical Terminology, 1997).

> [*Bond energy* (in theoretical chemistry) represents that] energy required to break a given type of bond between atoms in certain valence states ...
> (IUPAC Compendium of Chemical Terminology, 1997).

Possibly, analogies with physics or chemical reactions could also contribute to an understanding of the interactions between the different *market fields*. This particularly concerns mechanisms at a field's boundaries, dependencies between their different inner market logics and *inter-field* communication on *status hierarchies*.

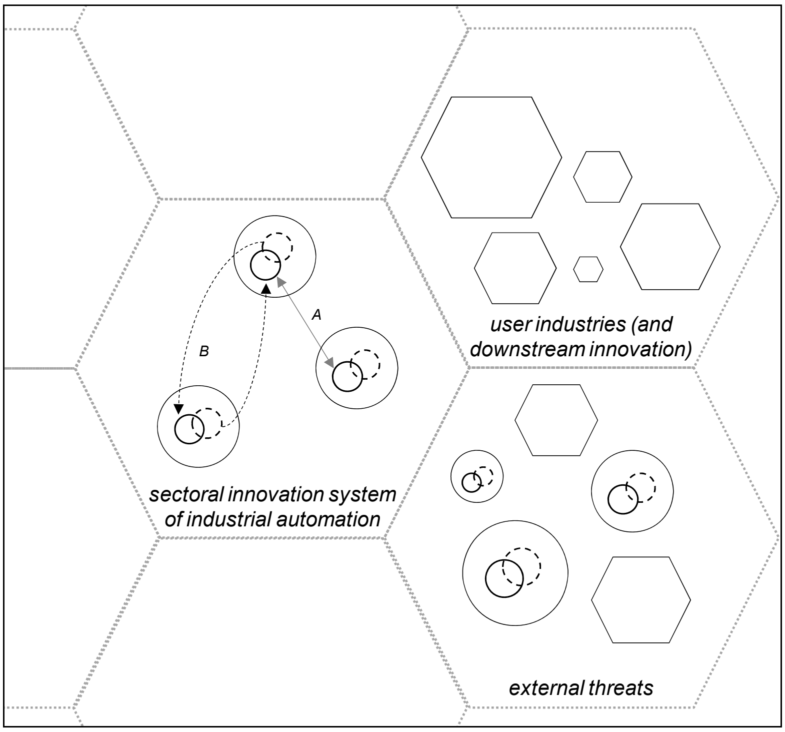
Furthermore, my model assumes that each agent follows a rational approach about which community to join and which membership layer to address. For instance, incumbent competitors from other standard-setting communities may be situated near to the core in order to watch innovation agenda and technological progress. Competitors then amplify the gathered innovation stimuli at their primary standard-setting community. Note that competition in industrial automation is threefold: first, community alliances (the molecules in our picture) compete for communities (atoms); second, firms within the community compete for status; and third, the different communities compete for committed members. The term 'community alliances' allows for a more simplified analysis of market structure; it expresses how some communities produce complementary standards although there is no formal agreement which would indicate joint organisation structures or a common agenda.

## 4 The meaning of market fields for unfolding industry dynamics

Taking into consideration the co-existence of competition, complementary cross-memberships and cooperation in standard-setting, two dynamics arguments on dynamic capability by Slowak (2008) should be considered: first, *"inputs from many industries or multi-use contexts of standards may imply technology lifecycles varying in speed/rate of technological change and level of innovation output/input, but also come with different intellectual property regimes"* (Slowak, 2008, p. 151); second, Slowak's model on the trade-off between value created versus value captured (Slowak, 2008, based on Simcoe, 2006) argues that "*incumbent firms compare the forces for cooperation with the forces for competition on standards in order to align exploration and exploitation activities within a specific industry context. In industrial automation users are indifferent to all but a few global, durable standards. They prefer standards which allow for continuous technological progress without disrupting their installed base in machines and automation systems rather than fundamental changes*" (Slowak, 2008, p. 156).

The meaning of such an *industry context* needs further clarification. Figure 2 suggests that standard-setting dynamics within *sectoral innovation systems* can be subdivided into collaboration (mark A) versus competition (mark B) dynamics. Collaboration dynamics target the advancement of business systems which refer to use cases or to a bundling of user industries and technologies. Competition dynamics rather affect underlying rules and external challenges of the *sectoral innovation system* and its population. The advancement of business systems includes the creation of new *industry solutions* or *business models*, the deployment of *complementary assets*, and the organisational development of standard-setting communities. The advancement of *sectoral innovation systems*[18] with respect to *standards diffusion* concerns practising and design of *conceptions of control*; it also includes mechanisms to maintain know-how-driven value creation within medium/low-tech industries – given that there are high-tech challengers from other industries and given an increase in open standards / standards, relevant knowledge of technology is to some extent a public good. I argue below that the interplay between *collaboration* and *competition dynamics* is required to resolve the *trade-off between exploration and exploitation* activities of the firm.

**Figure 2: Community dynamics and boundary spanning in the market field of industrial automation**




**Source: Own illustration.**

Markets for *General Purpose Technology* can be taken for downstream *product and service fields* whereas technology and business standards (thus business systems) are necessary to cultivate those fields in a competitive manner. Concerning dynamics intensity, product market contexts moderate the ‘value added’ strategies of the different agents. I adopt Sanchez’s (1996) trilogy of ‘stable’ versus ‘evolving’ versus ‘dynamic’ contexts in order to look at the tensions between market structure and dynamics from innovation or challengers ‘entering’ the *market field/sectoral innovation system* (see Figure 2). Note that ‘market context’ in industrial automation is twofold: in combination, competition between different standard-setting communities, and challenges from other, *downstream market fields* determine dynamics intensity. Also note Thoma (2006), who shows that the interplay of *General Purpose Technology* with downstream markets / application sectors leads to ‘technological imbalances’ such as from ‘the need for integration across the existing applications’ or a convergence of technology through IT-technologies / ‘the convergence of the devices in a global communication network, such as the Internet’ (Thoma, 2006, p. 12). In industrial automation, Industrial Ethernet, for instance, is turning into a common standard which integrates different field busses and Internet applications within one network.

**Table 1: Dynamics Intensity In the most Innovative Sub-fields**

<table>
<tr><th rowspan="2"></th><th colspan="3">Product Market Context</th></tr>
<tr><th>Stable</th><th>Evolving</th><th>Dynamic</th></tr>
<tr><td>[Firm] strategy</td><td>- Strategic commitment<br>- Ownership of production assets<br>- Hierarchical integration<br>- Direct control of processes<br>- Defence of market position</td><td>- Strategic change<br>- Accumulation of resources<br>- Partnering and alliances<br>- Teams, process re-engineering<br>- Create sustainable competitive advantage</td><td>- Strategic flexibility<br>- Fixed-asset parsimony, leveraging of intellectual assets<br>- Firm acts as ‘network actuator’ in development resource network<br>- Coordination through modular product architectures<br>- Flexible responses to changing market opportunities</td></tr>
<tr><td>Standard-setting effects in non-HT [a) b)]</td><td>- Evolutional renewal of basic standards</td><td>- Standards shake out or stepwise re-specification and alliance formation</td><td rowspan="2">- Absorption of third party technology, particular open high-technology standards through integration and industrial customisation<br>or<br>- Losing out to adjacent market fields</td></tr>
<tr><td rowspan="2">Application sectors [a)]</td><td rowspan="2">- Building automation, and e.g. machine tools</td><td>- Factory automation</td></tr>
<tr><td colspan="2">- Process automation</td></tr>
</table>

**(a) Own model extension for standard-setting context.**

**(b) Within the paper the sectoral innovation system of industrial automation is taken as representative of non-high-technology.**

**Source: Sanchez (1996, p. 124 Table 1), shortened and modified.**

In a ‘stable product market context’, firm strategy is about decrease of costs and about the control of distribution channels; in an ‘evolving product market context’ timing of product introduction becomes crucial in order to meet new demands (cf. Sanchez, 1996, pp. 123-125). Evolving market contexts lead to a strategy characterised by an ‘accumulation of resources’, but also to partnering and alliances (Sanchez, 1996, p. 124 Table 1). In a 'dynamic product market context' not only timing but 'speed-to-market' becomes important (cf. Sanchez, 1996, pp. 123-125). In such an unstable, velocity business environment, flexibility in distribution and variety of products are required. As open standards are an integrated part of product and service solutions, their lifecycles are probably related to the dynamics intensity of product and service market context. If the interplay of different *sectoral innovation systems* drives dynamics, the *market field* could in extremis become interdependent on high-velocity market technology lifecycles. In machine tools this fear has led to research projects trying to replace consumer operation systems and specialised proprietary software by Linux-based systems and virtual machine-operation systems.

Note that the different dynamics intensities also apply within one *market field*, if the *General Purpose Technology's* application sectors / thus downstream sub-fields are characterised by different rates of technological change and different stability of status hierarchies. As listed in Table 1, the application sectors in industrial automation differ from my interview insights. Process automation in integration with factory automation is perceived as a driver of innovation (in terms of complementary goods and services such as logistics or digital technologies and IT for better measurement and condition monitoring); whereas building automation is described as low-technology. The traditional core of factory automation shows both patterns to some extent, stability owing to a cautious community of mechanical engineering, but also dynamics owing to the integration of consumer market technology. Note that innovation pressure derives from innovative sub-fields. Thus, the stimuli of innovation need to be localised so we can judge the dynamics of the population's entire *market field*; these stimuli must be brought under control by the fields' *incumbents*.

