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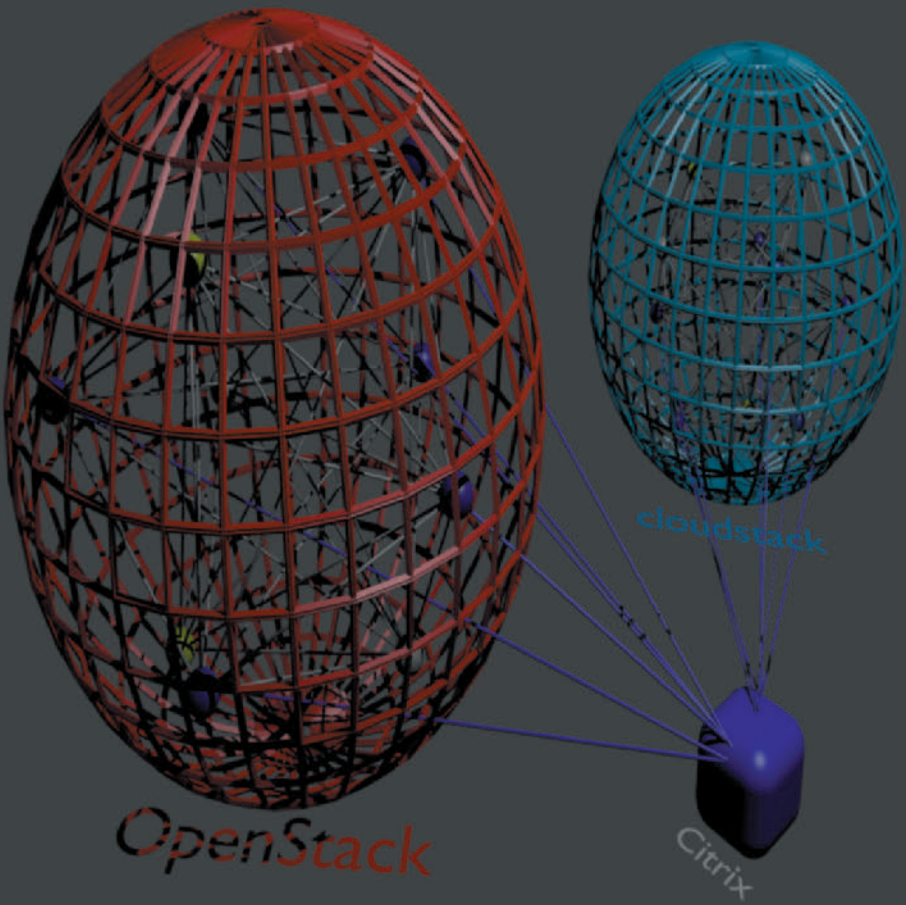

COOPETITION IN AN OPEN-SOURCE WAY

– Lessons from Mobile and Cloud Computing Infrastructures

Jose Teixeira

TURUN YLIOPISTON JULKAISUJA – ANNALES UNIVERSITATIS TURKUENSIS
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"I often compare open source to science. To where science took this whole notion of developing ideas in the open and improving on other peoples' ideas and making it into what science is today and the incredible advances that we have had. And I compare that to witchcraft and alchemy, where openness was something you didn't do." ... "But then science ended up being pretty closed, with very expensive journals and some of that going on. And open source is making a comeback in science, with things like arXiv and open journals. Wikipedia changed the world, too. So there are other examples, I'm sure there are more to come."

— **Linus Torvalds**, He did Linux and Git! What did you do?

Abstract

An increasing amount of technology is no longer developed in-house. Instead, we are in a new age where technology is developed by a networked community of individuals and organizations, who base their relations to each other on mutual interest. Advances arising from research in platforms, ecosystems, and infrastructures can provide valuable knowledge for better understanding and explaining technology development among a network of firms. More surprisingly, recent research suggests that technology can be jointly developed by rival competing firms in an open-source way. For instance, it is known that the mobile device makers Apple and Samsung continued collaborating in open-source projects while running expensive patent wars in the courts. On top of multidisciplinary theory in open-source software, cooperation among competitors (aka coopetition) and digital infrastructures, I (and my coauthors) explored how rival firms cooperate in the joint development of open-source infrastructures. While assimilating a wide variety of paradigms and analytical approaches, this doctoral research combined the qualitative analysis of naturally occurring data (QA) with the mining of software repositories (MSR) and social network analysis (SNA) within a set of case studies. By turning to the mobile and cloud computing industries in general, and the WebKit and OpenStack open-source infrastructures in particular, we found out that qualitative ethnographic materials, combined with social network visualizations, provide a rich medium that enables a better understanding of competitive and cooperative issues that are simultaneously present and interconnected in open-source infrastructures. Our research contributes back to managerial literature in coopetition strategy, but more importantly to Information Systems by addressing both cooperation and competition within the development of high-networked open-source infrastructures.

Keywords: Open-Source, Platforms, Ecosystems, Infrastructures, Coopetition, Open-Coopetition, Mobile, Cloud Computing

Tiivistelmä

Yhä suurempaa osaa teknologiasta ei enää kehitetä organisaatioiden omasta toimesta. Sen sijaan, olemme uudella aikakaudella jossa teknologiaa kehitetään verkostoituneessa yksilöiden ja organisaatioiden yhteisössä, missä toimitaan perustuen yhteiseen tavoitteeseen. Alustojen, ekosysteemien ja infrastruktuurien tutkimuksen tulokset voivat tuottaa arvokasta tietämystä teknologian kehittämisestä yritysten verkostossa. Erityisesti tuore tutkimustieto osoittaa että kilpailevat yritykset voivat yhdessä kehittää teknologiaa avoimeen lähdekoodiin perustuvilla käytännöillä. Esimerkiksi tiedetään että mobiililaitteiden valmistajat Apple ja Samsung tekivät yhteistyötä avoimen lähdekoodin projekteissa ja kävivät samaan aikaan kalliita patenttitaistoja eri oikeusfoorumeissa. Perustuen monitieteiseen teoriaan avoimen lähdekoodin ohjelmistoista, yhteistyöstä kilpailijoiden kesken (coopetition) sekä digitaalisista infrastruktuureista, minä (ja kanssakirjoittajani) tutkimme miten kilpailevat yritykset tekevät yhteistyötä avoimen lähdekoodin infrastruktuurien kehityksessä. Sulauttaessaan runsaan joukon paradigmoja ja analyyttisiä lähestymistapoja case-joukon puitteissa, tämä väitöskirjatutkimus yhdisti luonnollisesti esiintyvän datan kvantitatiivisen analyysin ohjelmapakettivarastojen louhintaan ja sosiaalisten verkostojen analyysiin. Tutkiessamme mobiili- ja pilvipalveluiden teollisuudenaloja yleisesti, ja WebKit ja OpenStack avoimen lähdekoodin infrastruktuureja erityisesti, havaitsimme että kvalitatiiviset etnografiset materiaalit yhdistettyinä sosiaalisten verkostojen visualisointiin tuottavat rikkaan aineiston joka mahdollistaa avoimen lähdekoodin infrastruktuuriin samanaikaisesti liittyvien kilpailullisten ja yhteistyökuvioiden hyvän ymmärtämisen. Tutkimuksemme antaa oman panoksensa johdon kirjallisuuteen coopetition strategy -alueella, mutta sitäkin enemmän tietojärjestelmätieteeseen, läpikäymällä sekä yhteistyötä että kilpailua tiiviisti verkostoituneessa avoimen lähdekoodin infrastruktuurien kehitystoiminnassa.

Avainsanat: Avoin lähdekoodi, alustatalous, ekosysteemit, infrastruktuurit, coopetition, open coopetition, mobiililaitteet, pilvipalvelut

Resumo

Uma crescente quantidade de tecnologia não é desenvolvida internamente por uma só organização. Em vez disso, estamos em uma nova era em que a tecnologia é desenvolvida por uma comunidade de indivíduos e organizações que baseiam suas relações umas com as outras numa rede de interesse mútuo. Os avanços teórico decorrentes da pesquisa em plataformas computacionais, ecossistemas e infraestruturas digitais fornecem conhecimentos valiosos para uma melhor compreensão e explicação do desenvolvimento tecnológico por uma rede de multiplas empresas. Mais surpreendentemente, pesquisas recentes sugerem que tecnologia pode ser desenvolvida conjuntamente por empresas rivais concorrentes e de uma forma aberta (em código aberto). Por exemplo, sabe-se que os fabricantes de dispositivos móveis Apple e Samsung continuam a colaborar em projetos de código aberto ao mesmo tempo que se confrontam em caras guerras de patentes nos tribunais. Baseados no conhecimento científico de software de código aberto, de cooperação entre concorrentes (também conhecida como coopetição) e de infraestruturas digitais, eu e os meus co-autores exploramos como empresas concorrentes cooperam no desenvolvimento conjunto de infraestruturas de código aberto. Ao utilizar uma variedade de paradigmas e abordagens analíticas, esta pesquisa de doutoramento combinou a análise qualitativa de dados de ocorrência natural (QA) com a análise de repositórios de softwares (MSR) e a análise de redes sociais (SNA) dentro de um conjunto de estudos de casos. Ao investigar as industrias de technologias móveis e de computação em nuvem em geral, e as infraestruturas em código aberto WebKit e OpenStack, em particular, descobrimos que o material etnográfico qualitativo, combinado com visualizações de redes sociais, fornece um meio rico que permite uma melhor compreensão das problemas competitivos e cooperativos que estão simultaneamente presentes e interligados em infraestruturas de código aberto. A nossa pesquisa contribui para a literatura em gestão estratégica e coompetição, mas mais importante para literatura em Sistemas de Informação, abordando a cooperação e concorrência no desenvolvimento de infraestruturas de código aberto por uma rede the indivíduos e organizações em interesse mútuo.

Palavras chave: Sistemas em código aberto, Plataformas computacionais, Ecossistemas digitais, Infraestruturas digitais, Coopetição, Coopetição aberta, Technologies móveis, Sistemas de computação em nuvem

Dedication

This doctoral dissertation is dedicated to my parents ***Maria Palmira*** *and* ***António****, also to my wife* ***Nea*** *and my very young children* ***Alda*** *and* ***Osmo****. For the last three, it was unfair the amount of doctoral research work at weekends, evenings and supposed 'holidays' during the period that they most needed me.*
Vos amo muito a todos.

Acknowledgments

This dissertation, addressing both strategic management and open-source software issues was possible in five very special circumstances. (1) A crucial event was on 9th of October 1991, when my parents bought a personal computer. It was a Schneider EuroSX with a fantastic hard disk capable of holding 17MB. At that time, a personal computer cost several times the average salary of a middle-class worker. (2) Then my studies in Computer Networks and Distributed Systems Engineering (Licenciatura em Engenharia de Redes e Sistemas Informáticos) at the Faculty of Sciences in the Universidade do Porto (Portugal). There I learned the hard and difficult disciplines of mathematics, computer science, logic, complexity, programming, communication networks, artificial intelligence, security and ethics of computing. At that time all the computers in the department of computer science were equipped with open-source software — they booted the so-called Linux operating system. (3) Thereafter come my early professional work at Sonae, Wipro, Airbus, and Tesco were I contributed to the development and implementation of different information systems that still today power fashion retailers, supermarket warehouses, and even very large airplanes (e.g., Airbus A380). All those organizations took very different and contrasting approaches to open-source software. (4) Also my studies towards an International Master in Management of Information Technology (IMMIT) offered by IAE Aix-Marseille Graduate School of Management, Aix-Marseille Université (France), University of Turku (Finland) and Tilburg University (The Netherlands) influenced this dissertation. Across the three countries I learned more soft disciplines such as accounting, economics, project management, strategy, leadership, finance, marketing and information systems. (5) Later then at Nokia, where I participated in the development of the first so-called 'Internet tablets' that were powered by an open-source based platform at that time called Maemo. This a few years before Android even existed. In Nokia and especially in the Maemo open-source community, I started getting interested in why and how individuals and firms can jointly develop 'whole product' technologies in an open-source way. The different attitudes of firms towards open-source software as well as the managerial issues of working with and within open-source communities laid down the path to this doctoral dissertation.

I would like to thank a number of individuals that directly or indirectly influenced this dissertation. I start with my supervisor Reima Suomi, but also Eija Koskivaara, Timo Leino and Hannu Salmela that motivated me to pursue my doctoral studies at Turku School of Economics. Further, I wish to express my sincere gratitude to all of my coauthors. I start with Lin Tingting with whom I coined the term 'open-coopetition', Reima Suomi that was also my supervisor, Martin D'Cruz, Sebastien Okser, Abayomi Baiyere, Sami Hyrynsalmi, Gregorio Robles, Jesus Gonzalez-Barahona, Salman Mian, Ulla Hytti, Joni Salminen, Eija Koskivaara, Karri Mikkonen, Mikko Pynnönen, Kari Korpela, Jukka Hallika, Helena Karsten and Gunilla Widén. At Turku School of Economics and at the Turku Centre for Computer Science, I was fortunate to meet great colleagues that found time to discuss my research issues: Lin Tingting, Natalia Diaz Rodriguez, Jussi Nissila, Tommi Tapanainen, Mikko Hallanoro, Sebastien Okser, Jani Merikivi, Timo Kestilä, Timo Lainema, Jonna Järveläinen, Hongxiu Li, Kai Kimppa, Sami Hyrynsalmi, Neeraj Sachdeva, Anne-Marie Tuikka, Abayomi Baiyere, Xiaoyu Xu, Najmul Islam, Farooq Mubarak, Olli Sjöblom, Ping Wang, Marko Niemimaa and Markus Zimmer. At a later stage, I also had the luck to meet Mervi Vähätalo, Tiina Mäkitalo-Keinonen, Tanja Lepistö, Olena Gonzales and Lenita Nieminen at the University Consortium of Pori. I developed much empathy, and even friendship, with such officemates.

I owe my debt of gratitude also to the organizers and other participants at the doctoral consortia from the International Conference on Open Source Systems (OSS DC 2013), the European Conference on Information Systems (ECIS DC 2015), and the International Conference on Information systems (ICIS DC 2015) as they brought many important insights into research. Part of this research was executed during scholarly visits to Carnegie Mellon University Silicon Valley Campus (USA), LERO the Irish Software Research Center at the University of Limerick (Ireland), the University of Bologna (Italy) and the Madeira Institute of Interactive Technologies (Portugal). In addition, there is also a number of scholars that I met at courses, seminars, workshops, conferences and symposia that influenced somehow my research output. Among others acknowledge Alan Hevner, Andreja Puchihar, Eric Monteiro, Patrick Finnegan, Klaas-Jan Stol, John Noll, Sarah Beecham, Liliana Pasquale, Aino Halinen-Kaila, Netta Iivari, Magnus Bergquist, Suprateek Sarker, Devi Gnyawali, Giovanni Dagnino, Rudy Hirsch eim, Natalia Levina, Sonali Shah and Annabelle Gawer, Joseph

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All this work would not have been possible without financial support: I owe much gratitude once again to my supervisor Reima Suomi but also Pertti Järvinen, Ulla Hytti, Timo Leino, Hannu Salmela, Rami Olkkonen, Matti Rossi, Mikko Pynnönen and Helena Karsten for recommending my applications to research funds. I will never forget two persons that always supported me along with the administrative issues at Turku School of Economics and the Turku Centre for Computer Science: Birgit Haanmäki, Eila Wilkman-Korkiamäki always found time to help me overcome many administrative issues. This was especially important given my limited comprehension of the Finnish language. I want to highlight special gratitude to my coauthors Gregorio Robles and Jesus Gonzalez-Barahona that brought much expertise from the Mining Software Repositories (MSR) field and Lin Tingting for exposing me to the fascinating world of Social Network Analysis (SNA). They added much value to this dissertation. I also want to thank to the two external evaluators, Tobias Mettler and Linus Nyman, and the opponent, Brian Fitzgerald, for the valuable criticism and encouragement. I really appreciate your time and effort devoted to this dissertation.

In addition to people, different organizations also played an important role. I start with Turku School of Economics, now part of the University of Turku where this research was conducted. Together with the Turku Centre for Computer Science and the EIT digital (former EIT ICT labs), they provided the much-needed infrastructure for basic research. Plenty of time and effort was spent in courses and seminars. I perceive that the INFORTE organization (arranging workshops and seminars on diverse areas of ICT) and the Kataja organization (providing doctoral level education in business studies in Finland) were of major importance for my doctoral research. This research was partially funded by the Fundação para a Ciência e a Tecnologia (grant SFRHBD615612009), Liikesivistysrahasto (many grants), Marcus Wallenberg Säätiö (grant "open-coopetition R&D management strategy"), Academy of Finland (decision no. 295743), Tekes (Systemic Competitive Advantage project), KAUTE säätiö (visiting abroad grant) and the Turku Centre for Computer Science (many travel grants) and Turun Yliopistosäätiön (one conference travel grant).

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List of original articles included in the dissertation

- Article 1 — **Jose Teixeira** and Abayomi Baiyere. Crafting a systematic literature review on open-source platforms, *In Proceedings of the 10th IFIP WG 2.13 International Conference on Open Source Systems (OSS 2014)*. Springer.