The model of industry context outlined above and illustrated in Figure 2 builds on four fundamentals:

- Interdependence with downstream markets. Note that 'complementarity' according to Teece (1986) may be applied to the same market, and also other market fields along the innovation chain. Note that the idea of an 'integrated innovation chain' (which is neither strictly open nor only linear) instead of a conventional innovation process comes from Alexander Gerybadze, Centre for International Management and Innovation, who is currently developing this idea further.

- The reasonable and fair use of intellectual property, particularly of trademarks and patents which are 'essential' to a standard (for the role of appropriation in the trade-off of value creation and value capture cf. Simcoe, 2006; and an extended model by Slowak, 2008, p. 154-156). Standard-setting communities create layers through IPR ownership (see the case of *IO-link*) or – mainly culture-bound – exclusion mechanisms (i.e. innovation at *PROFIBUS* takes place in Germany / the *PROFIBUS User Organisation* only; in other communities affiliation to the home-base seems to be important as well).

- An optimal number of standards which allows for a continuous advancement of the *market field*. Too many standards 'overcrowd' a *market field*. Swann shows that economic effects of standards are twofold:

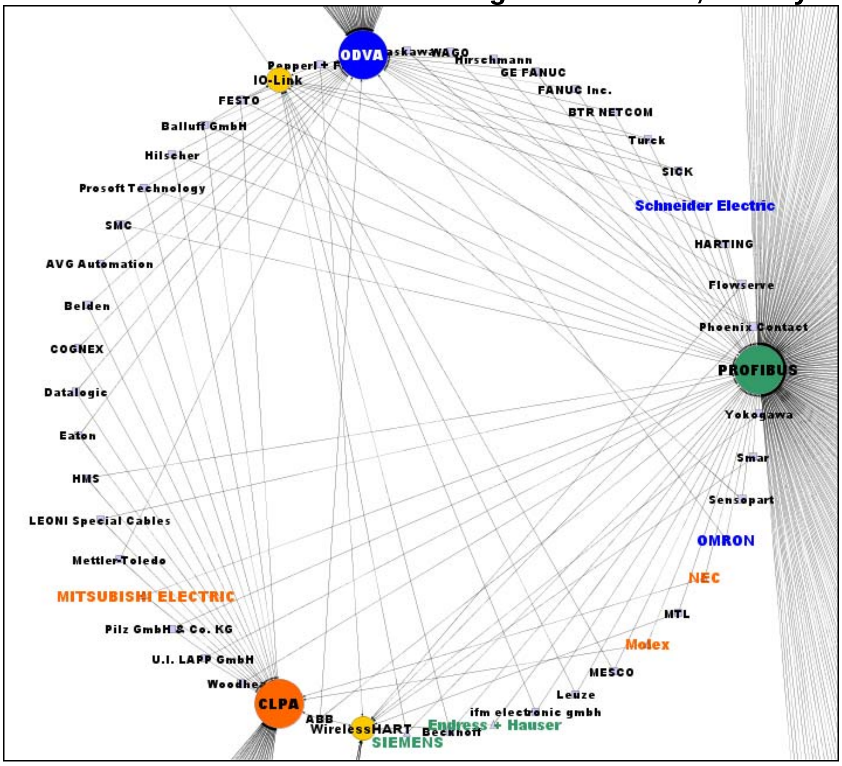
> [...] the growth of a standards system can be represented graphically in a manner that looks very similar to the growth of a tree. The analogy, moreover, is a compelling one, because the health of the trunk and branch structure plays a key role in determining the vigour of growth, leaves and fruit.
>
> (Swann, 2000, p. 25).

In industrial automation, the trade-off between variety reduction through standards (a strong standards tree) and variety (for product differentiation) needs to be addressed by value added strategies respecting an implicit agreement of the standard-setting which is open and standardised versus what is closed and specific to the firm's offers on the product market.[19]

- The idea of external threats. That is, firms from other *market fields* are challenging the own *sectoral innovation system*, either intentionally or without purpose. Cf. Gerybadze/Slowak (2008, pp. 47-49), who argue that medium-technology industries are transformed through new dynamics from R&D-intensive firms in high-technology from *downstream market fields* and complementary new technology. Thus, high-norm activities such as institution and option-building are required in order to defend status hierarchies against external challengers (cf. Gerybadze/Slowak, 2008, p. 49). External threats to conceptions of control in industrial automation particularly concern the entry of strong challengers from overlapping IT-industries and applicable consumer standards technology (substitutes to own standards), weak capability to absorb high-technology if relevant to product functionality or a lack of the capability to create promising new use cases.

Recently, the biggest threat to established field bus standards has come from Industrial Ethernet technology. The market of Ethernet field busses is characterised by intensified competition; it seems that this market has not yet consolidated / not yet established stable status hierarchies. I observed an increase of community alliances between the communities of conventional field busses and those Ethernet standards which are assumed to win the recent standards battle. This topic cannot, however, be addressed within the scope of this paper.

**Figure 3a: Firm affiliations to standard-setting communities, factory automation**



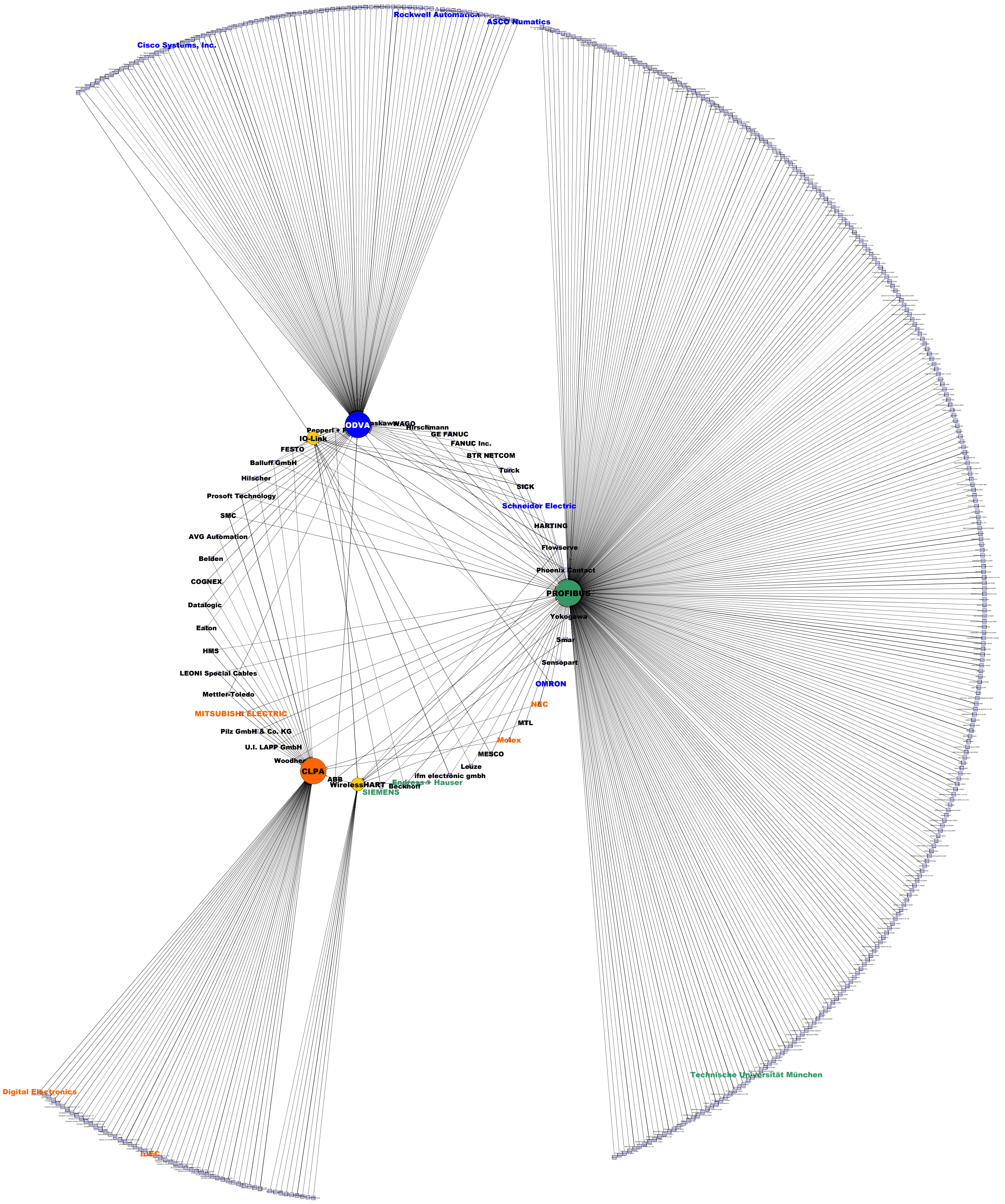

**Source: Own illustration / using SNA software.**

**N=516 network nodes; CLPA: 65, ODVA: 109, PROFIBUS: 310, IO-Link: 14, and WirelessHART: 18 members. A directed arc represents a membership affiliation. Size of nodes is for visualisation; it is not linked to any quantitative network analysis.**

**The members of the executive boards of the three standard-setting communities are marked by the background colour of the community nodes; *PROFIBUS*: Endress + Hauser, SIEMENS, TU Munich; *CLPA*: Digital Electronics, IDEC, MITSUBISHI ELECTRIC, Molex, NEC; *ODVA*: ASCO Numatics, Cisco Systems, OMRON, Rockwell Automation, Schneider Electric.**

**The full network is illustrated in Figure 3b as follows.**

Figure 3b: Firm affili...



The circular network graph in Figures 3a, b illustrate the firms' affiliations with selected standard-setting communities *CLPA*, *ODVA* and *PROFIBUS* or project consortia *IO-Link* and *WirelessHART*. The inner circle (see Figure 3a) covers all firms which are members of at least two of the above nodes (standard-setting communities, project consortia). Memberships are denoted by one-mode directed arcs. If the number of nodes / communities were extended, such a graph is capable of mapping different *market fields* in their inner structure and the linkages between different subfields. Problems arise from the heterogeneous population of agents – note that PROFIBUS's network position is overemphasised because my analysis does not control for the size of member firms. PROFIBUS has very many, but among them also some very small member firms. Additionally note that a high number of members at the home-base could also signalise an ethnocentric community; to control against misinterpretation, the number of members at the home-base needs to be set in relation to the global number of members. Furthermore, it can be difficult to separate standard-setting communities and 'projects'. Recently, *IO-link* has been working on design rules for other standard-setting communities than PROFIBUS so that it could grow to an own standard-setting community of sensor manufacturers. The case of *WirelessHART* is included to illustrate the overlapping of the market sub-fields factory and process automation. They are, for instance, interconnected by incumbents and some leading sensor firms. Note that *WirelessHART* belongs to the HART set of standards; HART is one of the leading standard-setting communities in process automation. *CLPA*, *ODVA* and PROFIBUS did first do business in factory automation only. Also note that the network graph does not include complementary communities such as *FDT Group* or *OPC Foundation* and liaison-partnerships with standardisation bodies, in particular *International Electrotechnical Commission*, *Institute of Electrical and Electronics Engineers* and *The World Wide Web Consortium* and wireless technology consortia. Finally, the more visualisation focuses on large communities only, the more incumbents become central network nodes and status hierarchies are represented. If instead projects are emphasised in visualisation, several specialists become central as well. Thus, it is necessary in future studies to conduct specific network studies for each set of resource bundles which strongly influences a firm's *status position within the market field*.

Then, the specificity of links becomes an issue. Standards of the own *market field* (competitive versus complementary) and standards integrated from other *market fields* may require different resources and strategic logics. Thus it could be necessary to denote the strength of links by different variables for different sub-networks. It is hence difficult to normalise between the sub-networks. Taking these difficulties into account, I decided to plot only a simple graph of membership affiliations rather than a plot which uses co-patenting or R&D intensity as indicators for the strength of links. Furthermore, I chose a tree design from a circle arrangement of nodes. See also network representations in Appendix C.

The selection of technology in standards specifications directly affects the value of a firm's *f* knowledge base, denoted as *K*, which consists of $k_{1f}...k_{if}$. That implies that standard-setting is always a game for status: agents are rewarded if their knowledge stocks (particularly represented by patents, trademarks or know-how of application sectors) are made 'essential' to the standard or if they can gain an extraordinary market position through the standard's diffusion; they are devalued if standards design neglects their knowledge stocks or threatens their access to application sectors. The idea of knowledge stock alignment is formalised in Slowak (2008, p. 160f); it has been separately conceptualised for the case of innovation clusters / spatial concentration of standard-setting specification activity in space by Christ/Slowak (2008, chapter 4.2 / pp. 31ff). From an evolutional perspective, firms need to cope with the pace of technical and structural change in their *product market field*; more precisely, they need to solve the trade-off between exploration and exploitation of assets and knowledge. That is, they promote, kill or modify and upgrade specific knowledge stocks with regard to business cases offered by their primary *market field*. They choose an optimum in between exploration and exploitation, capable of balancing both forces in managerial practice: the 'ambidextrous organisation' achieves funding for explorative activities, but does not neglect exploration, i.e. in terms of in-house R&D (cf. Güttel/Konlechner, 2007; see also Konlechner/Güttel, 2008). Within the standard-setting process the trade-off needs to be resolved in order to provide incentives for the creation of innovative, technological advanced standards. More precisely, there is 'a virtuous cycle of exploration and exploitation respecting some trade-off between the deployment of current know-how and experimentation with new alternatives from the external environment' which allows for a fair/perceived as reasonable redistribution of value created (cf. Slowak, 2008).[20] Given that incumbents cultivate *market fields* for standards, the firm's purpose is to replicate routines, to stabilise institutions working in favour of its goals and to replicate behavioural schemes from project to project which lead to standard-setting success. Note that an explicit management of evolutional patterns in standard-setting would require a somewhat 'synthesising' dynamic capability as an 'ability to align different standards vintages' in the course of time.

> [Standards] help create a strong, open, and well-organised technological infrastructure that will serve as a foundation for innovation-led growth. It is often asked whether, on balance, standardization acts more to constrain innovation or to enable innovation. From our perspective these two activities are inextricably linked. Standardization does constrain activities but in doing so creates an infrastructure for subsequent innovation. Well-designed standards should be able to reduce undesirable outcomes. Moreover, standardization is not just about producing norms for given technologies in given markets. Standardization helps to credibility, focus and critical mass in markets for new technologies.
>
> (Swann, 2000, p. IV).

The alignment of standards vintages respecting that synthesising process concerns the alignment of evolved and out-separated knowledge stocks over time, whereas the alignment of heterogeneous knowledge within a short time period is an issue of standards strength – 'well design' creates a clear use case for the critical mass.[21] The evolution of standards through future vintages creates variety respecting sophisticated infrastructure for a variety of products and services. Standards specification nonetheless always means a narrowing of possibilities in order to tell the market which path to take from technology to implementation.

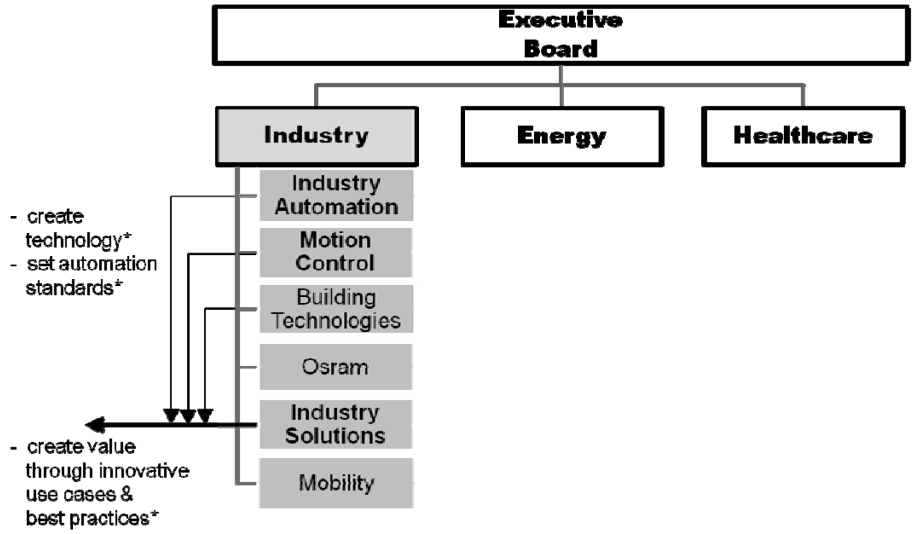
## 5 The role of network effects

Thoma (2006) argues that downstream co-invention and adaptation of technology by users are predictors of technology diffusion in the case of the field bus ‘LonWorks’. This paper finds that standards in industrial automation are subject to network effects caused by the layered market structure between integrator firms and affiliated technology suppliers,[22] implementers and users. Integrators with regard to incumbents create solutions and thus concentrate on a few standards including technologies for bundling complementary assets. The case of Siemens particularly demonstrates how automation solutions create proprietary value, although field bus technology is granted open (open standards such as PROFIBUS and PROFINET technologies, device descriptions or web technologies). Why so?

> Standard setting plays a critical role in network industries because of two factors: consumer expectations and interoperability. Consumer expectations are critical to the success of networks, either existing or emerging ones. The strength of a network’s market power depends upon its users' expectations of the likely behavior of other users of the network. Consumers fear making investments in a network and then becoming ‘stranded’ because there is insufficient consumer acceptance. Standards may alleviate those concerns, by assuring consumers that the network technology will be adopted.
>
> (Balto, 2000).

The incumbent Siemens and PROFIBUS/PROFINET-related standards experience reciprocal positive externalities. Whereas Siemens’s industry solutions-portfolio benefits from a consistent and integrated set of strong standards, their ‘core’ standards such as PROFIBUS, PROFINET (conventional and Ethernet field bus) or EDDL (device description) gain momentum from implementations and a psychology of probable success. Such psychology means that small firms in the *sectoral innovation system* orientate themselves towards big firms in order to reduce uncertainty. More precisely, integrators ascribe best practices to a standard (documented industry-specific solutions) and they create business cases / win big users for it. In sum, there are positive externalities to a standard from incumbents' market success.

**Figure 4: Siemens's organisational structure in automation business**




**New organisation structure from January 2008 after the restructuring of Siemens in 2007. The units subsumed under the sectors 'Energy' and 'Healthcare' are not illustrated in the above figure. Note that nonetheless the unit 'Oil and Gas' subsumed under the sector 'Energy' represents an important application sector for process automation.**
*** Own conclusion from field study / Siemens and other leading integrators' status within different activities.**

Siemens is a special case in industrial automation. The company is involved in many dominant standard-setting communities of the various *market fields*, whether factory automation and motion control, process or building automation. Furthermore, it has a very successful unit called 'Industry Solutions', which can demonstrate best practice use cases ('business cases') in many user industries. The company is also well-established in the factory/plant modernisation business and in industrial services & IT, particularly concerning the Manufacturing Execution System and connectivity between the different automation layers of a factory/plant. Whereas the units 'Industry Automation', 'Motion Control' and 'Building Technologies' own technology experience and influence the status hierarchies in their fields (they are the architects of standard-setting strategy and value added proprietary features), 'Industry Solutions', former 'Industry Suites' in cooperation with other units such as Siemens Services, bundles the relevant technologies for an industry-specific business case (proprietary value added strategies only):

> With the Industry Suites we have synergized the worlds of automation and power engineering with the customer specific plants to create a comprehensive, modular, sector-oriented range - including specific services over the entire life-cycle of a plant.
>
> (http://www.industry.siemens.de/meta/EN/INDEX.HTM, Siemens Industry, Industry Solutions).