- Article 2 — **Jose Teixeira**. On the openness of digital platforms/ecosystems, *In Proceedings of the 11th International Symposium on Open Collaboration (OpenSym 2015). ACM.*

- Article 3 — Salman Mian, **Jose Teixeira** and Eija Koskivaara. Open-source software implications in the competitive mobile platforms market, *In Proceedings of the 11th IFIP WG 6.11 Conference on E-business, E-services, and E-society (I3E 2011)*. Springer.

- Article 4 — **Jose Teixeira** and Tingting Lin. Collaboration in the open-source arena: The WebKit case, *In Proceedings of the 52nd ACM SIGMIS Computers and People Research (CPR 2014)*. ACM.

  (Runner up for the best paper award)

- Article 5 — **Jose Teixeira**, Gregorio Robles and Jesús González-Barahona Lessons learned from applying social network analysis on an industrial Free/Libre/Open Source Software ecosystem, *In Journal of Internet Services and Applications, 6(1), 1-27*. Springer.

- Article 6 — **Jose Teixeira**, Salman Mian and Ulla Hytti. Cooperation among competitors in the open-source arena: The case of OpenStack, *In Proceedings of the 37th International Conference on Information Systems (ICIS 2016)*. AIS.

Other original articles related to the dissertation

1. **Jose Teixeira** and Reima Suomi. Open-source disease control software development - The role of patients *In Proceedings of the 5h European Conference on Information Management and Evaluation (ECIME 2011)*. Academic Publishing Limited.

2. **Jose Teixeira** and Salman Mian. Open-source mobile software for sports: An new disruptive phenomenon in an era of innovative devices *In Proceedings of the IADIS International Conference ICT, Society and Human Beings (IADIS ICT 2011)*. IADIS Press.

3. **Jose Teixeira** and Joni Salminen. Open-Source as enabler of entrepreneurship ambitions among engineering students – A study involving 20 Finnish startups *In Proceedings of the 15th International Conference on Engineering Education (ICEE 2012)*. iNEER.

4. **Jose Teixeira**. Open-source technologies realizing social networks: A multiple descriptive case-study *In Proceedings of the IFIP WG 2.13 8th International Conference on Open Source Systems (OSS 2012)*. Springer.

5. Joni Salminen and **Jose Teixeira**. Fool's gold? Developer dilemmas in a closed mobile application market platform *In Proceedings of the 15th International Conference on Electronic Commerce (ICEC 2013)*. Springer.

6. **Jose Teixeira** and Tingting Lin. Rivalry and collaboration in the open-source arena: The WebKit case *In Proceedings of Sunbelt XXXIV (2014)*. INSNA.

7. **Jose Teixeira**. Understanding collaboration in the open-source arena *In Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering (EASE'14)*. ACM.

8. **Jose Teixeira**. Open-coopetition in the cloud computing Industry: the OpenStack NOVA case *In Proceedings of the 1st European Social Networks Conference (EUSN 2014)*. INSNA.

9. **Jose Teixeira**. Patients using open-source disease control software developed by other patients *In Proceedings of the 5th International Conference on Wellbeing in the Information Society (WIS 2014)*. Springer.

10. **Jose Teixeira**. Understanding coopetition in the open-source arena: The cases of WebKit and OpenStack *In Proceedings of the 10th International Symposium on Open Collaboration (OpenSym 2014)*. ACM.

11. **Jose Teixeira**. Developing a cloud computing platform for Big Data: The OpenStack Nova case *In Proceedings of the 2nd International Conference on Big Data (IEEE BigData 2014)*. IEEE.

12. **Jose Teixeira**. A multi-method study on how communities split: From Apple's WebKit to Google's Blink *In Proceedings of Sunbelt XXXV (2015)*. INSNA.

13. Karri Mikkonen, **Jose Teixeira**, Mikko Pynnönen, Kari Korpela and Jukka Hallikas. A purpose-based typology for systemic features enabling value co-creation in consumer information systems. *In Proceedings of the IEEE 49th Annual Hawaii International Conference on System Sciences (HICSS 2016)*. IEEE.

14. **Jose Teixeira**. Release early, release often and release on time. An empirical case study of release management *In Proceedings of the IFIP WG 2.13 13th International Conference on Open Source Systems (OSS 2017)*. Springer.

    (Runner up for the best paper award)

15. **Jose Teixeira** and Sami Hyrynsalmi. How do Software Ecosystems Co-Evolve? A view from OpenStack and beyond *In Proceedings of the 8th International Conference on Software Business (ICSOB 2017)*. Springer.

    (Best paper award)

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Part I

Dissertation overview

1 Introduction

> "Understanding the open-source process can generate new perspectives on very old and essential problems of social cooperation."
>
> Steven Weber, 2009

1.1 Motivation and scope

Plenty of technology is no longer developed in-house. Instead, the development of technology is often embedded within networked communities of individuals and organizations, who base their relations to each other on mutual interest. Advances arising from research in platforms, ecosystems, and infrastructures can provide valuable knowledge to better understand and explain technology development among a network of firms. More surprisingly, recent research suggests that technology can be jointly developed by rival competing firms in an open-source way. For example, it is known that the mobile-device makers Apple and Samsung collaborated on open-source projects while running expensive patent wars in the courts worldwide.

Increasing the understanding of how firms cooperate with competitors (aka coopetition) in the joint development of open-source technology motivates this study. In this doctoral research, lessons were procured from the mobile and cloud computing industries. Two open-source projects were treated as the key units of analysis: 1) the WebKit project developing web-browsing mobile technologies, and 2) the OpenStack project developing a cloud infrastructure for big data.

1.2 Problem statement

Computer-based platforms combine core components with complementary products and services habitually made by a variety of external entities (Gawer and Cusumano 2008). In the case of high-technology and high-competitive markets, many firms follow platform-based strategies due to the impossibility of satisfying an exceedingly complex consumer group by themselves (Hagiu 2004). Classical examples of computer-based platforms joint developed by multiple actors are operating systems, video game consoles and plenty of software frameworks. Platforms blur organizational boundaries as platforms' development and exploitation encompass collaboration with other players from the platform ecosystem (see Ceccagnoli et al. 2012; Ghazawneh and Henfridsson 2013). Platforms are not fully developed in-house (i.e., internally), they are instead relational and embedded in networks aggregating organizations and individuals.

My initial substantive interest was to understand the emergence of open-source software (OSS) within the mobile devices industry. More specifically, my goal was to understand how mobile device vendors embed technological components from the open-source community into their own mobile platforms (cf. West 2003; West and Gallagher 2006). After noticing that the emergence of OSS in the industry raises both issues of cooperation and competition (see Bengtsson and Kock 2014), the focus was narrowed down to the understanding of "how competitors cooperate in the joint-development of open-source technologies." However, the empirical background was extended – I procured with my coauthors answers both from the mobile and the cloud computing industries. The phenomenon of collaboration among competitors in the open-source arena is gaining ground; many cases exist in the mobile and cloud computing industries[1].

Even if cooperation among competitors and OSS are phenomena with recognized impact on how value is created, explored, and exploited in networked settings, there are very few studies addressing how rival firms simultaneously cooperate and compete in the open-source arena (Germonprez et al. 2013). From a practitioner's viewpoint, this is unfortunate because naive assumptions concerning "work with competitors" and "open-source work" can lead in practice to opportunistic behavior such as free-riding, unintended spillover effects, and

[1] See either Table 4.3, page 60 or dissertation article 6, page 95 for a list sampling cases where rival firms cooperate in an open-source way.

loss of reputation and trust among partners.

1.3 Research aim, objectives and questions

The herein reported doctoral research aims to contribute by providing theoretical and practical knowledge regarding coopetition in open-source infrastructures[2]. More specifically, it aims to explore the notions of openness, collaboration, and competition in large-scale distributed open-source infrastructures (high-networked open-source projects where many firms and individuals collaborate and compete without centralized control structures).

With an initial primary purposive-focus on the mobile devices industry, the author pursued a number of objectives: The first objective was (1) to investigate the open-source strategies used by mobile devices vendors. Furthermore, (2) to provide a better understanding of how companies like Apple, Google, and Nokia integrate OSS technological components under public domain into their own platforms that power mobile devices. Moreover, (3) to complement the existing body of theoretical knowledge on OSS, mostly seeing the OSS artifacts as products and technology[3]. In addition, I and my coauthors pointed our lenses to the social communities behind OSS. Open-source projects were not simply seen as a product, as software, or as technology, but as socio-technical platforms, ecosystems, and infrastructures. Finally, it was also our objective (4) to narrate the emergence of OSS in mobile platforms such as Maemo, Meego, and Android that are empowering big corporations such as Google, Apple, Nokia, Intel and Samsung within the high-competitive mobile devices market. With a secondary and complementary purposive-focus on the cloud computing industry, this doctoral research seeks to increase our understanding of how competing firms simultaneously collaborate and compete in OpenStack – an open-source infrastructure for big data that empowers the data centers of NASA, CERN, HP, IBM, Rackspace, and many others.

Lessons were procured both from the mobile and the cloud computing industries, all toward a theory to understand how firms embrace the open-source community when developing digital platforms, ecosystems, and infrastructures.

[2]Openness and heterogeneity distinguish the employed "infrastructures" theoretical construct from applications, platforms, and ecosystems (Hanseth and Lyytinen 2010).

[3]Based on preliminary results of a systematic literature review – see dissertation article 1, page 90.

This doctoral dissertation encompasses the following exploratory research questions:

RQ1 – *How do rival firms collaborate in open-source infrastructures? How does the collaboration evolve over time? How is collaboration affected by exogenous events in the surrounding industrial market?*

RQ2 – *Is there a tendency toward sub-grouping in open-source infrastructures? With whom do developers tend to work? Are there different sub-communities within the infrastructure's community?*

RQ3 – *How does competition for the same revenue model (e.g., Rackspace vs. HP on public clouds, Citrix vs. VMware on virtualization technologies, Google vs. Apple in web-browsers) affect collaboration in open-source infrastructures?*

RQ4 – *Why do firms collaborate with competitors in the open-source arena? Why do they contribute to open-source infrastructures? What are the motivators?*

The research questions followed a What, How, and Why logic. The researcher strategically addressed first the What and How questions, without rushing to answer to the final Why question (RQ4)[4].

1.4 Intended audience

This dissertation was crafted to target two major audiences: First, the free and libre open-source software (FLOSS) research community and, second, the Information Systems (IS) research community. While the later represents an legitimate discipline by itself (i.e., IS labels the name of many university departments), FLOSS research is very multidisciplinary (i.e., open-source researchers can be found within the departments of Sociology, Economics, Management, Information Systems, Software Engineering and Computer Science) (Aksulu and Wade 2010; Crowston et al. 2012; Raasch et al. 2013).

Besides the FLOSS and IS communities, this research might interest as well other communities: 1) Coopetition scholars – the ones interested in cooperation

[4]We thank David Silverman for the suggestion of purposively delaying the "Why" type of research question

among competitors[5]; 2) Software Engineering scholars, as we follow the development of information systems over long periods of time employing both sociological and technological lenses; and 3) Network scientists, as we developed a multidisciplinary social network analysis method that leverages both knowledge on the mining of software repositories (from Software Engineering) and qualitative analysis of natural occurring data[6].

Regarding practice, this doctoral research "speaks" broadly to practitioners involved within R&D management activities, either within managerial roles (e.g., chief technology officer) or within more technical roles (e.g., software developer or systems integrator). Practitioners interested in co-creating value with the open-source communities (i.e., not ignoring the potential of cooperating within the open-source arena) should gain relevant insights from this doctoral dissertation.

1.5 Overview of contributions from original articles

I and my coauthors argue that this dissertation work produced some original contributions, as reported in the original articles. Here we provide an brief overview of each article contribution.

Article 1 This article holds the preliminary results of our efforts in conducting a systematic literature review of literature on OSS and platforms[7]. Through our systematic literature review efforts, we were able to identify prior seminal work on the topic that guided the overall doctoral research. Surprisingly, much of the recent research on mobile platforms seems to ignore much of what was learned from the PC platforms (i.e., new work regarding mobile platforms does not cite prior work on PC platforms). From our review of literature, we must highlight that OSS should no longer be associated with alternative low-cost products. Tables have turned; within the current mobile platforms war, vendors that integrate OSS capture the most value from the market. Players that solely rely on

[5] See Bengtsson and Kock (2014); Czakon et al. (2014a,1) for recent reviews on coopetition.

[6] See Domínguez and Hollstein (2014) for an extensive review on the design and applications of mixed methods social networks research.

[7] To our view, the "platform" concept approximates and overlaps with the concepts of "ecosystem" and "infrastructure." We perceive a lack of conceptual clarity on such concepts across the literature.

proprietary software, such as Microsoft and Blackberry, are currently struggling with "shrunk" sales on the mobile-devices market. Apple, Google, and Samsung, all integrating OSS into their platforms, are effectively dominating the market. Vendors integrating OSS also charge more for their high-end devices than their competitors. Existing literature associating OSS with the "alternative low cost" is misleading.

Article 2 This article results from our difficulties on understanding what openness means in a platforms/ecosystems setting. The most used characterization of OSS comes from the distribution license attached to it (e.g., GPL, MIT, Apache, BSD, and Creative Commons, among many others). The license characterization on what is open-source fits nicely with open-source products, but not with open-source platforms[8]. Addressing such lack of understanding of what openness means within an platforms/ecosystem settings, we grasped openness more holistically, both by acknowledging that openness means different things to different people and by involving all stakeholders within the platforms/ecosystems. Toward the development of a theory of openness within digital settings, we proposed six novel aspects of openness for enabling a greater understanding of the OSS movement with a platforms/ecosystems context.

Article 3 This article resulted from our efforts on understanding the implications of the OSS phenomenon to the competitive mobile platforms market. This forced me to first assess, "What are the OSS components integrated by Apple, Google and Nokia in their mobile platforms?" and review the open-source platform-based strategies employed by Apple, Google, and Nokia. The main contribution is a detailed description on how differently Apple, Google, and Nokia make use of OSS components and on how differently they cooperate with communities behind OSS (communities developing software under terms that encourage its integration within wider computer-based platforms). This article had implications for the forthcoming articles: First, it identified WebKit as a very central open-source component to the mobile-devices platform (integrated by most of the leading players in the industry). Second, such efforts provided me much empirical knowledge on the mobile devices industry – the primary

[8]Note that platforms such as Meego, Android, and iOS include hundreds of open-source components, each bound by its own license.

empirical domain of this doctoral study.

Article 4 Based on the finding reported in the Article 3, we selected the WebKit project as one interesting case of cooperation within the joint development of open-source technologies. We explored collaboration networks in the WebKit by mining WebKit's source-code repository (aka version-control-system) data with social network analysis (SNA). Our contributions highlight the explanation power from network visualizations capturing the collaborative dynamics of the WebKit high-networked software project over time[9]. We also discuss the fork concept as a nexus enabling both features of competition and collaboration and reveal the WebKit project as a valuable research site for studying how rival firms collaborate with competitors in the open-source community[10].

Article 5 After developing a method that worked well for WebKit (see Article 5)[11], we were interested in applying the same method to other open-source cases where many competitors cooperate in the open-source arena. In cooperation with other FLOSS researchers, we opted to select the OpenStack case where a plenitude of firms collaborate in the joint development of an open-source infrastructure for big data. We explored how rival firms collaborate in OpenStack by employing a multi-method approach that combines qualitative analysis of archival data, mining software repositories (MSR), and SNA. Our research contributed to literature in software ecosystems by exploring the role of groups and sub-communities within a high-networked open-source ecosystem. We also addressed a novel, complex, and previously unexplored[12] open-source case (i.e., OpenStack) and attempted to contribute to more managerial literature in coopetition strategy and high-tech entrepreneurship. To our knowledge, this was the first paper employing coopetition theoretical lenses within the context of Information Systems development (ISD).

[9]We argue that it is an methodological contribution, or at least a novel combination of multidisciplinary methods.

[10]The term open-coopetition was coined in this article.

[11]Article 5 was a runner-up paper (i.e., made it to the top 3) for the best paper award from the *ACM SIGMIS Computers and People Research conference* (CPR 2014).

[12]At that time little or no research addressing OpenStack was published. This is slowly changing; for example, at AIS ICIS 2016 there was at least two full papers discussing socio-technical issues within OpenStack.

Moreover, by its publication time, such paper was apparently the first paper to explore the concept of homophily (with strong roots in social network theory and anthropology) in the context of ISD bringing a much researched social concept (see Gallivan and Ahuja 2015) in the context of software development.

Article 6 As suggested by coauthors and reviewers of Article 5, our research should be communicated to management and strategy scholars as well. We attempted then, to communicate our findings to a less technical audience interested in cooperation among competitors. We crafted the article as a narrative, complemented with social network visualizations, exploring the evolution of cooperation and competition in OpenStack. Contributing to the literature on strategic networks, ecosystems, and portfolio of alliances, we suggested that development of transparency and weak intellectual property rights (i.e., characteristics of open-source ecosystems) allow a focal firm to transfer information and resources more easily between multiple alliances.

This doctoral dissertation is structured as follows: In the following chapter 2 relevant literature in FLOSS, coopetition, platforms, ecosystems, and digital infrastructures[13] is covered; In chapter 3 ontological, epistemological, and methodological issues are discussed; In chapter 4 the results are aggregated; In chapter 5 the results are analyzed and discussed in relation to the exiting literature; In chapter 6, the conclusion chapter, the most relevant findings are discussed; the addressed research questions are revisited; and the methodological, theoretical, and practical contributions of this doctoral research are outlined.

[13] As argued before, these last three concepts approximate each other. See chapter 2, page 24 for a distinction in accordance with existing literature.

2 Literature review

2.1 Setting the scene

This research reviews multidisciplinary literature. The primary review efforts targeted the IS literature. Given the transdisciplinary nature of research in OSS[1] in general, and this doctoral research in particular, I was forced to review much literature across the disciplines of Software Engineering, Management, Strategy, and Economics, among other disciplines. I started by reviewing the current body of theoretical knowledge in OSS as previously addressed by Feller and Fitzgerald (2002); Lerner and Tirole (2002) and Weber (2004) among many other scholars investigating open-source communities. Then, at a later stage, I aimed at integrating knowledge in OSS with knowledge in computer-based platforms and multi-sided platforms[2] (e.g., Gawer and Cusumano 2008; Hagiu and Wright 2011; Rochet and Tirole 2003).

2.2 Open-source software

2.2.1 Reviewing research in open-source software

The open-source phenomenon has attracted consistent attention from multidisciplinary scholars in recent decades (Feller and Fitzgerald 2002; Lerner and Tirole 2002; Raymond 1999). To illustrate the growing academic relevance of the open-source phenomenon, we observed that many prominent academic outlets, including *Research Policy*, *IEEE Network*, *IEEE Software*, *First Monday*,

[1] By employing the OSS term, over the Free Software and FLOSS alternative terms I emphasize open-source as a way of developing technology over the more purist view of free software as a social movement. See `http://www.fsf.org/philosophy/free-software-for-freedom.htm` for a related discussion.

[2] This forced me to cover much research using the "ecosystem" and "infrastructure" constructs as well. As argued before. the constructs of "platform," "ecosystem," and "infrastructure" approximate each other.

Criticism, *Management Science*, *Information Systems Journal* and the *Journal of the Association for Information Systems*, have recently published special issues on OSS. Moreover, several recent and comprehensive literature reviews have addressed the open-source phenomenon across a wide set of disciplines (Aksulu and Wade 2010; Crowston et al. 2012; Stol and Babar 2009; Øyvind Hauge et al. 2010).

In an attempt to explain such transdisciplinary attention, von Krogh and Spaeth (2007) proposed five characteristics for why OSS is particularly attractive for examination in various fields and disciplines using a plethora of research methods, as follows: (1) impact: OSS has an extensive impact on the economy and society; (2) theoretical tension: the phenomenon deviates from the predictions and explanations offered by established theory across different fields (e.g., intellectual property theory); (3) transparency: OSS has offered researchers unprecedented access to data; (4) communal reflexivity: the community of OSS developers frequently engage in dialogue on its functioning (it also has its own research community); and (5) proximity: the innovation process in OSS resembles knowledge production in science (in many instances, OSS is an output of research processes). Regarding point (2) (theoretical tension), open-source is particularity challenging to a wide set of views on organizations and strategic alliances that emphasize the concepts of property, contract, and/or transaction (which are in turn de-emphasized in OSS).

Regarding the review of OSS literature, a crucial part of this research, the author individually digested several recent and comprehensive literature reviews addressing the OSS phenomena (Aksulu and Wade 2010; Crowston et al. 2012; Lindman 2011; Stol and Babar 2009; Øyvind Hauge et al. 2010). A notable systematic literature review by Stol and Babar (2009), covering specialized conference proceedings, pointed out the heterogeneity and lack of empirical studies dealing with OSS in organizations. Another systematic literature review from Øyvind Hauge et al. (2010) confirmed the heterogeneity in which companies approach OSS, prompting lack of empirical research on OSS adoption in organizations. As part of his doctoral studies, Lindman (2011) extended the two previous mentioned reviews in yet another systematic literature review covering both open-source journals (Øyvind Hauge et al. 2010) and top Information Systems journals (Rainer Jr and Miller 2005). He argued that current body of knowledge emphasis on OSS community-driven development with limited interest on OSS within organizations. A detailed and comprehensive literature review by Aksulu and Wade (2010) paused and reflected on the state of open-source research; analyzed and categorized a wide-set of open-source research; and proposed a framework to situate OSS research within a wider nomological network while proposing future directions for open-source research. The more recent review by Crowston et al. (2012), covering literature across multiple disciplines, organized the OSS literature based on the input-mediator-output-input (IMOI) model from the small groups literature. Crowston et al. (2012) outlined many issues for future inquiry and called for more longitudinal studies[3].

To a very high degree, much research addressing the OSS phenomenon took a perspective of open-source as technology, a project, a process, or a product (see Teixeira and Baiyere 2014). Research taking more networked perspectives that do not ignore the social and organizational aspects of OSS communities[4] (e.g., within the context of platforms, ecosystems, or even infrastructures) remains scarce (Teixeira and Baiyere 2014)[5].

2.2.2 Chronicle on open-source research

Much of the innovative programming that powers software applications, operating systems, cloud servers, and the Internet is the result of "open-source" code – that is, code that is freely distributed as opposed to being kept secret.

Consistently across recent reviews (Aksulu and Wade 2010; Crowston et al. 2012; Teixeira and Baiyere 2014), there is a general consensus that "open-source" (also known as free-software or software libre) emerged with a set of four freedoms as suggested by Stallman (1985). These freedoms laid down the foundations for the OSS as known today: 1) the freedom to run the program, for any purpose; 2) the freedom to study how the program works and change it so it does your computing as you wish; 3) the freedom to redistribute copies so you can help your neighbor; and 4) the freedom to distribute copies of your modified versions to others. Programmers dealing practically with the phenomenon often explain it with simple shorthand: when we talk about free software, think "free-speech," not "free-bear." Or, in French, "libre" not "gratuit" (Weber 2004).

The free software idea did not immediately become mainstream, and industry

[3]This doctoral research was conducted longitudinally. After all, OSS communities are not static but evolve over time – the phoenomena needed to be studied while evolving.

[4]Carillo and Bernard (2015), in a recent critical review on OSS research, urges researchers to give more importance to the social aspects of open-source communities besides the software.

[5]See dissertation article 1, page 90, for more details.

was especially suspicious of it. In 1998, the "hacking" activists Bruce Perens and Eric Raymond agreed that a significant part of the problem resided in Stallman's term "free software," which might understandably have an ominous ring to the ears of business people. Accordingly they, along with other prominent hackers, founded the "open-source" software movement (Perens et al. 1999). "Open-source" software incorporates essentially the same licensing practices as those pioneered by the free software movement. It differs from that movement primarily on philosophical grounds, preferring to emphasize the practical benefits of such licensing practices over issues regarding the moral rightness and importance of granting users the freedoms offered by OSS (Lakhani and von Hippel 2003).

Both reflecting the freedoms and the practical benefits of OSS, open-source licenses guarantee users the right to access the program's source-code, the right to modify that source-code, and the right to redistribute the program, either in its original or modified form. Consequently, the reuse of source-code is very common in OSS (see Haefliger et al. 2008) — a commons body of code is "built up as a feedstock for reuse and innovation, presumably lowering development costs for companies in the market" (Weber 2004, pp. 206) thus reducing duplication efforts. A less common, yet arguably significant, consequence of freedoms of OSS is code forking. A fork occurs when an existing program is used as the basis for a new development effort. Forking is an essential event shaping open-source communities (Gamalielsson and Lundell 2014; Nyman and Lindman 2013); it reflects the freedom of allowing anyone to create derivative works for any purpose. Such freedom is granted by all open-source licenses approved by OSI[6]. Forks may occur for a number of different reasons, but the motivations behind them are commonly of a pragmatic and noncompetitive nature Nyman and Mikkonen (2011); Robles and González-Barahona (2012).

Taking an industrial economics perspective, the economists Lerner and Tirole have recurrently accounted OSS[7]. Most of their research was driven by the paradox of *"Why should thousand of top-notch programmers contribute freely to the provision of a public good?"* (Lerner et al. 2006; Lerner and Tirole 2002).

[6]See `https://opensource.org/licenses.`

[7]The economists Lerner and Tirole have been particularly curious about the OSS phenomenon, they had proposed a number of theoretical models that were exemplified with empirical cases (e.g., Linux and Apache). See among others (Lerner and Tirole 2001), (Lerner and Tirole 2002), (Peyrache et al. 2002), (Lerner and Tirole 2005b), (Lerner and Tirole 2004), (Lerner and Tirole 2005a), and (Lerner et al. 2006).

Taking the perspective of individual programmers that contribute freely to the provision of the public good, early findings point out the following: 1) the value of recognizing and rewarding contributors' work is a key motivator within the open-source process (Lerner and Tirole 2002); 2) participants benefit with an opportunity to enhance their reputation among their peers; 3) an opportunity exists to improve their "development" performance; 4) there can be intrinsic pleasure from a "cool" open-source project that can be fun; and 5) in the long run, open-source contributions may lead to future job offers (Lerner et al. 2006).

Besides theorizing on the motivations of individual programmers, the same economists also took a corporate perspective, highlighting some of the varied reasons for why firms may choose to become involved with OSS. These include 1) the ability to leverage expertise in a proprietary segment of the market that is complementary to an open-source program; 2) in the case that a firm's product directly competes with an open-source product, that they may encourage their programmers to participate in open-source projects to learn about the product's strengths and weaknesses; 3) the opportunity to learn about potential employees when their staff interacts with open-source programmers; and 4) a chance to generate good public relations with communities of programmers (Lerner et al. 2006). In an academic analogy, the economists remark that *"open-source and academia have many parallels: the most obvious parallel relates to motivation. As in open-source, the direct financial returns from writing academic articles are typically nonexistent, but career concerns and the desire for peer recognition provide powerful inducements"* (Lerner and Tirole 2004).

Even if the mentioned analytical modeling articles from Lerner and Tirole got considerable attention from academia (evidenced by the number of citations and Tirole's 2014 award of Nobel Prize in Economic Sciences). However, contrary to expectations, the empirical work on motivations has found little evidence of the proposed individual and firm motivations (Crowston et al. 2012; David and Shapiro 2008; Fang and Neufeld 2009; Freeman 2007; Roberts et al. 2006; Shah 2006; Wu et al. 2007). The existing research has actually shown that as many as 45 percent of contributors were paid by firms for their participation (Hertel et al. 2003) and about 38 percent of the developers carried open-source programming during their regular working hours, although this did not imply that this work was part of their official jobs (Hars and Ou 2001). Shah (2006) remarked that individual motivations evolve over time and are strongly affected by the governance structure of the community. Even though scholars have addressed why individuals and firms contribute to OSS projects, to the best of our knowledge, there are no studies taking the network perspective by inquiring why firms establish strategic alliances to jointly develop open-source technologies.

From an innovation studies perspective, the early works of Lakhani and von Hippel suggested that OSS development shows that users program to solve their own as well as shared technical problems and freely reveal their innovations without appropriating private returns from selling the software (see Lakhani and von Hippel 2003; von Hippel 2009). The motivation of contributors to conduct ″free” work can be partially explained by the developers’ "possibility of gaining reputation and related benefits through helping" Lakhani and von Hippel (2003). Such "free" user-to-user assistance has turned open-source into a remarkable example of user-innovation (von Hippel 2009). It was also reported that the open-source trend has been so strong that previous, rather monolithic, organizations (e.g., SAP, Intel, Apple, Philips, Xerox, and IBM among others) decentralized research labs, opened up proprietary technology, and increased their absorptive capacity for outside-in innovation processes within open-source ecosystems (Chesbrough et al. 2006; Enkel et al. 2009; Gassmann et al. 2010).

From an organizational perspective, von Hippel and Krogh (2003) also propose that OSS development is an example of a compound model of innovation that contains elements of both the private investment and the collective action models. They also argue that addressing OSS may lead to a substantial rethinking of the concept of "organization for innovation" and a better understanding of innovation among distributed users who derive utility from freely revealing their information-based innovation to produce a collective good.

Within the software world, there is some agreement that open-source refers to products under a license approved by the Open Source Initiative (Fitzgerald 2006; Lerner and Tirole 2005b; West and Gallagher 2006). However, outside the software world (e.g., hardware, services, platforms, ecosystems), what is meant by "open-source" and "openness" is rather blurry (Teixeira 2015b)[8]. Given the rise of open-source outside the software domain, and given the lack of consensus over the meaning of openness (Grubb and Easterbrook 2011), I proposed six dimensions of openness within high-networked socio-technical ecosystems. The six dimensions emphasize 1) architectural openness (hardware and software); 2) compliance with standards; 3) transparency and inclusiveness of governance; 4) free market policies rewarding innovation and entrepreneurship; 5) the absence

[8]See dissertation article 2, page 90, for more details.

of purposive lock-in mechanisms; and 6) an open regime of intellectual property (see Teixeira 2015b).

The OSS phenomenon keeps evolving from the earliest purist views focusing on freedom (Stallman 1985) to newer perspectives considering open-source as an alternative and viable way of doing business (Agerfalk and Fitzgerald 2008; Feller and Fitzgerald 2002; Fitzgerald 2006). Moreover, the phenomenon has expanded from OSS to open data (Gurstein 2011; Janssen et al. 2012), open hardware (Maharaj et al. 2008; Söderberg 2013), open knowledge (Awazu and Desouza 2004), open-access (Antelman 2004; Davis et al. 2008; Swan 2007), open science (David 1998; Fabrizio and Di Minin 2008; Nosek et al. 2015), and open medicine (Bradner 2011; OMI 2015), among other manifestations of increasing openness in the way of doing things.

Even if the open-source phenomenon started to attract early scholarly attention in computer science and software engineering, the phenomenon is more recently capturing the most interest from business and management scholars (Raasch et al. 2013). Naturally, and as pointed out by Carillo and Bernard (2015) and von Krogh and Spaeth (2007), IS as a discipline is well positioned to be at the center of transdisciplinary research addressing the phenomenon.

2.2.3 Open-source software under a network perspective

As previously mentioned, research addressing the OSS phenomenon had attracted steady attention from multidisciplinary scholars in recent decades, and a wide variety of paradigms and research approaches were employed to better understand the phenomenon (Aksulu and Wade 2010; Carillo and Bernard 2015; Crowston et al. 2012; von Krogh and Spaeth 2007). In this research, I and my coauthors built upon research that had leveraged the relational perspective to study the open-source phenomenon, mostly by applying the network approach on top of digital trace data (see Crowston and Howison 2005; Lopez-Fernandez et al. 2004; Valverde and Solé 2007; Xu et al. 2006, among many others that "mined" software development repositories and/or email data in bug-fixing contexts).

However, we must note, that socio-technological analysis addressing collaboration[9] within large-scale OSS projects tends to adopt either of the two

[9]Note that we use the terms "collaboration" and "cooperation" interchangeably. During my doctoral research efforts, I did not recognize any difference between these two concepts, treating them as synonymous.

equally unsatisfactory alternatives: (1) providing thick qualitative descriptions of selected cases, thus overlooking the actors, actions, and interdependent patterns of the collaborative network (e.g., Bonaccorsi et al. 2006; Lerner and Tirole 2002; Mian et al. 2011); or (2) reducing figurational complexity to a set of quantitative indicators from a static network, thus disfiguring the practical purposes of the contextual and evolving phenomena under investigation (e.g., Crowston and Howison 2005; Lopez-Fernandez et al. 2004; Xu et al. 2006).

The potential of the relational network approach was also exploited in this research. However, unlike most of the above-mentioned research considering a single static cooperative network (i.e., analyzing an unique snapshot), we adopted a longitudinal view as we are more interested in how the collaboration network evolves over time – an evolutionary perspective. Moreover, my doctoral research departs from prior related network research by addressing not only collaborative issues, but also competitive issues present in large, complex and high-networked open-source projects. More concretely, rather than analyzing solely the social network of a given OSS community, I also acknowledged key actors and actions on the higher level of the industry, seeking to understand how key competitive-cooperative events in the industry have affected the technology and the social network intertwined within it. Rather than solely extracting quantitative indicators from the collaborative network by solely looking at IT artifacts, I also look at its surrounding industrial environment, seeking to understand how different happenings on the industry shaped the collaboration network developing the same IT artifacts. We then leveraged the distinctive advantages of the network approach and its ability to bring together quantitative, qualitative, and graphical analyses as advocated by organizational scholars (see Ibarra et al. 2005).

2.3 Coopetition

2.3.1 Theoretical foundations of coopetition

Within management strategy literature, the hybrid behavior comprising competition and cooperation has been named coopetition. A number of authors (Gnyawali and Madhavan 2001; Gnyawali and Park 2009; Lado et al. 1997; Nalebuff and Brandenburger 1996) among others, have emphasized the increasing importance of coopetition both for today's networked business and networked scientific investigation.

According to Dagnino and Padula (2009), the term 'coopetition' was coined by Raymond Noorda, former CEO of Novell, and introduced into research by Brandenburger and Stuart (1996) and Nalebuff and Brandenburger (1996). The current coopetition body of knowledge argues that competitors can be involved in both cooperative and competitive relationships with each other simultaneously while benefiting from both in a symbiotic way. Coopetitive relationships are complex and hard to manage as they consist of two diametrically opposed logics of interaction (Tidström 2009).