The Siemens emphasis or active co-development of a standard may force smaller solution providers and service firms to accept this standard. Nonetheless note that a standard should embed state-of-the-art technology in order to satisfy the population's purpose of adding value through the use of the standard in state-of-the-art products; the adoption of the incumbent's favoured standards can more easily be challenged by competitors the more a standard falls behind in terms of poor technological progress. In brief, there are no bets on weak standards offers brought to the industry's bargaining table; and possibly only weak bets on a strong standard if that standard is brought to the 'sectoral negotiation table' by the 'wrong' agents. Furthermore, the more technologies embedded in competing standards and costs of ownership become very similar, the more psychology, strong use cases and best industry practices matter.

Multinational implementers create a bandwagon effect as they bet on few global standards. For firms such as ABB or Bosch Rexroth field busses represent hidden costs in their products. Nonetheless, influence on common standards is important to these implementers; they need to ensure that a common standard fully supports their functionality or even works in their favour (as lean in architecture as possible, but tailored to their business). Thus, big implementers are committed to standard-setting, but they try to minimise the number of standards which they support. Small implementers need even more to bet on selected standards as their capacities are too limited to commit to many standards. Finally, users demand strong standards in order to achieve device and software interoperability between and within all levels of the factory/plant. Furthermore, *high-norm* activities of the standard-setter at the IEC are required because users refer to formal standards to decide which standards are 'second source'. Thus, users in industrial automation categorise standards by their formally specified core technology.

The role of complement providers and complementary assets is not addressed within this paper as the descriptive social network analysis for a few standard-setting communities does not provide enough evidence of the dynamics triggered by them.

Users, for instance, are manufacturers with assembly lines, such as automotive OEMs or with process plants such as oil refineries, chemical plants or pharmaceutical firms. They are customers of implementers or integrators who embed field bus standards into their machine, control systems or components. The 'users' expectations of the likely behaviour of the other users of the network [here: application sector] only moderately affect the choice of a standard. Users select from a fistful of leading standards, but there is no one-winner-takes-it-all-effect. Conversely, interoperability is extremely important. Users demand that standards are, as much as possible, backward-compatible with their installed base. They also need interoperability in order to combine machines and components of different vendors within the same factory/plant. Note that clever standard-setting tactics may build on detours in use case selection: Gerybadze (2008a, pp. 120ff) shows that Bosch succeeded in the CAN-standard through a deployment of multi-use strategy. The diffusion of CAN was first driven by implementation in elevator controls and textile machines – these are application sectors outside the targeted sector of automotive electronics. The creation of a profitable use case is crucial in order to reduce uncertainty from immature standards and to decrease costs of ownership until economies of scale take off.[23]

Networks effects as characterised above lead to markets where market structure becomes part of the product and service offering. Siemens's high status position within the *sectoral innovation system* tends to attach implicit guarantees to the standards PROFIBUS and PROFINET. The incumbent's commitment to the standard lets the population assume that there is long-term technology support and future technological progress. The open characteristics of the standard ensures against proprietary control and unfair licence terms. I argue that a user buys a bundle of predictable diffusion success, ongoing innovation and complementary goods and services. She buys products and services in (inter-temporal and recent) context. Therefore 'wise' modes of standard-setting should try to solve some kind of two-period consumption problem (for economic modelling of such constrained maximisation problem, for instance, see Foley/Michl, 1999, p. 86ff). That is, the life span of a standards vintage without modifications being made sets the time window of pure exploitation (implementations of stable vintages included mature complementary goods and tailored services), whereas innovation as modification of a standard by new vintages marks exploration activities (technological progress / investment in future consumption potential) and may constrain exploitation. Note that the IT industry resolves this trade-off through the provision of Beta-versions to a dedicated community of pioneer users, whereas users in industrial automation require reliable solutions from the very start of production. The outlined trade-off is evolutionary by nature: exploitation requires the evolution of a strong 'standards vintage'; exploration requires past or future exploitation in order to be profitable. The structure of the *sectoral innovation system* is socially constructed by expectations, cross-affiliations and value added strategies in the interplay of agents. Hence, it remains unclear what are the ends versus means of competitiveness; competing on implementations (value capture) cannot be imagined without cooperation on standards (i.e. value created from momentum, complementary assets and network size). The ability to align conceptions of control granted to each agent with the value of their contribution could resolve this trade-off.

## 6 Results and limitations

Firms not only compete in product markets, they also compete for *market fields* with regard to strategic options. They need to think in terms of business systems which include essential complementary assets, down- and upstream value creation activities and subtle / tactic standard-setting strategies. More precisely, a triad of 'population dynamics', 'technological change and standard-setting in innovative fields' and 'definition of businesses and use cases' drives the advancement of a *sectoral innovation system*. Such a system needs to be defined by the population's agents themselves; it may span different traditional or emerging industries. In brief, my model conceptualises a firm's *dynamic standard-setting capability ($SSDC_f$)* as follows:

$$\mathrm{SSDC}_{f,t} = \alpha_1 K_\mathrm{t}(\mathrm{centrality}_1, \mathrm{dcm}, \mathrm{dyn}_1, \mathrm{STIpolicy}) + \alpha_2 RD_t(\alpha_1 K_t, strat) + \sum_{j=1}^{J} ß_j(dcm, \mathrm{dyn}_m, IPR) + highnorm$$

*K* represents the aggregation of a firm's knowledge stocks $k_1...k_i$. The value / essentiality of *K* to a standard increases with the firm's network centrality in the own *market field's* status hierarchy (*centrality* in field 1); the less intensive the technology dynamics within the own *market field* ($dyn_1$), the more *STI-pol*icy works in favour of the incumbent. Status hierarchy is a terminus taken from Gerybadze/Slowak (2008, pp. 44ff) with reference to Fligstein (2001) and Podolny (2005). The ascribed status determines a firm's influence on standards design and on standards diffusion process. *Dcm* represents 'the capability to manage'. It covers both experience in influencing the population of agents within the *sectoral innovation system* and also the management of standard-setting activities within the multinational cooperation (process design).

Furthermore, dynamic standard-setting capability is shaped by R&D in progress ($RD_t$); such research represents the firm's technology offer brought to the standards negotiation table. Note that the value proposition of that research depends on the question whether it is in line with the standards relevant knowledge stocks, $\alpha_1 K_t$. It should thus be part of the firm's standard-setting strategy to synthesise appropriate R&D with standards design. Strategic logic (*strat*) is a terminus taken from competence-based management theory, particularly Sanchez/Heene/Thomas (1996, p. 10). It should be anticipated that it is also a strategic decision of the firm if research is exploited through collaborative standard-setting or through merely proprietary products.

$\sum ß_j(dcm, \mathrm{dyn}_m, IPR)$ represents the sum of standards from other *market fields* which are integrated into the own market fields standards. Note that integration into the own *market field* should be more difficult the more intensive the other fields' industry dynamics ($\mathrm{dyn}_m$) are. This modelling assumes that each standard j belongs to one *market field* m. The number and degree in the integration of other *market fields* standards into the own field also relies on there being no indispensable intellectual property rights given against integration or use of technology to be integrated by the own standard. *High-norm* activities at formal bodies create a business environment where a de facto standard turns into an obligatory and easily accessible technology.

The above model resolves two fundamental problems which have been described in the paper: first, industry dynamics between the *market fields* ($\mathrm{dyn}_1, \mathrm{dyn}_m$) are formalised; second, the role of R&D can be better understood if set in the context of status hierarchies (here measured by network centrality); and third, the model demonstrates that the knowledge stocks' value created depends on structural variables and the many interactions within the *market field's population of firms*. If the industry context is socially constructed and flexible, any strategic logic of the firm should aim to influence its creation and transformation.

Future studies should include more standard-setting communities if a *market field* analysis is to be conducted. This paper provides a model for how an industry context can be included in sectoral innovation and standard-setting analysis, and it suggests that status hierarchies can be visualised through social network graphs. Whereas this study only accounts for cross-memberships and status in terms of being a core member of a standard-setting community, further attributes such as R&D intensity, characteristics of a firm's knowledge stocks portfolio, trademarks owned by the firm and patenting activity allow for a more detailed picture. *Dcm* as 'capability to manage' also needs elaboration. Another field of promising research concerns the ability to appropriate not only technology or a standard but indirect techniques to capture major shares of growing *market fields* and to defend *incumbent status*. Additionally, physics as a field of analogy for evolutionary economics allows for more in-depth hypotheses on layered organisations (see atom models) or layered, *ecology*-like sectoral innovation systems (ideas of gravitation, energetic stages or *autopoesis*).