Early theoretical foundations of coopetition (see Bengtsson and Kock 2000) suggested that firms tend to more frequently cooperate in activities carried out at a greater distance from buyers and compete in activities closer to buyers. From a strategic point of view, this means that R&D activities are best suitable to be developed in cooperation with a competitor, but when it comes to marketing a new product, competitors choose to compete to distinguish the products from each other (Bengtsson and Kock 2000). A core driving force behind this behavior is the heterogeneity of resources, as each competitor holds unique resources that are best utilized in combination with other competitors' resources (Bengtsson and Kock 2000; Gnyawali and Park 2009). Other driving forces are shorter product life cycles, convergence of multiple technologies and increasing R&D and capital expenditures (Gnyawali and Park 2009); rapidly changing consumer preferences; and the speed and magnitude of technological changes (Deeds and Hill 1996). Additionally, firms need to speed-up their innovation efforts (Cassiman et al. 2009; Lynn and Akgün 1998) and aim at setting up standards and platforms (Gawer 2010; Gomes-Casseres 1994; Gueguen and Isckia 2011). Thanks to advancements in managerial research in coopetition, much is known about coopetitive relationships among individuals and among firms. However, competition among networks remains largely unexplored (Bengtsson and Kock 2014). In addition, the role of information systems in the orchestration of coopetitive relationships remains *terra incognita* (Yami et al. 2010).

The "coopetition" managerial term is quite abstract, and its definition may vary from discipline to discipline and author to author. In this dissertation, as in (Bengtsson and Kock 2000), I define coopetition as a paradoxical relationship between two or more actors simultaneously involved in cooperative and competitive interactions. I also clarify competitors as actors that produce and market the same products[10]. Competition is very often a core concept within

[10]A narrower concept than the one used by Nalebuff and Brandenburger (1996), however broader

economic theory; while on the other hand, collaboration is more often more present in literature within strategic alliances, standards and innovation studies. Economic theory on competition, built on the Schumpeterian tradition, gives insight into the advantages provided by intense rivalry between firms (D'Aveni 1994; Ilinitch et al. 1996). Intense competition is argued to be a central driving element in pressuring and stimulating firms to innovate and upgrade their competitive advantage. In this way, rivalry sharpens the "struggle" between competitors and therefore increases the dynamics within an industry (Bengtsson and Kock 2000).

On the other side, it is argued in economic theory that cooperation hampers competition, and antitrust law is seen as necessary to guarantee healthy competition (Bengtsson and Kock 2000). However, strategic alliance theorists contributed to a broader understanding of competition by pointing out that competitors on many occasions cooperate with each other (Bucklin and Sengupta 1993; Chen 2008; Chen and Miller 2015; Ring and Van de Ven 1992). If many economists argue that inter-firm rivalry and conflict drive innovation and firm's success, many within management strategy see rivalry and conflict as a threat because they can hamper the performance of a strategic alliance (Bengtsson and Kock 2014). While bridging economics and strategy, Caves and Porter (1977) point out that competition within strategic groups is less intensive than between strategic groups.

Both in traditional economic theories on competition and in the literature on strategic alliances, the assumption has been that cooperation in the first case and competition in the second case needs to be minimized, in order to get competition and cooperation to work. However, the possibility of combining cooperation and competition has recognized advantages. Lei and Slocum (1992) as well as Mason (1993) argue that firms, through cooperation in strategic alliances, can complement and enhance each other in different areas such as production, introduction of new products, or entry into new markets. On the other hand, Dyer et al. (2001) identified advantages related to the reduction of firms' costs and risks through the formation of strategic alliances. A third advantage pointed out in the literature is the possibility of technological and capability transfer within alliances (Bengtsson and Kock 2000; Berg et al. 1982; Doz 1987; Hamel et al. 1989). Even if the advantages of coopetition are well-recognized, there is a clear lack of research addressing coopetition

than the one used by Bengtsson and Kock (2000) in the technological sector in general, and software development in particular (Pellegrin-Boucher et al. 2013).

2.3.2 Coopetition in the technological sector

According to recent reviews on the motives and outcomes of coopetition (Bengtsson et al. 2013; Bengtsson and Kock 2014) firms benefit from coopetition with: (1) increased competitiveness and competitive advantages; (2) development of technological innovations, (3) exploration of international opportunities, and (4) access to needed resources. The high-tech sector in general, and the mobile-devices industry in particular, are often characterized by technological complexity, turbulent competitive scenarios and pressure to innovate continuously. Therefore, firms in the high-tech sector are among the ones that benefit most from considering coopetition.

Even though the existing literature addressing coopetition in the technological sector is still scarce, there is a growing stream of research addressing coopetition grounded in empirical material from the technological sector. For instance, Luo (2007) described how Nokia, Eriksson, and Motorola cooperated to improve the Chinese telecom infrastructure (i.e. coopetition for the exploitation of international opportunities) while competing on the same market with different mobile devices. These firms collaborated with a common goal of new market creation while sharing risks and resources. On the LCD-TV markets, Sony and Samsung cooperated strongly in R&D and manufacturing while commercializing innovative flat-screen TVs. Addressing this collaboration among high-tech giants, Gnyawali and Park (2011) found that both Sony and Samsung were able to reap major benefits from applying coopetitive elements in their strategy.

By examining data from Taiwanese firms in the information and communication technology industry, Huang and Yu (2011) suggested that R&D collaboration, either noncompetitive or competitive, enables firms' innovation performance. Addressing the manufacturing of telecommunication satellites – one of the most competitive segments of the space aircraft industry – Fernandez et al. (2014) pointed out that coopetition is filled with tension due to inherent contradictory and opposing forces. They contributed a conceptual framework that increases the understanding of the key drivers of tension in coopetition and key approaches to cope with it. Using empirical data from the semiconductor industry, Park et al. (2014) examined the delicate balance between competition and cooperation and its effects on innovation performance. The authors concluded that competition and cooperation intensities have a nonmonotonic positive relationship with firms' coopetition-based innovation performance. The European wireless telecommunication sector was addressed by Yami and Nemeh (2014), who proposed a framework that clarifies links between forms of coopetition and innovation.

Collaboration at the infrastructure level, while maintaining competition at the end-user level, is not uncommon in the technology sector. Ritala et al. (2014) mentioned the historical AIM alliance (i.e., Apple, IBM, Motorola) in the 1990s, which competed in the microprocessor industry with its RISC architecture. While IBM and Apple were competing in the PC market at the time, the cooperation at the infrastructural level challenged the dominance of Microsoft and Intel with the so-called "Wintel monopoly" and its CISC architectural legacy. The same authors also provide the example of Amazon.com that offers technological services to competitors through its Marketplace and Web Services IT infrastructures. Similarly, in a recent paper, Rusko (2014) addressed coopetition with secondary data in the mobile-devices industries by exploring the strategic networks between smartphone producers and operating systems.

2.3.3 Coopetition under a network-perspective

The network-perspective is strongly embedded in the theories of coopetition as they explore relationships among individuals, firms and networks (Bengtsson and Kock 2014). For example, Powell et al. (1996) explored learning and knowledge sharing through networks. The importance of network characteristics and positions for the joint development of competitive advantages was deeply investigated by Gnyawali and Madhavan (2001) as well. More recently, Dagnino et al. (2008) identified key determinants that constrain the emergence, morphology, and evolutionary dynamics of interfirm networks. Now that firms are changing from a former industrial logic focusing on internal resources to a new logic based on the ability to integrate external resources through networks (Chesbrough 2003; Enkel et al. 2009), the network perspective gains strong momentum.

As coopetition addresses networked relationships that are becoming increasingly important to firms, the mathematical but nonstatistical method of SNA (Scott 2012; Wasserman and Faust 1994) is particularly well-suited for investigating coopetition under a network perspective. SNA is a re-emergent method widely established across the disciplines of social sciences in general (Borgatti and Foster 2003; Uzzi 1996; Wasserman and Faust 1994; Watts 2004) and marketing in particular (Arabie and Wind 1994; Iacobucci 1996; Li and Shiu 2012; Pitt et al. 2006; Watts and Dodds 2007). Besides increasing recognition of SNA as a valuable research method, there are still few studies on coopetition leveraging the method of SNA addressing either coopetition or open-source research.

Using data from the global steel industry, Gnyawali et al. (2006) modeled the relationships of firms within strategic alliances exploring cooperative ties between competitors. They suggested that differential structural positions among firms in a coopetitive network reflect resource asymmetries among them. Moreover, they also suggest that such asymmetries lead to differences in the volume and diversity of competitive actions undertaken by those firms. Also under a network perspective, Tsai (2002) investigated the effectiveness of coordination mechanisms on knowledge sharing in intrafirm networks that consist of both collaborative and competitive ties among organizational units. The author reported that a formal hierarchical structure, in the form of centralization, has a significant negative effect on knowledge sharing. Moreover, informal lateral relations, in the form of social interaction, have a significant positive effect on knowledge sharing among coopetitive units.

Within an underexplored coopetitive territory, virtual platforms emerge as a strong support for coopetition. In Hutter et al. (2011) work investigating the OSRAM online contest for new LED ideas and designs, a virtual platform allows users to competitively pitch ideas to firms while collaborating with like-minded peers (i.e., communicating, discussing, and sharing their insights and experiences). Meanwhile, through the same platform, they are also able to build social networks and establish a cooperative sense of community. By employing SNA over digital trace data logs from the IT infrastructure server supporting the online contest, they found that users with more central cooperative network positions are characterized by active engagement in commenting designs from others, active sharing of their experiences, and high involvement in conversations with other designers in the contest (Hutter et al. 2011).

2.4 Platforms, ecosystems, and digital infrastructures

Academics have long been examining open-source using the platforms and ecosystems constructs. Some investigate interfirm relations in the mobile ecosystems (Basole 2009); some review the open-source strategies employed by different platform vendors (West 2003); some benchmark the architectural openness of different platform stacks (Anvaari and Jansen 2010); and many others take the view of software developers by investigating their perceptions of platform openness (Hilkert et al. 2011)[11]. This dissertation also made use of the platform and ecosystem terminology. However, we also used a third notion of digital infrastructures which emerged more recently in the IS literature[12].

As organizations and information systems become more interconnected (Ciborra 2000), emerging literature has adopted the notion of infrastructure as a way of conceptualizing interconnected system collectives over stand-alone information systems (Henfridsson and Bygstad 2013). Emergent sociotechnological properties such as openness, heterogeneity, organization, and control, among others, distinguish digital infrastructures from the more often addressed applications, platforms, and ecosystems (Hanseth and Lyytinen 2010). Digital infrastructure is a very heterogeneous conceptual term, aggregating many definitions, research streams, philosophical traditions, and theoretical roots (Henfridsson and Bygstad 2013). In this research, we adopt the definition commonly employed by Hanseth and Lyytinen (2010) and Tilson et al. (2010) of digital infrastructures as shared, unbounded, heterogeneous, open, and evolving sociotechnical systems comprising an installed base of diverse information technology capabilities and their user, operations, and design communities.

According to Elaluf-Calderwood et al. (2011), digital infrastructures are established and operated by a heterogeneous collection of public and private organizations, each governed by its interests in the collaborative arrangement. Digital infrastructures are a new species of artifact. They bundle both industries and products that transform industrial organizations and services as industries undergo comprehensive digitalization. Such transformation is now taking place at a rate and with a scope that no longer allows the taking of traditional IS

[11] See Shuradze et al. (2015) for a recent review on "technological platforms" and their relationship with innovation.

[12] A recent review on "digital infrastructures" by Tilson et al. (2010) organizes future research avenues for IS research. It was pinpointed that firms must constantly ask "what needs to remain open and what needs to be closed in a digital product platform."

approaches and research questions for granted (Tilson et al. 2010). Therefore, Information Systems research cannot limit itself to the study of infrastructural artifacts in isolation but must extend investigations into the traditional core of the discipline (Tilson et al. 2010). It is acknowledged that OSS lowers costs and encourages a global and wide participation in both service production and distribution, however for better understanding the paradoxical control of digital infrastructures, more research is needed on how open-source levers the evolution of digital infrastructures (Tilson et al. 2010).

This research employed three similar (but yet different) constructs to refer to selected units of analysis (e.g, WebKit, OpenStack): platforms, ecosystems, and digital infrastructures. But, *why use three different constructs?* – different constructs emphasize different facets of the units of analysis. By "platforms," we emphasize the technologies that enable the creation of third-party products and services; by "ecosystems," we emphasize the networks of companies interacting with each other, directly and indirectly, to provide a broad array of products and services; and by "digital infrastructures," we emphasized the openness and heterogeneity of large, complex and evolving sociotechnical systems. The use of different constructs also facilitated the academic debate by adopting common and shared languages (i.e., different scholars might refer to the the same, or similar, things using different terminology).

I must remark that other possible constructs were also identified. I my and my co-authors view, platforms, ecosystems and digital infrastructures approximate what others called "networked collaborations" (Normann and Ramirez 1993); "lattices" (Gore 1985); "webs" (Hastings 1993); "constellations" (Normann and Ramirez 1994); "holonic organizations" (McHugh et al. 1995); "interfaces" (Gilmore and Krantz 1991); "organization networks" (Perrow 1972); and "interorganizational domain" (Trist 1977,7).

2.5 Defining key concepts

This study integrates with previous research on OSS, coopetition, platforms, ecosystems, and digital infrastructures (see Bengtsson and Kock 2014; Crowston et al. 2012; Manikas and Hansen 2013; Shuradze et al. 2015; Suominen et al. 2016; Tilson et al. 2010, for recent reviews on such topics).

Across prior related research, the same concepts are often constructed in distinct ways, but they mean different things from researcher to researcher and from discipline to discipline. For example, some define OSS as those systems that give users free access to and the right to modify their source-code (Manikas and Hansen 2013); others see OSS as software that is made available along with source-code at no cost (Crofts et al. 2005). Regarding coopetition, Bengtsson and Kock (2000) see competitors as actors who produce and market the same products; this contrasts with the original and broader view of Nalebuff and Brandenburger (1996) that stated that "a player is your competitor if customers value your product less when they have the other player's product than when they have your product alone."

Especially within literature on platforms, ecosystems and digital infrastructures, *what is what* is not always crystal clear. There is much conceptual overlapping. For instance, Ghazawneh and Henfridsson (2011) defined platform as a set of interrelated specification layers that support interoperability between the technological modules of a system. On the other hand, West (2003) defined platform as an architecture of related standards controlled by one or more sponsoring firms. Regarding the ecosystems construct that attempts to make the inter-firm network dependencies more explicit, Basole (2009) characterized an ecosystem as a network of companies interacting with each other, directly and indirectly, to provide a broad array of products and services to end customers. Guided by earlier work of Cusumano and Gawer (2002), Tiwana et al. (2010) conceptualized ecosystems as "the collection of the platform and the modules specific to it" – thus proposing ecosystems as enveloping platforms and its complements. Regarding digital infrastructures, they were defined early on by Tilson et al. (2010) as "basic information technologies and organizational structures, along with the related services and facilities necessary for an enterprise or industry to function." On the other hand, more morphologically, Hanseth and Lyytinen (2010) defined digital infrastructures as "shared, open, heterogeneous and evolving socio-technical system of Information Technology (IT) capabilities."

Even if this research started by dealing with the platform and ecosystem concepts, I later recognized that the units of analysis of this doctoral research (see Section 3.4) were established and operated by a heterogeneous collection of public and private organizations. Moreover, they are very open and heterogeneous while involving many diverse actors. As research evolved, we started recognizing that we were dealing with the digital infrastructures that, in our view, are special cases of platforms and ecosystems.

As this research is built on top of prior theoretical work dealing with previously defined concepts, in Table 2.1 we list the original sources that guided our conceptualizations.

Table 2.1: References guiding key conceptualizations.

Article	Open-Source	Coopetition	Platform	Ecosystem
Article 1	The four freedoms of Stallman;[a] the Debian social contract[b] and the OSI open-source definition.[c]	NC	The concept of computer-based platform consisting of "an architecture of related standards controlled by one or more sponsoring firm".[d]	"platform leader and its complementors form an 'ecosystem' for innovation".[e]
Article 2	The compliance with an OSI approved license.[f]	NC	"technologies that enable the creation of third- party products and services."	"networks of companies interacting with each other, directly and indirectly, to provide a broad array of products and services."
Article 3	The four freedoms of Stallman;[a] and "volunteer developers collaborating over Internet in a distributed 'organization' toward a common goal. Representing a more efficient way than the traditional hierarchical and controlled way used by corporate software house".[g]	NC	"Platforms as 'systems of technologies that combine core components with complementary products and services habitually made by a variety of firms (complementers)'".[e]	"platform leader and its complementors form an 'ecosystem' for innovation".[e]

(continues next page)

Article 4	NC	NC	NC	"a complex network of companies interacting with each other, directly and indirectly, to provide a broad array of products and services"[h].
Article 5	NC	"hybrid behavior comprising competition and cooperation"[i].	NC	"a networked community of individuals and organizations, which base their relations to each other on mutual interest"
Article 6	The four freedoms of Stallman[a], the Debian social contract[b], the OSI open-source definition[c]	"hybrid behavior comprising competition and cooperation"[i].	NC	"networked interdependencies of the firm"[j] and "actor-to-actor networked relationships"[k].