Any understanding *sectoral innovation systems* as functionally specialised with regard to an associated *population of agents* needs to be discussed in terms of which modelling of dynamics best suits this *ecology* perspective. Should it be evolutional in terms of biology / Darwinism, evolutional in terms of an historical perspective or post-Darwinism, or should it take from chemistry and physics a description of the state of matter – non-visible to human eyes? Finally, should it be evolutional at all? Note that time-frames of firms' rational behaviour and analysis could differ; any *stability of a market field* needs to be seen as stability in the context of a specific time-frame. It furthermore seems that both standards design and time-to-standard are relevant to standard-setting success. Therefore, I suggest that if analysis accounts for time-frames and *technology lifecycles* (time-to-standards, and exploration versus exploitation) and institutional structures (formal versus industry self-organisation), an integrated evolutional economics and competence-based study of industry dynamics should be very fruitful. In-depth evolutionary studies, particularly concerning cross-sectional and technology comparison studies, however, are regrettably represented very rarely in mainstream economic journals.

Finally, Gerybadze (2008a, p. 126) argues that clever standard-setting strategies are different for early versus late innovation phases. Also note that tipping a winning standard implies self-referencing mechanisms: in the early innovation stage standards are often not yet specified, and the bets of the other agents are not yet known. Therefore, the *psychology of standard-setting* may be more complex in interrelated *market fields* than it is for clearly arranged systems / consumer products such as video or game consoles.

There are just two limitations to the formal conceptualisation undertaken and its empirical evidence. First, the characterisation of the *market field* needs a more detailed, complete representation, that is, a large number of user organisations should be included in social network analysis; second, a further elaboration of the network analysis should work out the characteristics of ties between firms and status with respect to measurable firm resources (R&D intensity, patents and other indicators) and cooperation activities (licensing, co-patenting, collaborative R&D and other indicators). The belonging of firms to corporate groups should also be anticipated; therefore, this study might underestimate the number of cross-affiliations. It might also be biased if leading field bus organisations' interrelationships are not representative of the entire population of standard-setting communities within the *market field*.

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## Appendix A: Industry Structure: Members At The Home-bases of CLPA (Japan), ODVA (USA) and PROFIBUS (Germany)

**Originally listed firm names have been harmonised for network analysis.**

**CLPA, Japan (http://www.cc-link.org/jp/pa_html/partner.html, 22.11.2008):**

ABB
Animatics Corporation
AVG Automation
Balluff GmbH
Belden
Chang Zhou Qinh Automation Co., Ltd
CKC. TECHNOLOGY CO. LTD.
CKD
COGNEX
Control Engineering Co., Ltd
CREVIS CO., LTD
Cutes Corporation
DASA TECH CO., LTD
Datalogic
DEYANG JIE TONG TECHNOLOGY CO., LTD.
DINKLE ENTERPRISE CO.,LTD.
Dong Bang Fanics Corporation
DONG IL TECHNOLOGY LTD.
Eaton
Electronic and Information Institute, Tongji University
FESTO
FujiElectric FA Components & Systems Co., Ltd
GTS GENEL TEKNIK SISTEMLER LTD.STI.
Han Way Technology
Hangzhou Chaoxin Automation Engineering Co.,Ltd
Hangzhou Yeegao Mech-tronics CO., Ltd.
Hanovic (Dong Guan) Limited
HanYang System
Hilscher
HMS
HYUNDAI HEAVY INDUSTRIES CO., LTD
IDEC
JSS PRECISION CO.,LTD.
KOREA AUTO CONTROLS CO.,LTD.
LEONI Special Cables
LG Cable
LS Industrial Systems Co.,Ltd.
Mettler-Toledo
MITSUBISHI ELECTRIC
Mooho Semicon,Inc.
Nanjing Tie Hai Mechanical & Electrical Equipment Co.,Ltd
NKE
Northern Design (Electronics) Ltd.
Northwire,Inc.

**CLPA, Japan (continued)**
Pilz GmbH & Co. KG
Prosoft Technology
PROTEC CO.,LTD.
Rockford Contract Mfg.& Design
Shanghai HuaTai Digital Control Co.,Ltd
Shanghai Institute of Process Automation Instrumentation
Shanghai Wenjiang Electric Co., Ltd
Shanghai Yunchuang Science Technology Co., Ltd
SMC
Southwest China Normal University
SUNX
TangShan KaiCheng Electorical Equipment Co., Ltd.
Tianjin Discovery Co., Ltd
TPC Mechatronics Corp.
TSK DENKO CO.,LTD.
U.I. LAPP GmbH
United Equipment Accessories, Inc.
Woodhead

**ODVA, USA (http://www.odva.org/Home/ABOUTODVA/TheODVACommunity/MemberRoster/tabid/115/Default.aspx, member search for "United States", 12.12.2008)**

ABB
Acromag, Inc.
Advanced Micro Controls Inc. (AMCI)
Advantech Corporation
Aerotech
AGM Electronics, Inc.
Alpha Wire Company
Altera Corporation
AMETEK, Inc.
Amphenol Alden Products Company
AquaSensors
ATI Industrial Automation
Automationdirect.com
AVG Automation
Baldor Electric
Balluff GmbH
Balogh T.A.G., Corporation
Banner Engineering Corporation
Belden
Brooks Instrument (Div. of Emerson)
BTR NETCOM
C&M Corporation
Celerity, Inc.
Cervis Inc.
Cisco Systems, Inc.
COGNEX
CommScope, Inc.
Comtrol Corporation
Conxall Corporation Inc.
Cooper Interconnect
Datalogic
Delta Computer Systems Inc.

**ODVA, USA (continued)**
Digi International, Inc.
Eaton
EIM Valve Controls
Escort Memory Systems
EXOR Electronic R & D
FANUC Inc.
FESTO
FiberFin, Inc.
Flowserve
Fluke Networks
Frontline Test Equipment
GE FANUC
Graco Inc.
Grid Connect
Hardy Instruments, Inc.
HARTING
Hilscher
Hirschmann
Holjeron
Horiba-STEC Inc.
Horner Electric
Huron Net Works
Industrial Control Communication, Inc.
Innovasic Semiconductor
ITT
Lapp USA, Inc. (Olflex Wire & Cable)
Meggitt Airdynamics, Inc., a Division of Whittaker Controls
Mencom Corporation
Mettler-Toledo
MISCO Refractometer
Moog Inc.
MORI SEIKI CO., LTD
MYNAH Technologies
National Semiconductor
Nor-Cal Products, Inc.
Northern Network Solutions, LLC
NT International
N-Tron Corporation
Numatics, Inc.
Online Development Inc. (Automation Value)
OPTO 22
Panduit Corporation
Parker Hannifin Corp. (Veriflo Division)
Pepperl + Fuchs
Phoenix Contact
Prosoft Technology
Proteus Industries Inc.
PULS GmbH
Pyramid Solutions, Inc.
Racine Federated, Inc.
Real Time Automation
Real Time Objects & Systems, LLC
Red Lion Controls
RFID, Inc.
Rockwell Automation
Ross Controls
Salem Automation Inc.
Schneider Electric
Schweitzer Engineering Laboratories
SICK

**ODVA, USA (continued)**
SMC
SoftDEL Systems Limited
Sola/Hevi-Duty
Souriau
Spectrum Controls, Inc.
StoneL Corp.
Symbol Technologies, Inc.
Ten X Technology, Inc.
Turck
Tyco Electronics
WAGO
WATLOW
Welding Technology Corporation
Western Reserve Controls Inc.
Yaskawa

**PROFIBUS User Organisation, Germany (http://www.profibus.com/rpa/germany/membership/memberlist/, 12.12.2008)**

2E mechatronic GmbH + Co.KG
3S - Smart Software Solutions GmbH
A-M-Systeme GmbH
ABB
ACS-Control-System GmbH
Adescom Inc. AG
ads-tec GmbH
AIRTEC Pneumatic GmbH
alpha-bit Gesellschaft für software-engineering mbH
ARCA-Regler GmbH
Argos Messtechnik GmbH
ARIS Antriebe und Steuerungen GmbH
ARTIS Gesellschaft für angewandte Meßtechnik mbH
ASCO JOUCOMATIC GmbH
ascolab GmbH
AUMA Riester GmbH & Co. KG
AutomationX GmbH
G. Bachmann Electronic GmbH
Balluff GmbH
BARTEC GmbH
BASF AG
Baumer Ident GmbH
Baumüller Nürnberg Electronic GmbH & Co
BBH Systems GmbH
Beckhoff
Berger Lahr GmbH & Co. KG
Bernecker + Rainer Industrie-Elektronik GmbH
Bernstein AG
Berthold Technologies GmbH & Co. KG
betacontrol gmbh
Bihl + Wiedemann GmbH
BINDER GROUP
franz binder gmbh + co. elektrische bauelemente kg
BMR elektrischer & elektronischer Gerätebau GmbH
Bopp & Reuther Meßtechnik GmbH