NC stands for **not explicitly conceptualized** within the dissertation article with an explicit definition.
[a] See Stallman (1985).
[b] See Debian (2004).
[c] See Perens et al. (1999).
[d] See Bresnahan and Greenstein (1999); Ferguson and Morris (2002); West (2003).
[e] See Gawer and Cusumano (2008).
[f] See O'Reilly (1999).
[g] See Raymond (2001).
[h] See Adner and Kapoor (2010); Autio and Thomas (2014); Basole (2009).
[i] See Bengtsson and Kock (2000,1); Gnyawali and Madhavan (2001); Gnyawali and Park (2009); Lado et al. (1997); Nalebuff and Brandenburger (1996).
[j] See Adner and Kapoor (2010).
[k] See Iansiti and Levien (2004); Moore (1996).

3 Methodological approach

After introducing and motivating my doctoral research and reviewing relevant literature, in this Chapter 3, I here disclose the methodological details of the executed doctoral research. I and my coauthors did not use one single method but rather combined several of them. Furthermore, this dissertation "borrowed" methods that are established across different disciplines (e.g., visualization of collaborative networks – established in social studies of science; mining of software repositories – established in software engineering). We employed a plenitude of ontologies, epistemologies, and methods that are available to FLOSS and IS researchers.

3.1 Ontological and epistemological orientation

I committed early on to an article-collection dissertation strategy[1]. I did not follow a single epistemological and ontological trajectory. Rather than choosing a particular research approach apriori of the field work, I and my coauthors adopted different approaches for each paper while pursuing epistemological consistency on each individual research project. We took the stance of pluralists (see Mingers 2004) by employing multidimensional research strategies (Mason 2006), that is, accepting and adopting a wide variety of paradigms and research approaches on the same topic (Mingers 2001).

Driven by What, How, and Why research questions, the approach of this research is mostly qualitative, even if much quantitative evidence was integrated as well. Most of the original articles were crafted as positivist case studies (Dubé and Paré 2003; Eisenhardt 1989; Yin 2008)[2]. Our qualitative research efforts were conducted according to ethnographic principles that empower

[1] The article-collection format is becoming a standard in the Nordic countries and it allows an easier integration of research conducted in collaboration with other scholars.

[2] Even if we went in a positivist way, we also acknowledge the value of interpretative case study research (Klein and Myers 1999; Walsham 1995).

data collection with limited influence from the established body of theoretical knowledge (Atkinson 2006; Myers 1999). The author was more interested in building theoretical propositions than in building variance-based models (see Benbasat et al. 1987; Markus and Robey 1988; Myers 1997; Urquhart and Fernández 2013). Inspired by ethnographic studies, the theoretical integration was performed mostly *a posteriori* of the field work and data collection. Most of the ethnographic work was virtual; physical proximity with key actors within the selected cases was important but very limited. Given that this research was executed within the doctoral studies scope, many of the existing theories explaining the observed phenomenon were discovered from the literature after collecting the data.

Much of the analysis was based on SNA, and we try to not engage in the ongoing academic debate on whether SNA analytic methods are quantitative or qualitative. Here, we take the stance of Brandes et al. (2013) that remarked that network analysis is neither purely quantitative nor qualitative. Even though the foundations of network science are mathematical and quantitative, the qualitative approach is perhaps even more sensitive to the issues of connectivity, systematicity, and dependence. The point is not whether one is researching in a qualitative or quantitative way, but that the understanding of the phenomenon treats relational connectivity and dependence as central (Brandes et al. 2013). As indicated by Carrington (2014) "the fundamental quest is to understand the structure of the network, which is neither a quantity nor a quality." As recognized by organizational research scholars, the network approach is distinctive by its ability to bring together quantitative, qualitative, and graphical analyses (Ibarra et al. 2005). In this sense, as SNA studies often integrate qualitative and quantitative data in mixed methods approaches (Hollstein 2014), the appropriation of network science by the IS community should decrease the *Qual. vs Quant.* divide (see Chen and Hirschheim 2004; Howison et al. 2011; Venkatesh et al. 2013).

3.2 Multidisciplinary and mixed-methods approach

I and my coauthors engaged in a multidisciplinary approach while employing a multitude of research methods (Ågerfalk 2013; Chen and Hirschheim 2004; Venkatesh et al. 2013). For example, a lot of Internet data was scrutinized under the guidance of methodological notes on Netnography (aka virtual ethnography), an established method for the study of online communities that got established in marketing (see Kozinets 2009). Techniques for the mining of software version and revision control systems, which are established in Software Engineering[3], were extensively used. The core methodological approach of this dissertation, Social Network Analysis (SNA), is a re-emergent method that is getting widely established across disciplines such physics, mathematics, computer science, biomedicine, anthropology, innovation studies, and many other disciplines (Wasserman and Faust 1994). Table 3.1 captures our cross-disciplinary orientation that celebrates the use and combination of different research methods on the same topic (Mingers 2001,0). The mixed methods design[4] was often parallel (i.e., methods were employed concurrently) and inferences from each method informed each other (see Bellotti 2014; Hollstein 2014).

3.3 Employed methodologies

I built much of my methodological awareness both by attending doctoral-level courses and seminars and by reviewing a number of methodological books. The most influential course/seminar was the one conducted by Professors Sudha Ram (University of Arizona) and Matti Rossi (Aalto University) entitled *Big Data and Social Media Analytics*[5] – the idea of mining open-source project source-code with SNA emerged in this seminar in a joint exercise with Lin Tingting and Salman Mian (now co-authors). Five books were revealed to be extremely influential. In the following chronological order, they are: (1) Silverman (2009) – an overview of qualitative research, (2) Eriksson and Kovalainen (2008) – an overview of qualitative research within management studies, (3) Myers and Avison (2002) – an overview of qualitative research in IS, (4) Wasserman and Faust (1994) – a seminal reference in SNA, and (5) Domínguez and Hollstein (2014) – a recent edited volume demonstrating the potential of mixed-methods designs for the research of social networks. All are widely recognized qualitative and SNA research methodology books that have influenced research in social sciences, business studies, and IS.

[3] The *Working Conference on Mining Software Repositories (MSR)*, currently in its 11th edition, is the main conference in the area.

[4] The dissertation articles 4-6 discuss the use of multiple methods explicitly.

[5] Description of the event is available at `http://inforte.jyu.fi/events/bigdata_sna`.

Also included, the Table 3.1 summarizes the research questions, methods, and methodological sources driving each individual research project. Fine-grained methodological details are reported for each dissertation article bundled in this doctoral dissertation.

Table 3.1: Methods employed in each article/research-question

Article	Research Question	Method	Methodological references
1	**What** do we know about open-source and platforms?	Literature review	Webster and Watson (2002) Järvinen (2008) Vom Brocke et al. (2009) Okoli and Schabram (2010)
2	**What** do we mean by openness in the context of platforms, ecosystems and digital infrastructures?	Conceptual article[a]	Conceptual article[a]
3	**What** are the OSS implications in the competitive mobile platforms market?[b]	Descriptive case-study	Yin (2008) Flyvbjerg (2006) Seaman (1999) Romano et al. (2003)
4	**How** actors collaborate in the joint development of the WebKit project?[cd]	Mix-methods case-study	Myers (1999) Wasserman and Faust (1994) Scott (2012) Xu et al. (2006)
5	**How** do actors simultaneously collaborate and compete within the development of the OpenStack project?[de]	Mix-methods case-study	Yin (2008) Eisenhardt (1989) Wasserman and Faust (1994) Howison et al. (2011) Nick et al. (2013)
6	**How** does cooperation among competitors evolve within an open-source ecosystem?[bd] and **Why** open-coopetition?[g]		

[a] Conceptual article – Review of selected literature with no empirical work.
[b] Such a question is related to the research questions RQ1 and RQ4 from the overall dissertation – **Why and How** type of questions.
[c] Such question is related to the research questions RQ1, RQ2 and RQ4 from the overall dissertation – **Why and How** type of questions.
[d] Exploratory research question. Emerged along with the investigation.
[e] Such a question is related to the research questions RQ1, RQ2 and RQ3 from the overall dissertation – **Why and How** type of questions.
[f] Such a question is related with the research question RQ4 from the overall dissertation – **Why** type of question.
[g] Such a question, as the final **Why** type of question, was intentionally postponed to later stages of the doctoral project, as recommended by Professor David Silverman at the Doctoral Seminar on Qualitative Methods in Business Research – A three-day seminar jointly organized by EIASM, KATAJA and EDEN, 6-9 May, Brussels.

3.4 Units of analysis

In order to better understand and explain the emergence of OSS in the mobile devices industry, I and my co-authors turned to to the "iOS," "Android," "Symbian," and "Maemo" mobile platforms developed by a number of firms that led the mobile-devices industry. Then, in order to better understand and explain coopetition in open-source digital infrastructures, we "zoom in" and focus our lenses to the WebKit project (producing web-browsing technologies) and the OpenStack project (producing an IT cloud computing infrastructure for big data). These two high-networked projects aggregate contributions from public organizations (e.g., universities and research institutes), for-profit firms, and unaffiliated individuals (e.g., volunteers) contributing to the project. Additional commonalities include decentralized governance structures, distributed control, and no clear ownership of project outcomes. The material outcomes (i.e., the software) can be freely used, studied, modified, and distributed by anyone for any purpose (i.e., under an open-source license).

In the following table 3.2, we disclose some more information on the three units of analysis. It is important to note that, in all cases, we took into consideration both social and material aspects – we investigated both the technology and the social community behind it. No research was performed looking solely at the material aspects (e.g., technology design) or solely at the social aspects (e.g., community structures).

3.5 Data collection

Data was collected mostly from publicly available and naturally occurring data on the Internet. Examples of the collected data include financial information of publicly listed companies, companies' press releases, generalist press, specialized press in technology and mobile devices, the documentation of OSS projects, the source-code of OSS projects and its change-log as well as meta-data provided by the different OSS project repositories (aka version-control systems). A small set of interviews was also conducted.

Among the use of different and heterogeneous sources of data, the bulk of this dissertation was conducted by looking at the WebKit and the OpenStack open-source projects. We made use of their source-code, their source-code repository, and other related websites covering developers' contributions to the projects

Table 3.2: Units of analysis

Unit	Description	Organizations	Official websites
Mobile industry	The "iOS," "Android," "Symbian," and "Maemo" mobile platforms powering mobile devices such as phones, smartphones, and tablets.	Apple, Google, Samsung, Motorola, HTC, and Nokia, among many others.	http://www.apple.com/ios http://www.android.com/ http://www.symbian.org/ http://www.maemo.org
WebKit	WebKit is the web browser engine used by Safari, App Store, and many other OS X, iOS, and Linux applications.	Apple, Igalia, Google, Samsung, and Nokia, among many others.	http://webkit.org/
OpenStack	Open-source cloud computing software for public and private clouds. Controls large pools of compute, storage, and networking resources throughout a datacenter.	Rackspace, IBM, Citrix, VMware, HP, and Intel, among many others.	http://www.openstack.org/

from the beginning of each project till our most recent analysis execution. All raw project data is natural-occurring and not provoked by the researchers. The initial raw data, as well as the processed data that supported our research results, was archived in our project website at `http://users.utu.fi/joante/WebKitSNA/` and `http://users.utu.fi/joante/OpenStackSNA/`. Data-cleansing efforts were minimal thanks to extremely strict peer-review and code-commit policies from the studied projects. In addition to naturally occurring data, I was also able to interview, on-site, six actors (managers, developers and testers) from a major firm within the mobile devices industry. Semi-structured interviews were performed[6] according to established guidelines for Information Systems research (Myers and Avison 1997; Myers and Newman 2007) – all with the purposive aim of addressing the Why research question (RQ4).

The Table 3.3 sensitizes the research data collection procedures employed at each individual research project. More details are provided at each article bundled with this doctoral dissertation as well as in the previously mentioned websites that supported this research.

[6]Even if the interview data was already collected and transcribed, its analysis is still pending. Results should be communicated in a new forthcoming publication out of the scope of this doctoral dissertation. The contact with practitioners dealing with OSS in the mobile devices industry was extremely insightful to the overall research project.

Table 3.3: Original data sources.

Article	Research Question	Unit-of-Analysis	Collected data
1	What do we know about open-source and platforms?	Body of Knowledge	Research papers retrieved from research databases indexing books, journals, and conference proceedings[a]
2	Measuring the openness of computer-based multisided platforms.	Body of Knowledge plus the **Milkymist** open-source project	Research papers retrieved from research databases indexing books, journals, and conference proceedings; also public information on the empirical case.
3	RQ1 *What ...*	**Mobile devices industry players** controlling the iOS, Android, and Maemo platforms	Open-source software projects source-code and documentation
4	RQ3 *How ...*	The **WebKit** OSS project	Open-source software project related websites and the change-log from the project version-control-system
5	RQ3 *How ...*	The **OpenStack** OSS project	
6	RQ4 *How and Why ...*		

3.6 Data analysis

In line with calls for more pluralism in IS research (see Mason 2006; Mingers 2001) a multitude of approaches were employed. In my view, and from a methodological perspective, this doctoral dissertation is a combination of several qualitative, quantitative, and relational methods. I distinguish the later "relational" to reflect an ongoing debate on whether SNA is a qualitative or qualitative method (see Brandes et al. 2013; Carrington 2014) and to highlight the (Dyer and Singh 1998; Lazer et al. 2009) relational dependence of social actors.

In order to address RQ1, RQ2 and RQ3, and after attaining an initial understanding of the competitive dynamics of the respective industries using ethnographic approaches, we extracted and analyzed the social network of an open-source project leveraging SNA, which is an emergent method widely established across disciplines of social sciences in general (Uzzi 1996; Wasserman and Faust 1994) and IS and FLOSS research in particular (Howison et al. 2011; Lindberg et al. 2013; Oinas-Kukkonen et al. 2010). We focused on the visualization of the collaboration network and sub-community detection, using the following established Social Network Analysis methods:

- 2D Longitudinal visualizations using different geometries and layouts.
- 3D Longitudinal visualizations using modeling and animation techniques.
- Calculations of nodes and groups centrality measures (classical and eigenvector).
- Sub-community detection with Markov chain clustering, modularity maximization heuristics and hub-based community detection with different parameter configurations.
- Calculations of community and sub-community cohesion measures (density, transitivity, connectedness, number of cliques, among others).
- Extraction of Simmelian backbones[7].

We adopted a descriptive and narrative style to report our case studies. In our dissertation articles relying on the SNA methodology (Article 4, 5 and 6), the

[7]The extraction of Simmelian backbones - a novel sub-community detection method motivated by Simmel's concept of membership in social group (see Nick et al. 2013; Simmel and Wolff 1950) was particularity fruitful to our research.

obtained exploratory social network visualizations (e.g., Figure 3.1 and Figure 3.2), a key output of the data analysis, added rigor and comparative logic to the qualitative description (via triangulation of research methods) as suggested by Eisenhardt (1991). However, it also added ‘pictures’ of the social structure, which *per se* increased the richness of the qualitative description as rejoindered by Dyer and Wilkins (1991).

In order to better address RQ4, a *Why* "type" of a question, we are currently embracing the Grounded Theory method both for textual data analysis and theory building. Guided by seminal works on Grounded Theory within Information Systems research (Levina and Vaast 2008; Urquhart and Fernandez 2006; Urquhart and Fernández 2013), we opted already for the *Glaser and Strauss 67* "flavor" of Grounded Theory, as it is already established in the discipline (see Glaser and Strauss 1967).

The Table 3.4 details the employed data analysis approaches and corresponding methodological sources that guided the research design. More detail is provided in each dissertation article.

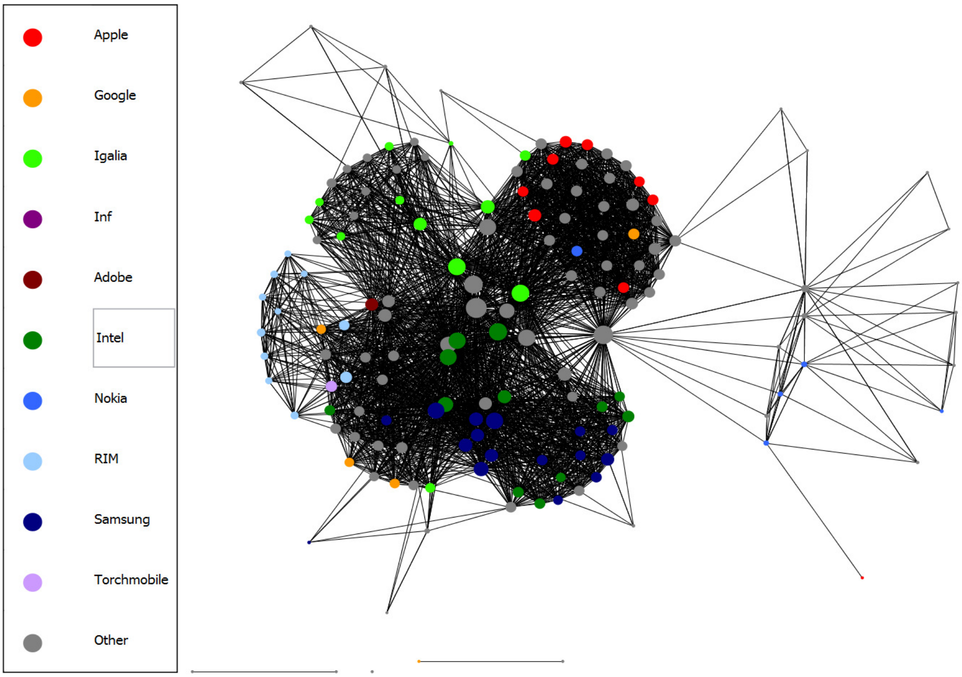

Figure 3.1: Mapping collaboration in the WebKit project from June 2009 to February 2011: Reflecting the Nokia and Microsoft plans to form a broad strategic partnership that forced Intel to search for new partners for MeeGo.