**PROFIBUS User Organisation, Germany (continued)**

Bosch Rexroth Electric Drives and Controls GmbH
Brandt-Data GmbH
Braun GmbH
Bruns Spezialkabel e.K.
BTR NETCOM
BUXBAUM AUTOMATION GmbH
Bürkert Fluid Control Systems
CANDEO Engineering
Carlo Gavazzi GmbH
CEAG Sicherheitstechnik GmbH
Circutor S.A.
CIS ELECTRONIC GmbH
COMSOFT GmbH
ConCab kabel gmbh
CONEC Elektronische Bauelemente GmbH
COPA-DATA GmbH
Creative Chips GmbH
Danaher Motion GmbH
Danfoss GmbH
Delphin Technology AG
Deutschmann Automation GmbH
DIA-LOG GmbH
Dietz Automation GmbH
DREHMO GmbH
DRESCHER Industrieelektronik GmbH
Dyna Systems GmbH
EAE electronics GmbH
EES-Promotion GmbH
EKS Ralph Engel Einzelgesellschaft
ELAU AG
Elektro-Elektronik K. Pranjic
Elektronikbau Franke
elkom elektronik GmbH
ELMOS Industries GmbH
ELZET80 Mikrocomputer GmbH & Co. KG
embex GmbH
Endress + Hauser
ERNI Elektroapparate GmbH
Ernst & Engbring GmbH & Co. KG
esd gmbh
esitron-electronic GmbH
ESR Pollmeier GmbH
EUCHNER GmbH + Co. KG
evosoft GmbH
Fachhochschule Hannover
Fachhochschule Köln
Fachhochschule Lübeck
FANUC Inc.
FESTO
Flowserve
Ulrich Fock
Forschungszentrum Jülich GmbH
Forschungszentrum Karlsruhe GmbH
Foxboro Eckardt GmbH
FRABA Posital GmbH
Fraunhofer IIS
Gantner Instruments Test & Measurement GmbH

**PROFIBUS User Organisation, Germany (continued)**

gat Gesellschaft für Automatisierungstechnik GmbH
GE FANUC
Gebauer & Griller Kabelwerke GmbH
W. Gessmann GmbH
Gleichmann & Co. Electronics Deutschland GmbH
GOSSEN Müller & Weigert
GS Industrie-Elektronik GmbH
HACH LANGE GmbH
halstrup-walcher GmbH
Harms + Wende GmbH & Co. KG
HARTING
HARTING
HEIDENHAIN
Heino Grab
Heinrichs Messtechnik GmbH
Helmut-Schmidt-Universität
HELUKABEL GmbH
Hengstler GmbH
Hilscher
HIMA Paul Hildebrandt GmbH + Co KG
Hirschmann
HMS
Homag AG
Huber + Suhner GmbH
Hummel Elektrotechnik GmbH
Hydac Electronic GmbH
IBH Softec GmbH
ICS Industrielle Computer Systeme GmbH
IDEAL INDUSTRIES GmbH
IEP GmbH
ifak Institut
ifak system GmbH
ifm electronic gmbh
IfTA GmbH
Ilme GmbH
INAT GmbH
Indu-Sol GmbH
INFICON AG
Infineon Technologies AG
Ingenieurbüro Mewes & Partner GmbH
Innominate Security Technologies AG
Institut Industrial IT (inIT)
INTEX SP. Z O.O.
IPP-Ingenieurbüro Podbielski & Partner GbR
ISH Ingenieursozietät GmbH
ISW-Universität Stuttgart
IVO GmbH & Co. KG
IXXAT Automation GmbH
J. Schmalz GmbH
Janitza electronics GmbH
JUMO GmbH & Co. KG
Jäger Computergesteuerte Messtechnik GmbH
KBR GmbH
KEB Antriebstechnik GmbH
KEBA AG
Keller HCW GmbH
KERPEN GmbH & Co. KG
KFM Regelungstechnik GmbH

**PROFIBUS User Organisation, Germany (continued)**
Kisters Maschinenbau GmbH
Klöckner-Holstein-Seitz
Knick Elektronische Messgeräte GmbH & Co. KG
Kontron Modular Computers GmbH
Koralewski Industrie-Elektronik OHG
KROHNE Messtechnik GmbH & Co.KG
Kuhnke GmbH
KUKA Roboter GmbH
KW-Software GmbH
kws Computersysteme GmbH
König Prozessautomatisierungs GmbH
Fritz Kübler GmbH
LABOM Mess- und Regeltechnik GmbH
Lang Apparatebau GmbH an ECOLAB Company
U.I. LAPP GmbH
LARsys-Automation GmbH
Elektronik-Systeme Lauer
LENO Electronics GmbH
Lenord, Bauer & Co. GmbH
Lenze Drive Systems GmbH
LEONI Special Cables
lesswire AG
Leuze
LIKA Electronic
LJU Industrieelektronik GmbH
Logic GmbH & Co.KG
Loher AG
LSS Licht-, Steuer- und Schaltanlagenbau GmbH
LTi DRiVES GmbH
Lumberg Automation Components GmbH & Co. KG
FRIEDRICH LÜTZE GmbH & Co.KG
M&M Software GmbH
Martens Elektronik GmbH
MAXIM GmbH
MESCO
MESOMATIC GmbH
Metronix GmbH
microSYST Systemelectronic GmbH
MITSUBISHI ELECTRIC
MKS Instruments Deutschland GmbH
MLS Lanny GmbH
Moeller GmbH
Molex
Moxa Europe GmbH
MTL
MTS Sensor Technologie GmbH
Murrelektronik Automation GmbH
Nanotec Electronic GmbH
Nautibus electronic GmbH
NBB Nachrichtentechnik GmbH + Co. KG
NEC
NEXANS Deutschland Industrties GmbH & Co. KG
NIVUS GmbH
NORD Electronic Drivesystems GmbH
Norgren GmbH

**PROFIBUS User Organisation, Germany (continued)**
NOVOTRON Industrie-Automation GmbH
OMATIVE Systems Europe GmbH
OMRON
Panasonic Electric Works Deutschland GmbH
Pepperl + Fuchs
Pfeiffer Vacuum GmbH
Phoenix Contact
Pilz GmbH & Co. KG
plating electronic
PMA Prozeß- und Maschinen-Automation GmbH
PROCENTEC GmbH
PROCOS Gesellschaft für Prozessleitsysteme GmbH
Industrievertretung Göhringer
profichip GmbH
PROMETEC GmbH
PROMICON Elektronik GmbH und Co. KG
ProMinent Dosiertechnik GmbH
Prosoft Technology
Prozessmesstechnik O. Peisker
PSi Engineering GmbH
R&M Prozesstechnik GmbH
R. STAHL
Reichle & De-Massari GmbH
REO Elektronik GmbH
ReSatron GmbH
Rittal Electronic Systems GmbH & Co. KG
Roland Electronic GmbH
Ropex Industrie-Elektronik GmbH
Helmut Rossmanith GmbH
RWTH Aachen
SafeSquare GmbH
SAIA-Burgess Electronics GmbH & Co. KG
SAMSON AG
Sartorius Hamburg GmbH
Sasse Elektronik GmbH
Schaeper Automation GmbH
Dieter Schauf GmbH
Schenck Process GmbH
Scheurich GmbH
Schildknecht Industrieelektronik
K.A. Schmersal GmbH & Co.
Schneider Electric
Sensopart
SEW-EURODRIVE GmbH & Co.
Shell & DEA Oil GmbH
SICK
Siebert Industrieelektronik GmbH
SIEMENS
Sigmann Elektronik GmbH
SIPOS Aktorik GmbH
Smar
SMC
SOCOMEC GmbH
Softing AG
SoliDat Solutions in Data Processing GmbH
SOURIAU Germany GmbH
Max Stegmann GmbH
STEINHOFF Automation & Fieldbus-Systems

**PROFIBUS User Organisation, Germany (continued)**
STMicroelectronics Design & Application GmbH
Stucke Elektronik GmbH
STÖGRA Antriebstechnik GmbH
Stöber Antriebstechnik GmbH & Co.
SWAC Schmitt-Walter Automation Consult GmbH
SysDesign GmbH
SysTec GmbH
Systeme Helmholz GmbH
SÜTRON electronic GmbH
TCE TeleControlExpert GmbH
Technische Universität Braunschweig
Technische Universität München
Telegaertner Karl Gärtner GmbH
Testo AG
TMG TE GmbH
TR-Electronic GmbH
TR-Systemtechnik GmbH
Trebing & Himstedt Prozeßautomation GmbH & Co. KG
Trimble GmbH
TU Bergakademie Freiberg
TU Wien, Institut für Computertechnik
Turck
TWK Elektronik GmbH
UNIPO Verwaltung + Vertrieb GmbH & Co.KG
Universität Otto-von-Guericke
VACOM Steuerungsbau und Service GmbH
VCA software GmbH
VEGA Grieshaber KG
VIPA GmbH
VIPCO GmbH
VISUAL ELECTRONIC GmbH
Wachendorff Prozesstechnik GmbH & Co. KG
WAGO
Weatherford Oil Tool GmbH
Weidmüller Interface GmbH & Co. KG
Wenglor Sensoric GmbH
Westermo Data Communications GmbH
Wieland Electric GmbH
WIKA Alexander Wiegand GmbH & Co. KG
Wind River GmbH
Woodhead
Yacoub Automation GmbH
Yamaichi Electronics GmbH
Yaskawa
Yokogawa
Dr. Zinngrebe GmbH
ZMD AG

**Following Executive Board Members have been added to the home-base lists (those Executive Board Members who are included in previous community lists are not mentioned below):**

Molex (CLPA)
NEC (CLPA)
Digital Electronics (CLPA)
ASCO Numatics (ODVA)
OMRON (ODVA)

## Appendix B:

## IO-link founding members (March 2006) (Source: own investigation)

Balluff GmbH
Beckhoff
Gemü
FESTO
ifm electronic gmbh
Leuze
MESCO
Pepperl + Fuchs
Phoenix Contact
Schneider Electric
Sensopart
SICK
SIEMENS
Turck

## WirelessHART founding members

*WirelessHART technology was developed from user input through the combined, cooperative efforts of HCF member companies and leaders in wireless technology, including ABB, Adaptive Instruments, Crossbow Technology, Dust Networks, ELPRO Technologies, Emerson Process Management, Endress+Hauser, Flowserve, Honeywell, MACTek, MTL, Omnex Control Systems, Pepperl+Fuchs, Phoenix Contact, Siemens, Smar, Yamatake and Yokogawa.*