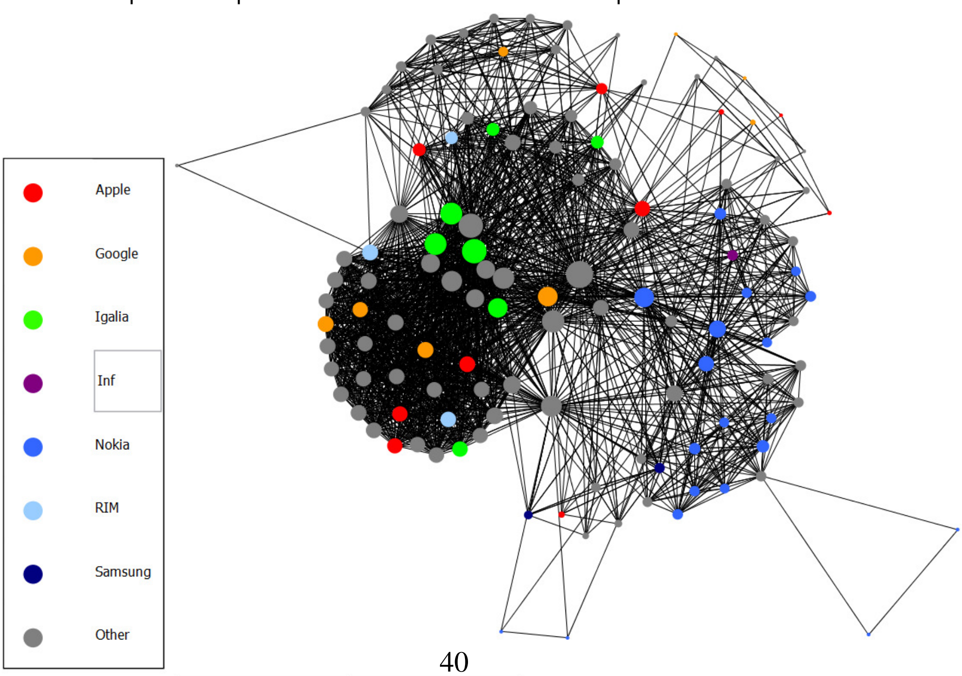

Figure 3.2: Mapping collaboration in the WebKit project from July 2012 to April 2013: Reflecting patent wars, trademarking, and forking.

Table 3.4: Approaches to data analysis.

Article	Collected data	Approach	Methodological references
1	Research papers retrieved from research databases indexing books, journals, and conference proceedings	Analysis of systematic literature review	Webster and Watson (2002) Järvinen (2008) Vom Brocke et al. (2009) Okoli and Schabram (2010)
2	Research papers retrieved from research databases indexing books, journals, and conference proceedings; Also public information on the Milkymist empirical case	Conceptual article. Review of literature complemented with an empirical case	Webster and Watson (2002) Järvinen (2008)
3	Open-source software projects source-code and documentation	Multiple-case study with a description of OSS components integrated by Apple, Nokia and Google	Yin (2008) Eisenhardt (1989)
4, 5 6	Open-source software projects' related websites and the change-log from the project source-code repository	Social Network Analysis and Figuralization	Elias (1978) Cambrosio et al. (2004) Wasserman and Faust (1994)

3.7 Theory building

Also reflecting the pluralism employed on this research (see Mason 2006; Mingers 2001) a multitude of theory-building approaches were employed. In Table 3.5, I provide details on the employed theory-building approaches and corresponding methodological sources that guided the research design. More details are provided in each dissertation article.

It is important to note that the bulk of the articles of this dissertation do not have explicit theoretical contributions. With the exception of articles 2, 5, and 6, the remaining articles had no theory creation goal. Whereas article 2 is purely conceptual and has theoretical value by deconstructing the meaning of openness within an platforms/ecosystem setting, articles 5 and 6 contribute to extant theory by outlining a few theoretical propositions (see discussion in Chapter 5).

Table 3.5: Approaches to theory building

Article	Collected data	Theory Building Approach	Key reference
1	Research papers retrieved from research databases indexing books, journals, and conference proceedings	No explicit theory building	
2	Research papers retrieved from research databases indexing books, journals, and conference proceedings; also public information on the Milkymist empirical case	Conceptual article	
3	Open-source software projects source-code and documentation	No explicit theory building	
4	Open-source software project related websites and the change-log from the project version-control system	No explicit theory building	
5	Open-source software project related websites and the change-log from the project version-control system	Inductive reasoning	Eisenhardt (1989)
6	Open-source software project related websites and the change-log from the project version-control system	Inductive reasoning	Eisenhardt (1989)

4 Results

In this chapter, I outline key research results from applying the chosen methods to the collected data. More detailed results, in light of existing literature, theory, and practice, are presented across each of the six dissertation articles.

Here, I purposively outline key results in a more "raw" manner. The interpretation of these results and their significance is discussed later in Chapter 5. As initially expected, only some of these results turned out to have implications for theory or practice; some results did not add anything relevant to extant knowledge.

4.1 Review of results from original articles

4.1.1 Article 1 (IFIP OSS conference paper – literature review)

The first article was a systematic literature review with the aim of assessing extant knowledge in open-sources and platforms. We used databases indexing academic publications in the form of journals, conference proceedings, and books (e.g., Emerald EBSCO, ProQuest ABI/ Inform, Google books, Volter database[1] and AIS eLibrary).

Using search keywords to retrieve and identify relevant articles, we systematically collected and analyzed hundreds of publications. This was a long process that took multiple years, almost from the start of my doctoral studies. Sizable spreadsheets were produced and managed with the goal of identifying research that looked at OSS from a platform's perspective.

By May 2014, when Article 1 was presented[2], we conducted a meta-description analysis of the retrieved 360 articles. By that time, we read and

[1] The Volter database indexes books from multiple Finnish universities. Such service is provided by the Finnish national network of libraries.

[2] The first article that resulted from our literature review efforts. The article emphasized much on conceptualizing platforms and OSS. The same article disclosed fine-grained methodological decisions that guided our literature search.

content-analyzed circa 170 related articles.

The following key results were reported:

- Based on citation analysis of the retrieved publications, the economic works of Economides and Katsamakas (2006), the open-source adoption studies of Dedrick and West (2003), and the R&D management strategy work of West (2003) were identified as seminal works on open-source platforms.

- When crossing literature from both mobile and open-source platforms, we also found out that novel studies addressing the mobile-devices industry did not integrate with the the identified works on open-source platforms that captured much attention. For example, efforts from Basole (2009) in visualizing relational interactions within a converging mobile ecosystem, or the description of the paradoxical relationship between control and generativity on the Apple and Google ecosystems accounted by Eaton et al. (2011), did not explicitly consider or exploit previous seminal works on open-source platforms mostly derived from the PC industry – something surprising, as lessons learned from the mobile industry might not be that different from what was already known from the PC industry. This raised a need for further theoretical integration.

- Previous seminal works from Economides, Katsamakas, Dedrick, and West assume a scenario where open-source is an alternative strategy for low-cost players, with reduced market share, against more successful corporations enjoying a quasi-monopoly situation (see Dedrick and West 2003; Economides and Katsamakas 2006; West 2003). To our view, this is something that does not happen with more contemporary platforms – tables turned. Among other evidences, open-source platforms like the Android mobile platform are leading the market. Conversely, systems that fully rely on proprietary software (e.g., Windows CE, PocketPC, Windows mobile and Windows phone) are either defunct or holding a minimal market share. Open-source should not longer be associated with platforms characterized by low-cost or reduced market share. This warns on generalizations from previous platform-wars to more recent ones. Apple, Google and Google Android partners, all with strategies that esteem OSS, are effectively dominating the market, while charging more for their high-end devices than their competitors. This warns practitioners within the industry on the dangers of ignoring OSS.

- Finally, we noted a scenario of convergence across multiple platforms. Firms push for similar technological standards across different platforms (e.g., Microsoft Windows within Xbox, Surface Tablets, PC, Netbooks, and Mobile phones). This convergence between industries remains unexplored by academia. Interesting research questions dealing with the implications of such convergence remain unexplored. Among other unexplored research questions exploring such convergence, I outline: "Should firms concentrate on 'winning' one platform-war or run several platform-wars in parallel?", "How can firms leverage resources from one platform to another?", or "How policy makers should regulate possible abuses of platform dominance to foster competition and innovation?".

Overall, the execution of a systematic literature review outlined much of what is known and what still needs to be known, therefore guiding my doctoral research efforts as a whole.

4.1.2 Article 2 (ACM OpenSym conference paper - conceptual)

The second article was a pure conceptual paper. Lack of clarity on what openness means and how it can be measured motivated my conceptual efforts. I proposed a multi-dimensional framework that was enriched with an empirical case. The Milkymist,[3] a video DJ computer-based platform/ecosystem initiated by a young French enthusiast, was analyzed trough the lenses of the proposed multi-dimensional framework – this added some empirical value to our conceptual arguments on what openness means within the context of digital platforms/ecosystems.

As a result of our review and theorizing efforts, we proposed six different aspects of openness that should be useful to scholars and practitioners by enabling a more clear understanding of the open-source software phenomenon in a platforms/ecosystems setting. As captured in Figure 4.1, the proposed six different aspects were: 1) architecture (hardware and software), 2) compliance with standards, 3) transparency and inclusiveness of governance, 4) free market

[3] Information about the Milkymist is available at its official website `https://m-labs.hk/m1.html`

policies rewarding innovation and entrepreneurship, 5) presence/absence of purposive lock-in mechanisms, and 6) an open regime of intellectual property.

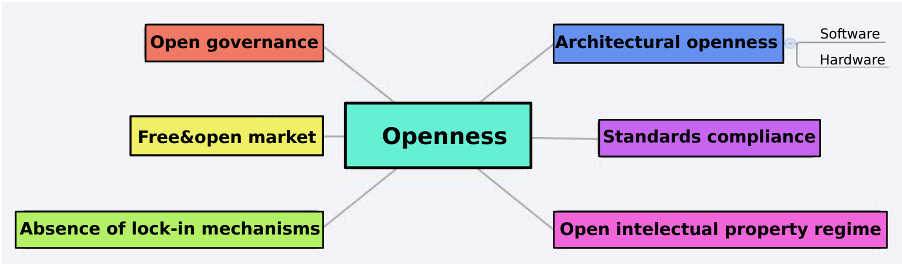

Figure 4.1: Assessing how different stakeholders construct openness in a platform/ecosystem

Overall, my efforts increased our understanding of what openness means within the context of large, networked, and heterogeneous information systems (e.g., platforms, ecosystems, and digital infrastructures among others). Given that current views on openness are problematic in such "relational" settings, such steep was, in my view, much needed to shape future research. After attaining a more clear and context-aware view on openness, developing a measurement would be a "natural" next step.

4.1.3 Article 3 (IFIP I3E conference paper - multiple case study)

The third article included in this dissertation analyzed the market of mobile platforms. Our multiple descriptive case study took four units of analysis: "iOS," "Android," "Symbian," and "Maemo." At the time of our research execution, such mobile platforms developed by Apple, Google, and Nokia were capturing much attention from customers in the mobile-devices market. The authors systematically analyzed much natural occurring data on the Internet. Qualitative online content was retrieved from: (1) press releases from mobile-device vendors, (2) software development portals, (3) discussion forums covering each platform, and (4) generalist press in business, economics and technology. Moreover, some websites with a very strong focus on the personal electronics industry were also systematically analyzed — many of them are on-line versions of the traditional "press" magazines (e.g., Engadget and Wired).

The first goal of Article 3 was to assess "what open-source software components are integrated by Apple, Google and Nokia in their mobile platforms?"

We found that the iOS 4.3.3 platform integrated 28 OSS packages[4], Android 2.3 platform integrated 108 OSS packages, and the Maemo platform integrated 151 OSS packages[5]. By pure serendipity, we also noted that Apple integrated OSS technology in a peculiar way[6]: While Google and Nokia integrated the most recent versions of OSS project (i.e., the later software releases), we noticed that Apple integrates older versions of OSS technology, perhaps seeking architectural simplicity and stability over the integration of the last project features, more prone to bugs.

While screening the collected data, we found many peculiarities that we were not initially looking for. For instance, we noted that most of the integrated OSS components were heavily modified to facilitate adaptation to each platform operable architecture – meaning, that the efforts from the studied mobile-platform makers are not just limited to take "ready" OSS software, much work was needed until such technology can power each specific mobile device. Moreover, and from the point of view of the architecture of OSS components integrated by platform providers, we found a high similitude between the Maemo and the Android platforms.

We noted, however, that Maemo architects appeared to be more satisfied with the original work from the open-source communities. Compared with Android, Maemo was not modifying so much the source-code from open-source projects integrated into the platform. In other words, Nokia and its partners did not put much effort into modifying the OSS components integrated into Maemo as Google and its partners did for Android. This can be partially explained by the fact that Maemo was based on Debian GNU/Linux, while Android wrapped a modified Linux kernel with a Java-like application programming interface (API). Such wrapping limited the access of applications to core operating system services that are provided in Linux with basic GNU libraries such as *glibc*. While Maemo applications are linked and cross-compiled with the platform-core, Android applications are instead interpreted by the platform-core[7].

In multiple aspects, the Maemo platform was the most open of the three

[4]Package, component, and project have similar meaning in this context.

[5]A surprising result, as Nokia is not as known for investing in open-source technology.

[6]Here we contrast Apple and its iOS platform from the others (i.e., in relation to the efforts of Google and Nokia in the Android and Maemo platforms).

[7]For discussions from the point of view of software developers, see: `http://android.stackexchange.com/questions/16239/` and `http://wiki.maemo.org/Documentation/Maemo_5_Developer_Guide/`.

investigated platforms. It integrated the highest number of OSS packages (151) and the platform allowed third party developers to directly access the integrated APIs. Thanks to the transparency of the Maemo open-source platform community, we were able to obtain interesting data on how many platform-packages were modified versus directly integrated. It is important to note that the number of packages are not correlated with the effort spent on its development, because each integrated project differs in size and complexity. As outlined in Table 4.1 Nokia integrated as many as 68 OSS projects directly from the community (i.e., without modifying them). A total of 89 projects were modified to fit the platform needs. This shows that Nokia's commitment with the open-source community was more than just taking ready software from the open-source community[8]. Nokia actually initiated at least 49 projects in an open-source way to support its Maemo platform.

Table 4.1: Core decisions taken by the Maemo architecture and integration teams.

Architecture Integration approach	Number of packages
OSS directly integrated from communities (downstream)	68
OSS modified by Nokia during the integration process	79
OSS project initiated and developed under Nokia umbrella	49
Proprietary components developed under Nokia umbrella	92
Proprietary components by third parties	2

As a key result of Article 3, the following Figure 4.2 outlines a number of projects that are commonly integrated by three contemporary mobile platforms (i.e., Nokia Maemo, Apple iOS, and Google Android). We can note that open-source mature tools and libraries from the long-established and reputed GNU and Apache communities are integrated across the three platforms. Such results also drove our attention to the WebKit project, as its web-browsing technologies were powering the most successful mobile platforms at the time. WebKit drove much of our interest, as noted in Articles 4 and 5.

[8]For official and informal discussions on Nokia's commitment to the open-source community see:
`https://blog.networks.nokia.com/mobile-networks/2014/05/20/`,
`http://company.nokia.com/en/news/press-releases/2000/09/08/` and
`http://blog.mardy.it/2011/02/committed-to-linux.html`.

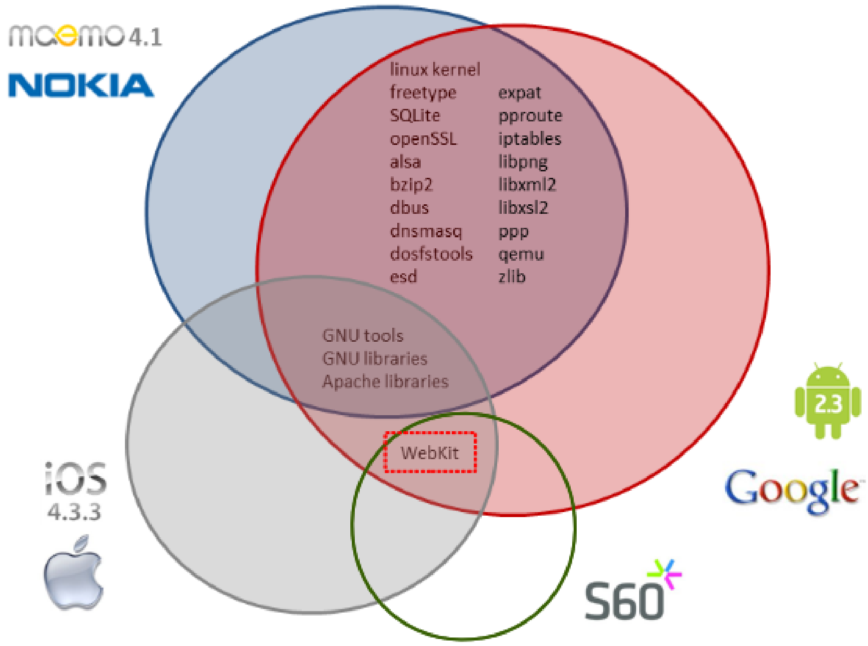

Figure 4.2: Venn diagram with open-source technology commonly used by four platforms.