(HART Communication Foundation, 'WirelessHART Communication Supported by Leading Process Automation Companies' [press release], http://www.hartcomm2.org/hcf/press/pr2007/wireless_support.html, last accessed on 19 Dec 2008)

ABB
Adaptive Instruments
Crossbow Technology
Dust Networks
ELPRO Technologies
Emerson Process Management
Endress + Hauser
Flowserve
Honeywell
MACTek
MTL
Omnex Control Systems
Pepperl + Fuchs
Phoenix Contact
SIEMENS
Smar
Yamatake
Yokogawa

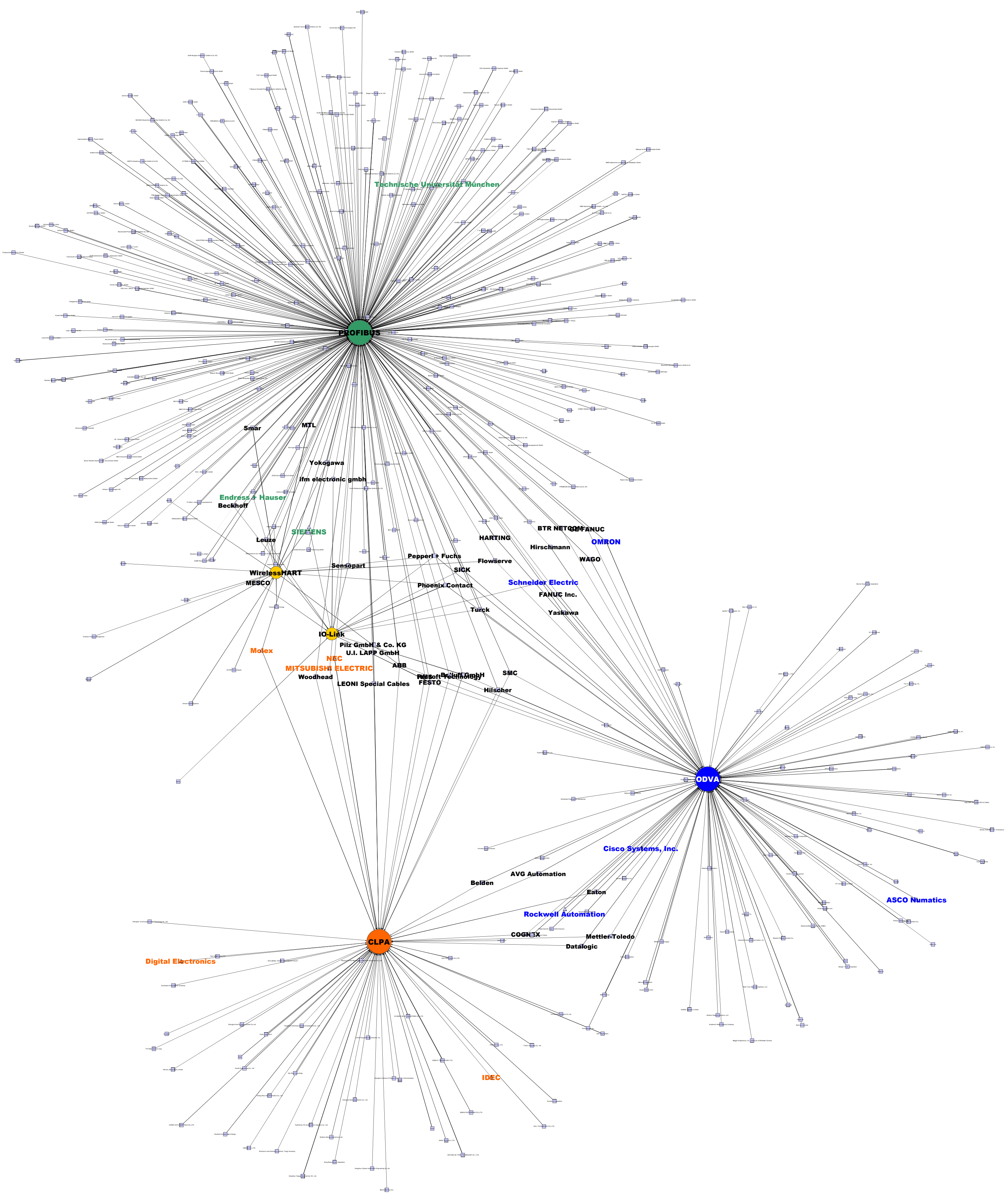
## Appendix C: Social network analysis

See Appendices C1 and C2 on the following pages; legend see down.

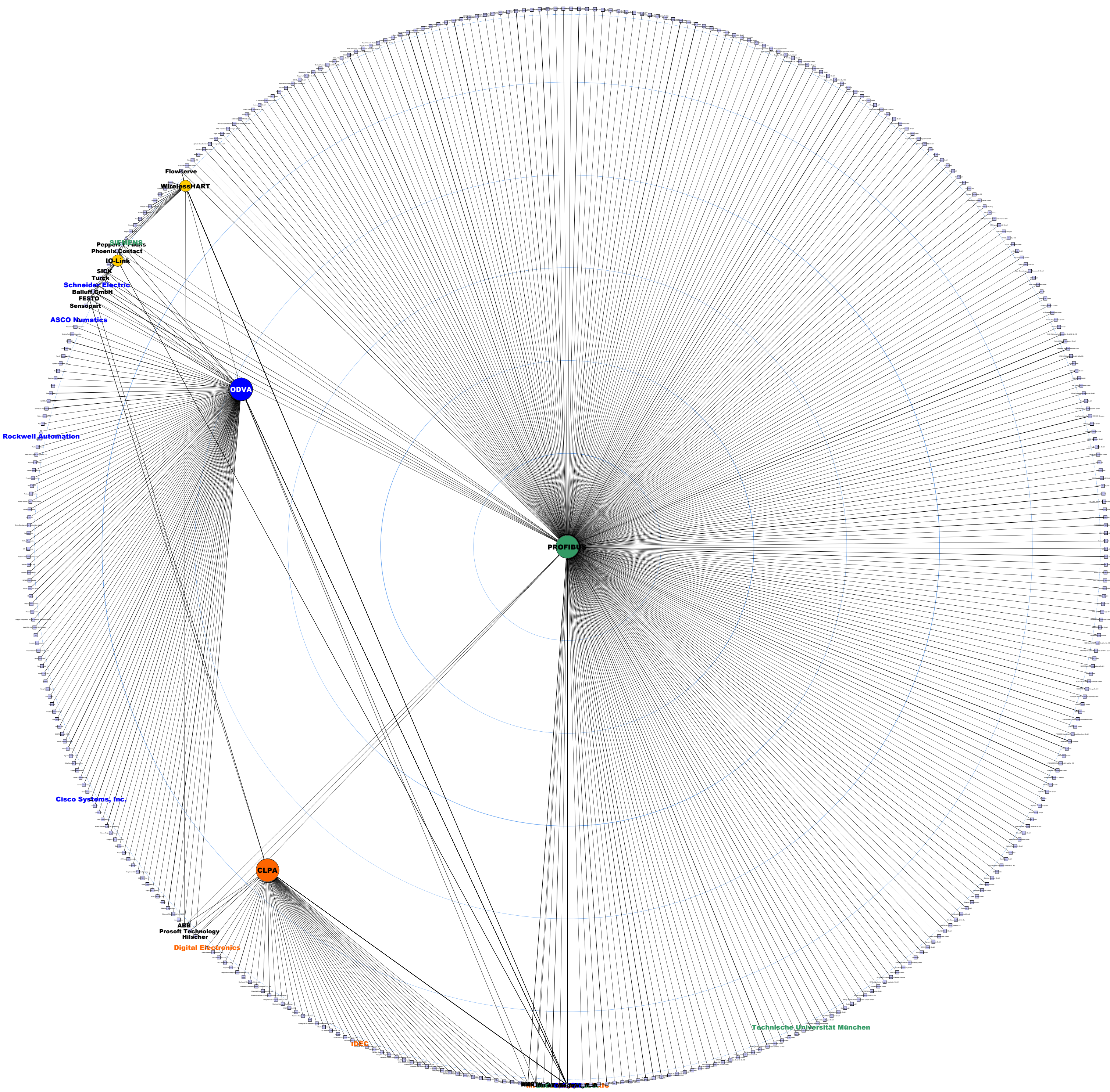
*Appendix C1* figures the population of the different field bus user organisations. It shows that the standard-setting communities are interconnected by few incumbent firms and by common project consortia of several member firms, here IO-Link. Furthermore, it seems that CLPA, ODVA and PROFIBUS represent separate sub-networks within the market field of industrial automation/particularly factory automation.

*Appendix C2* denotes network centrality measured through network authority of each node. The figure shows that a simple count of memberships provides a biased analysis in favour of PROFIBUS. Future studies need to account for particular characteristics of each node and the strength of ties in order to provide a more realistic picture of status hierarchies.

# Appendix C1: Populations



# Appendix C2: Network authority



**Notes**

1 For comprehensive speeches on recent antitrust issues and policies, see Balto (2000) or Wellford (2007). A comprehensive list of American publications concerning antitrust can be found at '10th Anniversary' [booklet], American Antitrust Institute, http://www.antitrustinstitute.org/archives/files/10th%20Anniversary%20Booklet%20Low%20Res_072920081537.pdf. European antitrust cases are documented at http://ec.europa.eu/comm/competition/antitrust/cases/, European Commission, DG Competition (cases treated under Articles 81 and 82 of the EC Treaty); see http://ec.europa.eu/competition/antitrust/cases/decisions/39247/proceedings.pdf, 'Commission initiates formal proceedings against Qualcomm'.