The second goal of Article 3 was to describe the open-source platform-based strategies employed by Apple, Google, and Nokia. This description was conducted from the point of view of the openness of their mobile platforms. We provided some "inbound" description on how the vendors integrated technological components from the open-source community, but it mattered as well to describe the "outbound" – how vendors open up their platforms' blueprints. We found out that vendors greatly differ on how their core blueprints are shared back to the public domain (i.e., the open-source commons).

- Apple seems to provide the source-code of core components of its platform just to avoid legal litigation (i.e., opened the source-code of its derivative when the software distribution license of the integrated component required it).

- Nokia provided circa 80 percent of its Maemo platform source-code, but hided components like hardware adaptation, network connectivity and user interface (UI) elements like sounds and fonts.
- Google provides almost 100 percent of the platform source-code; however, it delays the release of the source-code for selected versions. This means that Google keeps a momentum where it protects the blueprints of its latest developments[9].

We also noted strong evidence that Google and Nokia maintained two repositories: (1) a public version of their platform, and (2) an internal, closed version that was shared only with limited partners (e.g., telecommunications companiess (TELCOs), software development suppliers, and third-party hardware vendors, among others). Apple's iOS was developed in a more closed way; we were unable to retrieve information on how Apple managed the access to its platform repository.

The third goal of Article 3 was to assess how third-party application developers were coping with the strategies announced by the three platform providers. This assessment was conducted by qualitatively analyzing textual discussions among a set of software development portals and forums using Romano et al. (2003) method for analysis of web-based qualitative data. Free-form text communication from different software developers of mobile applications was collected, covering the first quarter of 2011 (January to March) for post-classification and analysis. We designed a coding scheme to capture three facets from the third-party application developers' perspective: (1) perceived valuation of the platform, (2) intention to complement the platform, and (3) desire for platform openness.

Many third-party application developers continuously provide positive or negative feedback, reacting to the platform's continuous development. Most developers' "reactions" followed the release of new developer tools and API interfaces from the platform providers. Surprisingly, there is no evidence that planned events such as the Apple Worldwide Developers Conference, the Google IO, the Symbian's developer's conference, and the Maemo Summit have immediate effects on the evaluation attitude of the platform software developers. From a set of findings, we highlight:

[9] For a discussion on how Google delayed the release of the Android 3.0 Honeycomb (a tablet-oriented version) for a few months, see `https://www.engadget.com/2011/03/24/google-keeping-honeycomb-source-code-on-ice-says-its-not-ready/`.

- The Symbian platform was associated with negative value perception.
- The iOS, Android, and Maemo platforms were associated with positive value perception.
- The inclusion of Qt[10] technologies in the Symbian platform was associated with positive value perception.
- Experienced developers had the most positive perceptions on Symbian.
- Developers often provided contradictory sentences regarding their "wishes" of complementing the platform. After several weeks "coding" a real-world application, developers' perceptions and intentions toward a platform changed.
- After many Nokia strategic shifts[11], a high number of developers stated that they would stop developing for the Symbian platform. However, it was surprising that many developers were willing to complement to the Maemo platform.
- Android appeared to be the platform in position to collect the highest number of contributions from third-party complementors.
- A number of software developers revealed a desire in having the iOS platform running on devices not branded by Apple.
- All opinions expressed on "openness" revealed a desire for a more open platform (i.e., no developer called for a more "closed" platform).
- There was criticism of the impossibility of accessing with "root" privileges to handsets shipped with the iOS, Symbian, and Android platforms by legal means[12].
- There was also criticism to the fact that, in iOS and Android, third-party applications can be only installed from the vendors' Internet markets, commonly referred to as "app stores" or "app markets." This issue raised strong debate among complementers.

[10]The Qt cross-platform software development kit (SDK) allowed developers to cross-compile their applications to multiple platforms. For more information see `https://en.wikipedia.org/wiki/Qt_software`.

[11]Many came with the arrival of a new CEO (Stephen Elop, who came from Microsoft).

[12]This contrasts with the PC industry, where users and developers can take high control of the hardware and the operating system with a special "root" or "administrator" authentication.

To my view, the results of this third article are mostly empirical. We focused on describing the multiple cases, and we did not attempt to theorize explicitly from our results. In any case, after the article publication, I do note that high engagement with OSS communities was a common success factor; for the companies that are now leading the mobile-devices industry, all of them integrated OSS at some level. However, they embraced the OSS community in very different ways, patterns on "upstream" and "downstream"[13] largely varied across vendors.

4.1.4 Article 4 (ACM SIGMIS conference paper - case WebKit)

On the follow-up of our prior research efforts, we directed our attention to the WebKit project – its web-browsing technologies were powering the most successful mobile platforms at the time. Our initial driving impetus was to assess if the different mobile-devices vendors (e.g., Apple, Google, Nokia, and Samsung, among many others) really collaborated with each other "jointly" in the WebKit project, or alternatively if each worked on "its own corner" within the WebKit project[14]. We quickly noticed that "yes, they really collaborated with each other in the development of common components" and further developed an exploratory study addressing collaboration in the WebKit project.

We were forced to become familiar with the WebKit project, its surrounding industrial background, and its software development practices. We digested many WebKit-related websites toward and understanding of its development and the evolutionary context in which it is embedded. Then, we made use of WebKit change-logs retrieved from the version-control system[15] that provided

[13] The "upstream" and "downstream" terms are often employed by the OSS communities – after all, "upstream fist" is a philosophical value of OSS communities. In the terms of source-code control, developers are "downstream" when they copy (clone, check out, etc.) from a project repository. Information flows "downstream" to them. When they make changes, they usually want to send them back "upstream," so they make it into that original repository so that everyone pulling from the same source is working with all the same changes. While the first is a flow from the collective to the individual, the second is a flow from the individual to the collective.

[14] This idea surged by pure serendipity at the Inforte seminar on Big Data and Social Media Analytics by Sudha Ram and Matti Rossi (April 2013). We thank the encouragement of Sudha Ram that boosted our research motivation.

[15] We accessed to the project version-control system (aka repository) via SVN, GIT, and the many change-log files within the WebKit source-code tree. See `https://webkit.org/contributing-code/` and `https://trac.webkit.org/` for more information on such

digital traces of *who worked with who in WebKit*.

We combined the screening of both endogenous Webkit practices and exogenous key happenings in the mobile devices industry with a computer-based method of SNA. The screening of public and naturally occurring data informed the SNA execution, and the interpretation of the retrieved SNA two-dimensional (2D) visualizations of WebKit's social-structure was also informed by qualitative textual data on the Internet. We went back and forth in the dynamic history of the mobile-devices industry, trying to make sense of our online observations. My practice-accumulated skills regarding software development, open-source software, and software version control systems, dealing with very specific concepts and terminologies, revealed to be essential for sense-making of the collected textual data.

Thanks to the initial screening, we have identified a set of key events that, according to our interpretations, could have impacted the evolutionary dynamics of the WebKit project (see Table 4.2). These major events gave us a rather clear history line to understand WebKit's evolution within the industrial context that it is embedded. After visualizing the dynamic evolution of the WebKit collaborative network using SNA techniques we found out that some of these events impacted the collaborative network more than others. In Table 4.2 we highlight in bold the events that most affected the collaborative network of WebKit (i.e., Apple published the source-code of WebKit, Apple released the first iPhone, Google launched Chrome and Android, Nokia and Microsoft formed a broad strategic partnership leaving Intel alone with MeeGo[16], and Google forked of WebKit).

Our qualitative efforts dealing with naturally occurring textual data related to WebKit on the Internet, conducted prior to and during our computerized SNA, revealed to be fundamental while analyzing the WebKit social network evolutionary dynamics. The identified industry events were used as partitions on the whole period of the project history. We then applied SNA and constructed the collaboration network of developers in each partitioned time slice. Thus, we are able to assess how the collaboration network evolved over time in response to the exogenous events in the industry.

To model collaboration among software developers, we assumed that software

change-log files.

[16]MeeGo is a mobile platform that resulted from the merging of the Nokia Maemo and the Intel Moblin projects. A good amount of historical information related with MeeGo is available at `https://en.wikipedia.org/wiki/MeeGo`.

Table 4.2: Major events shaping the WebKit community

Date	Event
Jun 2001	WebKit started within Apple as a fork of KHTML and KJS open-source projects.
Sep 2006	**Apple, forced by the open-source community, published WebKit source-code in a public repository.**
Jun 2007	**Apple released 1st generation of iPhone.**
Sep 2008	**Google launched Chrome and Android.**
Jun 2009	Nokia and Intel Announced Strategic Relationship. Nokia's Maemo and Intel's Moblin merge into MeeGo
Feb 2011	**Nokia and Microsoft formed a broad strategic partnership. Intel searched for new partners for MeeGo.**
Jul 2012	The patent war broke out between Apple and Samsung, and their hostilities reached climax with the first trial in U.S. $1.049 billion in damages.
Apr 2013	**Google announced to fork WebKit's core components, just 1 month after Apple registered WebKit as its trademark.**

developers collaborate when coediting the same software source-code files (see Figure 4.3 for an illustration). This view on collaboration among software developers maps many social studies of science that assume that researchers collaborate when coauthoring the same scientific articles (e.g., Acedo et al. 2006; Gallivan and Ahuja 2015; Glänzel and Schubert 2005; Melin and Persson 1998).

We modeled software developers as network nodes, and the collaborative relationships among software developers were modeled as network edges. Moreover, we added to each node an affiliation attribute, assigning, whenever possible, each developer to an organization contributing to WebKit[17]. Within the retrieved SNA visualizations (aka sociograms[18]), such affiliation that can be recognized by the color of the network nodes (see Figure 3.1, Figure 3.2 and Figure 4.4). This approach plugs with the social network views on "affiliation networks" (e.g., Faust 1997; Lattanzi and Sivakumar 2009; Wang et al. 2009) and "two-mode networks" (e.g., Doreian et al. 2013; Latapy et al. 2008; Opsahl 2013).

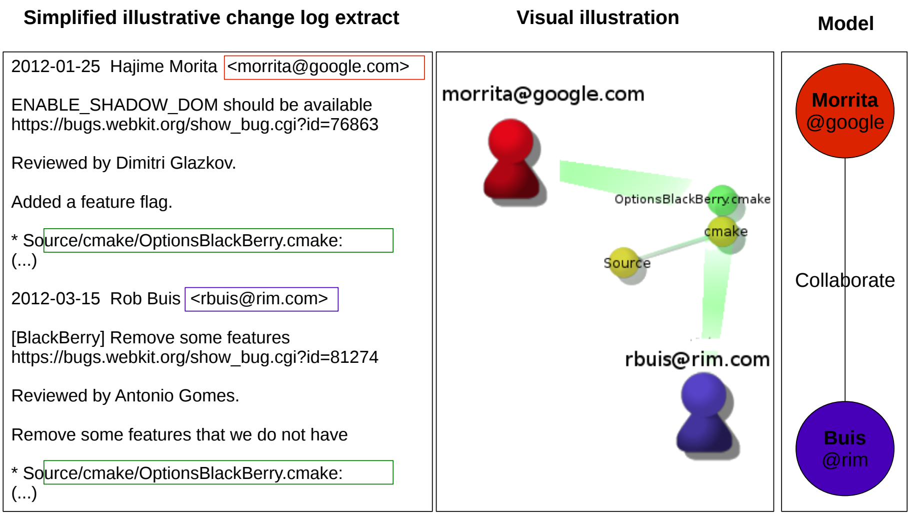

Figure 4.3: Modeling collaborative software development networks

[17]It is important to remark that many of the software developers contributing to WebKit are not explicitly affiliated with an organization. They are often individual altruists working on a volunteer basis. See (Aksulu and Wade 2010; Carillo and Bernard 2015; Crowston et al. 2012; David and Shapiro 2008; Shah 2006) for recent and comprehensive reviews on the motivation of OSS developers.

[18]Sociograms, as sociometric charts plotting the structure of interpersonal relations in a group situation, were early developed by Jacob L. Moreno to analyze choices or preferences within a group. See (Moreno 1934) and (Moreno 1951).

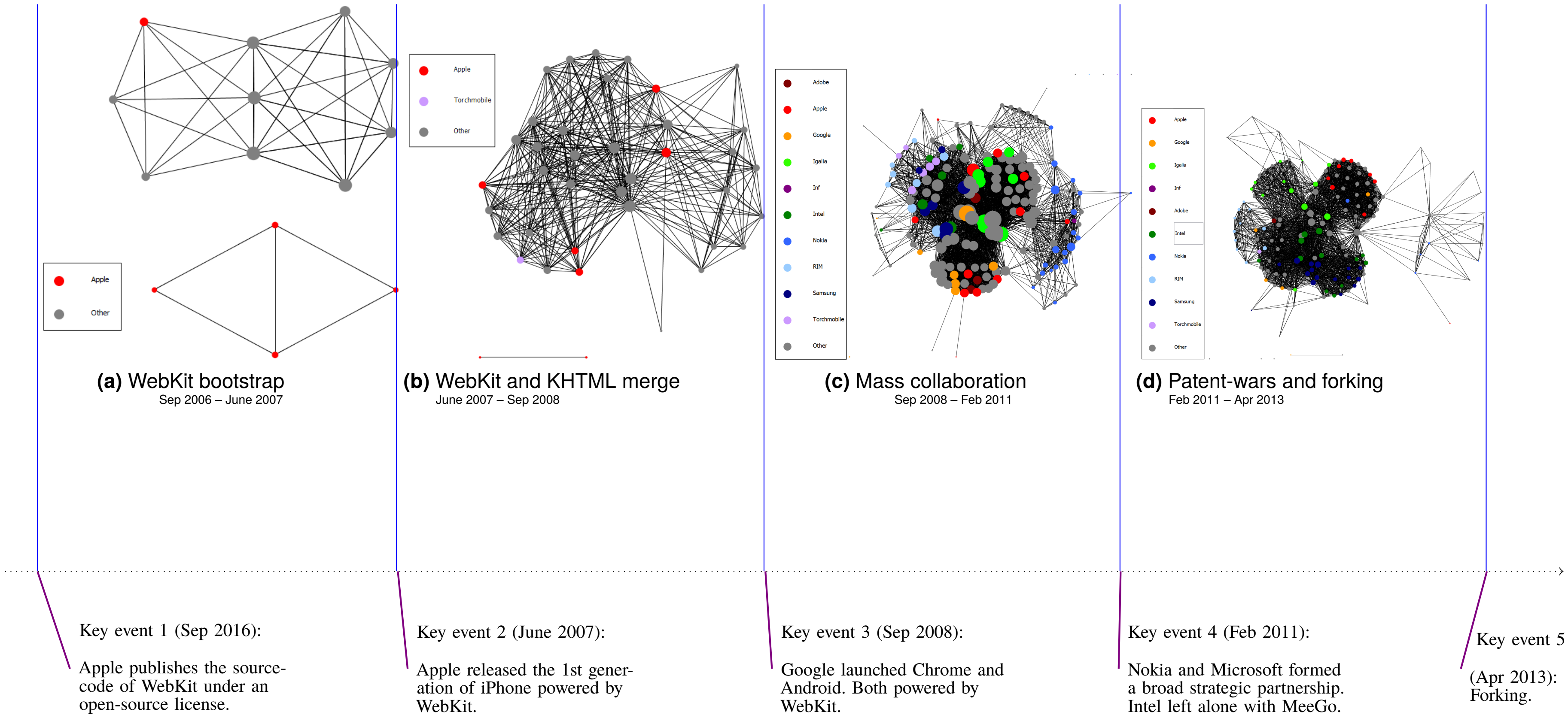

Figure 4.4: Longitudinal sequence of WebKit collaborative networks partitioned by key events in the industry.

Our sociostructural visualizations of collaboration in the WebKit project (e.g., Figure 3.1, Figure 3.2, and Figure 4.4) lead to a set of interesting findings[19] such as:

- Nokia contributed substantial amounts of code to the WebKit project, but in a social periphery, i.e., mostly Nokians working with Nokians (forming a sub-community).
- The Nokia and Intel breakage of cooperation can be easily visualized over time. Nokia's marriage with Microsoft caused immediate damage to collaboration in the Webkit project.
- However, even if Samsung and Apple were involved in expensive patent wars in the courts and stopped collaborating on hardware components, their contributions remained strong and central within the WebKit open-source project.
- Nonaffiliated developers, who are often volunteers without firm sponsorship, together with developers affiliated with smaller firms, were more central within the WebKit collaboration network than developers affiliated with the TOP10 organizations outlined in a recent empirical study from Bitergia (2013).
- Several forks occurred on the initial WebKit codebase: Webkit is a fork of KHTML, WebKit2 is a fork of WebKit led by Nokia and its partners, and Blink is a fork of WebKit led by Google.
- The open-source freedom to fork a project acted as a nexus enabling both features of competition and collaboration. On one hand, the freedom of forking unites the community against the danger of forking. While, on the other hand, the freedom of forking is always there – anticooperative competitive behaviors can split a previously united community in two (i.e., forking of the project).
- By forking the project, Google is "recruiting" WebKit developers previously affiliated with Apple and Nokia to its Blink open-source project. This finding triggered a motivation for future postdoctoral research on how virtual communities split.