Note that the analysis of antitrust issues in standard-setting interferes with the analysis of firms' (unfair) deployment of standards' essential intellectual property rights. Particularly, 'patent ambushes' and 'patent thickets' indicate discriminatory and prohibited firm behaviour. For a comprehensive paper on IPR policies in standard-setting organisations see Lemley (2002), writing on the telecommunications industry.

2 Among others see Eickhoff/Hartlieb (2002), Blind (2006), DeLacey/Herman/Kiron/Lerner (2006) or Farrell/Simcoe (2007).

The analysis of organisations/communities for de jure/formal versus de facto standards cannot be separated because there is confusion about appropriate terminology (standard-setting bodies, standard-setting organisations, standard-setting consortia, standardisation bodies, standard-setting communities, etc.). Possibly, the two kinds of organisations can be best distinguished by the terminology for the standards produced – de facto versus de jure/formal.

3 With regard to the open source software community, there is a multifaceted interplay between standard-setting, standardisation particularly in terms of Linux kernel integration or W3C specifications, and R&D projects which cannot be accurately addressed within this paper. Many open source projects are listed at http://www.sourceforge.net/, SourceForge Inc., Mountain View (CA), USA. They exemplify the variety of open source licences and community project structures. For a reflection on the terminus 'open' see *Consortium Standards Bulletins*, IV (3) titled 'What Does 'Open' Mean?', March 2005 (http://www.consortiuminfo.org/bulletins/pdf/mar05.pdf).

One of the most prominent open source software standard-setting consortia is the Linux Foundation, founded as a merger by the Open Source Development Labs (OSDL) and the Free Standards Group. The Linux Foundation sets standards on the Linux operation system (http://www.linuxfoundation.org, the Linux Foundation). In order to promote open source technologies it is also committed to the 'Patent Commons Project' (http://www.patent-commons.org/). Note that 'Patent Commons' terms of commitment (cf. http://www.patent-commons.org/resources/about_commitments.php, The Linux Foundation, Commitments) determine whether a commons is open source or rather a semi-open category depending on the particular case. The term 'open source' is defined by the Open Source Initiative (http://www.opensource.org/docs/osd, The Open Source Definition, 2006).

'Openness' of standards represents an elusive construct and thus a research issue in its own right. The many 'means of openness' refer to the purpose of the agent who claims openness, i.e. modification rights versus implementation rights versus access only. Particularly cf. West (2007), Updegrove (2005), or Krechmer (1998/2006).

4 *"[…] technical standards represent specifications on technology agreed on and advanced in research and standard-setting collaboration. They are embedded in business systems which include agreements on intellectual property rights, knowledge mapping, behaviour*

*and decision-making but also an alignment between collaborative activities and subsequent proprietary market activities."* (Slowak, 2008, p. 147).

5 '$s_{iv}$' represents a standard or an integrated set of standards s of firm i at vintage v.

6 Slowak's concept of evolution in standard-setting refers to Nooteboom (2007) and Hodgson/Knudsen (2006).

7 As concluded from informal interviews with market consultants.

Unlike general-purpose computers, programmable logic controllers (PLCs) are digital real-time systems capable of computing multiple in- and outputs. They are particularly designed for technical conditions and requirements given in industrial automation processes. PLC technology often refers to the standard IEC 61131.

8 This introduction is taken from Slowak (2008, p 150f).

9 A list of industry associations and user organisations dealing with automation technology ('technology associations') can be found at http://www.aud24.net/pi/index.php?StoryID=223, Technologievereinigungen von A-Z, A&D, publish-industry, Munich.

10 For more detailed information on community organisational structure and member rights see bylaws accessible as follows:

CLPA Membership Agreement (http://www.cc-link.org.tw/doc/regulation.pdf).

ODVA Bylaws, PUB00030R4, 1 January, 2007 (http://www.odva.org/Portals/0/Library/Publications_Numbered/PUB00030R4.pdf).

PNO Bylaws [Satzung der PROFIBUS Nutzerorganisation e.V., PROFIBUS User Organisation], Apr 24, 1996 (http://www.profibus.com/celummdb/doc/RPA/GERMANY/Satzung_PNO.pdf).

11 This paragraph is taken from Gerybadze/Slowak (2008) and Slowak (2008, p. 151f).

12 Rockwell International purchased Allen-Bradley in 1985.

13 'Consortia' shall be defined as project-orientated and industry-driven organisations with the purpose of setting a specific standard. The definition of 'standard-setting communities' includes such consortia, but it also includes industry-driven organisations with the purpose of setting up a system of coordinated technical standards and business agreements. Note that consortia can be established from a standard-setting organisation's working groups, i.e. IO-link was founded by a PROFIBUS working group.

14 'High-norm activities' as terminology used by Gerybadze/Slowak (2008) subsume all activities of the firm at formal standardisation bodies which are conducted with the purpose of setting a global de jure standard (globally and thus 'high'-level; and formal, not de facto, standardisation).

15 *"The background of the invention is the networking of sensors, for example of one-dimensional or two-dimensional optical code readers or of laser measuring systems, via a digital fieldbus, for example, of the type Profibus or DeviceNet. It is known for this purpose to provide the sensors with their own fieldbus interface which permits a connection of the sensor to the fieldbus and communication between the sensor and the fieldbus. A fieldbus interface integrated in the sensor, however, makes the actual sensor module undesirably expensive and undesirably voluminous for some applications. The relevant sensor is moreover admittedly adapted to a specific fieldbus; but the sensor can no longer easily be*

*used for other fieldbus types*" (US Patent 7299310, Connection module for the connection of a sensor to a fieldbus, Assignee: Sick).

16 For a list of so-called 'industry consortia' in standard-setting see ConsortiumInfo.org (http://consortiuminfo.org/links/, Standard Setting Organisation and Standards List, Industry Categories). They are often layered organisations in terms of layered membership types.

17 In-depth analogy between atom physics and collaborative standard-setting would imply that atom cores compete for elements – a misleading view of chemical reactions and spins within the atom layers. The analogy between standard-setting communities and atoms is therefore limited, if not inappropriate,despite the idea that 'context matters'. Conversely, the analogy between chemical reactions and dynamics within sectoral innovation systems may lead to new findings. In chemical reactions, enthalpy leads to the fact that protons switch affiliation from one molecule to another if the new affiliation creates more energy than has been spent in breaking up with the old molecule. This is to say that communities need both to create value and to distribute it fairly among members.

18 "*Firms in sectors have commonalities and at the same time are heterogeneous … it is proposed that a sectoral system of innovation (and production) is composed of a set of agents carrying out market and non-market interactions for the creation, production and sale of sectoral products. Sectoral systems have a knowledge base, technologies, inputs and (potential or existing) demand.*" (Malerba, 2004, p. 10).

19 On the relationship between standardisation and innovation see also Swann in DTI (2005), Chapter 4/Project 3: 'Do Standards Enable or Constrain Innovation?', pp. 76-109. Using data on the stock of British de jure standards from years 1998 to 2000/PERINORM database, Swann finds that standards may inform and constrain innovation at the same time. The relationship must thus not only depend on the 'conditions' of the industry's/nation's stock of standards, but also on several firm characteristics.

20 "*Compared to pure exploration and pure exploitation organizations, resource allocation decisions in ambidextrous organizations are critical for the maintenance of ambidexterity. Exploitative activities (replication of consulting projects, optimization etc.) are necessary to provide sufficient financial resources in order to fund exploration, which is necessary to preserve an accepted integration within the scientific community. In exploration organizations, general funding is provided by central stakeholders or organizations develop routines to arrange funding through application at competitive scientific funding institutions. Consequently, in these organizations even funding strategies display an explorative character. In exploitation organizations, the replication of existing operative routines (e.g. consulting projects that are based on methodical templates or standardized laboratory tests) is the main source for funding as business firms or administrative institutions pay for these services. In contrast to exploration and exploitation organizations, ambidextrous organizations dispose of multifarious objectives. Therefore, strategic practices in ambidextrous organizations concentrate on exploration (e.g. long-term development in the sphere of science) and on exploitation (e.g. optimization of operative activities)*." (Güttel/Konlechner, 2007, p. 367).

21 Note that the relationship between innovation as variety-generating and standards specification as variety reduction is very simplified within this paper. In particular, a linear time model – which vintages imply – is highly problematic: more detailed dynamics models of innovation such as that by Utterback (1996, chapter 4 / pp. 79-102) indicate that different types of innovation, particularly product and process innovation, show different time patterns concerning industry evolution. It would hence be fruitful to compare the varieties in standard-setting with varieties in innovation dynamics.

[22] In the PROFIBUS case, NEC developed ASICs for Siemens which are essential to PROFINET's real-time functionality. 'Affiliation' here means that a technology provider co-established a standard through key contributions to core member firms, or to the founding members' consortia of a standard.

[23] "*As industrial automation represents a medium/low-tech industry, use cases are well-established. Field buses serve the automation of production processes and motions in factories and process plants. Therefore, in contrast with embryonic/immature industries such as cell cloning, the construction of a meaningful use case is not part of the standard-setting process ... User organizations specify how and why a set of standards shall be used. They create a generic case of industry-specific use and industry-tailored services, but they also integrate third industries' open standards if those deliver new features to industry (creation of use case)*." (Slowak, 2008, p. 148).

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