[19] More details on how we arrived at such findings, as well as more detailed visualizations, are publicly available both in the dissertation article here introduced and in a doctoral project related website at `http://users.utu.fi/joante/WebKitSNA/`.

With a high empirical orientation, our theoretical contributions to understanding collaboration among individual and firms in the open-source arena were very limited. However, the key findings pointed out that even if firms were competing with each other in an environment of high rivalry (e.g., Apple and Samsung fought patent wars across multiple courts worldwide), they still collaborated in the open-source arena. This forced to engage with interorganizational theory in coopetition (i.e., theory explaining collaboration among competitors) as reflected in more recent articles included in this doctoral dissertation.

4.1.5 Article 5 (Springer JISA journal paper - case OpenStack)

After following the WebKit project for a while, I began, jointly with coauthors, seeking other cases of cooperation among competitors in the open-source arena. Initially, we thought that we could reuse much of our prior WebKit project research efforts within another case. Moreover, I and my coauthors anticipated that many lessons could be learned by comparing the two cases.

As illustrated by Table 4.3, there are many cases of cooperation among competitors in the open-source arena[20]. Most cases are relatively recent, so I could argue that cooperation among competitors in the open-source arena is a relatively new phenomenon. From many possible cases, we opted to study OpenStack due to its perceived novelty, its high internetworked nature (i.e., an "ecosystem" involving many firms and individual contributors), its heterogeneity (i.e., an ecosystem involving both start-ups and high-tech corporate giants), its market size ($1.7bn by 2016, as claimed by specialized analysts in August of 2014[21]), its complexity (i.e., involving different programming languages, different operating systems, different hardware configurations), and its size (17,020 community members, 100,000 code reviews, and 1,766,546 lines of code as reported by Red Hat [22].).

OpenStack is a cloud computing infrastructure for big data – or in other words, an operating system for data centers. It is primarily deployed as an "Infrastructure as a Service" (IaaS) solution. It started as a joint project of Rackspace, an established IT web hosting company, and NASA, the well-known U.S. governmental agency responsible for the civilian space program,

[20] I maintain an open and publicly available version of this table at Wikipedia; see `https://en.wikipedia.org/wiki/Draft:Open_coopetition`.

[21] See `https://451research.com/report-short?entityId=82593`.

[22] See `http://opensource.com/business/14/6/openstack-number` (Pub. June 2014)

Table 4.3: Known cases of cooperation among competitors in the open-source arena (i.e. open-coopetition)

Project	Domain	Examples of competing firms cooperating in the project
WebKit	Web browsing	Apple, Nokia, Google, Samsung, Intel, and BlackBerry
Blink	Web browsing	Google, Opera, Intel, and Samsung
OpenStack	Cloud computing	Rackspace, Canonical, IBM, HP, VMware, and Citrix
CloudStack	Cloud computing	Citrix, SunGard AS, and ShapeBlue
Cloud Foundry	Cloud computing	Cisco, Canonical, IBM, EMC, VMware, and SAP
Docker	Virtualization	Docker, Red Hat, IBM, Google, VMware, and Amadeus
Xen	Virtualization	University of Cambridge, Citrix, IBM, HP, and Red Hat
Hadoop	Distributed computing	Facebook, Twitter, LinkedIn, Jive, and Microsoft
Android	Mobile devices	Google, LG, Samsung, HTC, Huawei, ZTE, and Lenovo
Tizen	Mobile devices platform	Fujitsu, Huawei, NEC, Casio, Panasonic, and Samsung
GENIVI	In-vehicle infotainment	Volvo, BMW, Honda, Hyundai, Renault, and PSA
Linux	Operating system	Fujitsu, HP, IBM, Intel, Samsung, Hitachi, and Red Hat
Yocto project	Dev. tools	Broadcom, AMD, Texas Instruments, and Intel
Linaro	Dev. tools	ARM, Samsung, ST-Ericsson, and Texas Instruments
Eclipse	Dev. tools	Actuate, CA, IBM, Google, Oracle, and SAP
Adempiere	ERP	e-Evolution, Erpcya, SCM Software, and mckayERP
Odoo	ERP	Odoo, Vauxoo, Akretion, AvanzOSC, and ADHOC
Open MAMA	Financial trading	J.P. Morgan, Bank of America, and NYSE Technologies
OpenEMR	Medical practice	OEMR, EnSoftek, MI-Squared, and Visolve
IoTivity	Internet of Things	Microsoft, Intel, Samsung, General Electric, and Electrolux
RepRap	3D printing	MakerBot, Printbot, Prusa, 3Drag, SolidRay, and Kossel
Dronecode	Unmanned aerial vehicles	Intel, Qualcomm, Parrot, Aerotenna, FLYPRO, and Baidu
R Consortium	Statistical computing	Microsoft, R Studio, Alteryx, Tibco Analytics, and Google

aeronautics, and aerospace research. Today, more than 200 firms and many nonaffiliated individual contributors pitch in to a set of different open-source projects governed by the OpenStack Foundation[23].

OpenStack is developed by a vast and heterogeneous network that comprises private companies (e.g., AT&T, AMD, Canonical, Cisco, Dell, EMC, Ericsson, HP, IBM, Intel, and NEC, among many others), public entities (e.g., NASA, CERN, Johns Hopkins University, Instituto de Telecomunicações, Universidade

[23]From a legal perspective, the OpenStack Foundation is a nonprofit, non-stock "foundation" within the meaning of Section 501(c)(6) of the Internal Revenue Code of 1986, "Delaware Corporate Law."

Federal de Campina Grande, and Kungliga Tekniska Högskolan, among others) and independent nonaffiliated developers in a scenario of pooled R&D in an open-source way (i.e., emphasizing development transparency while giving up intellectual property rights). I must acknowledge my coauthor Gregorio Robles for bringing contaminating enthusiasm to study OpenStack from a social network perspective.

As in early research of ours that took a social network perspective to open-source ecosystem (see prior Section 4.1.4), our initial driving impetus was to assess if the different vendors (e.g., AMD, Intel, IBM, and HP among many others) really collaborated with each other "jointly: in the OpenStack project or, alternatively, if each worked on "its own corner" within the project. We quickly figured out that competing companies were closely cooperating together, and we attempted to investigate this cooperation among competitors guided by the theoretical perspective of coopetition[24].

We retrieved much qualitative archival data from the Internet regarding the OpenStack project in general. In addition, the OpenStack Nova source-code repository was mined with social network analysis in particular.The OpenStack Nova project, a key unit of analysis, is a cloud computing fabric controller, the main part of an cloud computing infrastructure. It is the largest and the most "core" project governed by the OpenStack Foundation. The project has a long time span, and it originally started at the NASA Ames Research Laboratory before evolving into a high-networked open-source ecosystem with hundreds of firms and thousands of developers.

More specifically, we reviewed the most relevant public announcements of companies, publicly available financial reports, publicly available documentation supporting software development, news from both specialized and generalist press, discussions in forums, white papers, and blogs pertaining to OpenStack. The selection of sources took into consideration key guidelines on how to conduct qualitative empirical research online (see Jawecki and Fuller 2008; Kozinets 2009).

We also took into consideration specific notes on how to account archival data within a case study, we counteracted possible biases by including many and diverse media sources (Yin 2011), we exploited peer debriefing by conducing the

[24]Coopetition theory is highly established in strategic management and industrial marketing. See Afuah (2000); Chen and Miller (2015); Hung and Chang (2012) and Bengtsson and Kock (2000,1) for seminal works.

analysis as a group instead of an individual working alone (see Runeson and Höst 2008; Runeson et al. 2012), and we organized the collected quantitative textual data within a digital content management system for meticulous record-keeping (Benbasat et al. 1987). I also point out that, from the initially selected sources, we followed many "links" and ended up visiting many other sites (e.g., corporate sites from companies involved in the development and commercialization of OpenStack technologies or blogs from individual OpenStack contributors). After the initial qualitative and virtual ethnographic efforts, we also conducted an SNA to visualize the evolution of cooperative dynamics. Knowledge gained from earlier phases of this study (qualitative inquiry) on OpenStack's actors, events, processes, and technology informed the subsequent SNA design. The input data of the network analysis was based on the different source-code release versions of the OpenStack Nova project. The last source-code snapshot from the repository of the OpenStack Nova project was performed on 16 June 2014, using *git* (v1.8.5.1).

The mining of software repositories with SNA allowed us to construct longitudinal social network visualizations that capture the evolution of cooperative behaviors among software developers (see Figure 4.5). The interpretation of these cooperative networks forced us to: (1) go back to the collected quantitative textual data, (2) perform additional data collection, (3) conduct phone interviews with software developers, and (4) revisit theory seeking complementary explanations for the visualized networks – all toward understanding and explaining why each network visualization took one particular shape and not another. The Figure 4.5[25] (as in a poster presented in IEEE BigData 2014 Washington DC, October 27-30, 2014) highlights key happenings (i.e., events) within the OpenStack ecosystem that partially explain the evolution of the captured cooperative networks.

[25] Please note that the complex figure is in a scalable vector format that allows zoom in and zoom out for better visualization. For the related article, see (Teixeira 2014a).

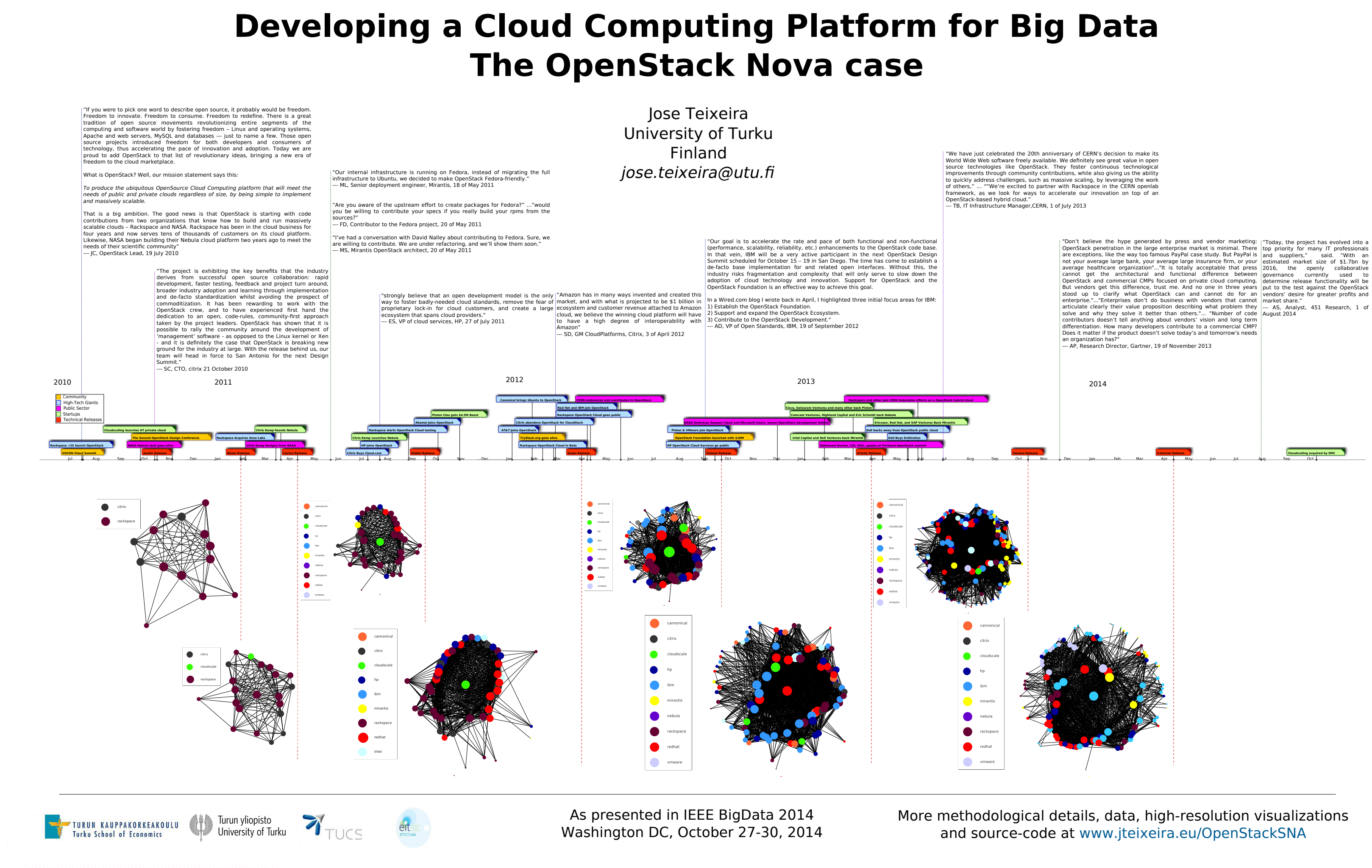

Figure 4.5: Developing a Cloud Computing Platform for Big Data: The OpenStack Nova case

To finalize our review of results communicated in dissertation article 5, that address the RQ2 and the RQ3 research questions of the main dissertation, and uses data from the OpenStack open-source infrastructure for big data, we here outline a set of the most interesting findings:

- By employing sub-community detection methods (a computational process based on topological properties of collaborative networks), we ascertained the hyper-collaborative nature of OpenStack. Sub-communities in the OpenStack project are highly heterogeneous (sub-communities tend to include developers from many different firms).

- While detecting the different sub-communities of the OpenStack community, we found that the expected social tendency of developers to work with developers from the same firm (i.e., social homophily[26]) did not hold within the OpenStack ecosystem. Surprisingly, developers tend to work with developers who are not affiliated with the same firm.

- We also assessed how revenue models (the way of making money when defining a business model in an internetworked setting) affected collaboration in OpenStack: Contrary to expectations, firms competing for the same revenue model (i.e., where rivalry is expected) tend to collaborate more than firms that do not compete for the same revenue model, with the exception of a few firms providing public cloud services based on OpenStack (HP, Rackspace, and Canonical).

Our findings[27] highlight the value of theory in open-source software, coopetition, and social network theory to both understand and explain the evolution of the OpenStack ecosystem. Some results were somewhat surprising for the established body of theoretical knowledge in coopetition (see Bengtsson and Kock 2000) and homophily (see McPherson et al. 2001). In a more practical perspective, our results call for the development of code-collaboration metrics and visualizations as a valuable complement to established software development metrics emphasizing code size, code quality, and productivity.

[26] For a seminal review on the homophily of social networks, see McPherson et al. (2001); for recent IS research exploring the concept, see Gallivan and Ahuja (2015).

[27] More details on such findings are publicly available on the doctoral project website at `http://users.utu.fi/joante/OpenStackSNA`.

4.1.6 Article 6 (AIS ICIS conference paper - case OpenStack)

The last dissertation article started with the same unit of analysis as the earlier dissertation article 5 (i.e., the OpenStack cloud computing infrastructure for big data); however, our analysis forced us to also study CloudStack[28], another open-source cloud computing infrastructure competing with OpenStack. In order to make sense of the collected empirical material, we expanded the data collection – we collected additional qualitative archival data from the Internet (much regarding CloudStack and Citrix[29]) and complementary software repositories data was collected as well to complement our social network analysis efforts. The analysis that relied mostly on 2D visualizations capturing the evolution of cooperative behaviors within an ecosystem was complemented with three-dimensional (3D) visualizations capturing the evolution of cooperative behaviors within and between competing ecosystems.

While encompassing the same unit of analysis, and while relying in similar data and methods, this last dissertation article greatly differed from dissertation article 5 by its theoretical background. The article was framed by theory on "organizational paradoxes" (e.g., Poole and Van de Ven 1989; Smith and Lewis 2011) and "portfolio of alliances" (e.g., Hoffmann 2007; Jiang et al. 2010). To better understand "cooperation among competitors in the open-source arena," we were forced to rely on theory that spanned across multiple disciplines. While the results from the SNA were mostly common across dissertation article 5 and dissertation article 6 (i.e., the 2D visualizations capturing cooperation within OpenStack were the same), the narrative that discusses and interprets such visualizations was different. The narrative reflected a distinct theoretical background in strategic networks, ecosystems, and "portfolio of alliances" (see Adner and Kapoor 2010; Hoffmann 2005; Jarillo 1988).

Our inquiry increases our understanding of how OSS technology can be developed by a network of firms that often compete with each other (i.e., what is special about OSS in a high-networked coopetitive settings?), and from another

[28] More information regarding CloudStack is available at its official website at `https://cloudstack.apache.org/`. Our analysis noted some intercooperative behaviors among CloudStack and OpenStack (two competing cloud computing infrastructures).

[29] Citrix Systems Inc. is an American multinational software company that provides server, application and desktop virtualization, networking, software as a service, and cloud computing technologies. It contributed both to OpenStack and CloudStack. As OpenStack and CloudStack are software ecosystems competing with each other, we were interested in how Citrix engaged in multilevel coopetition.

perspective, how collaboration among competitors can happen in the open-source arena with little emphasis in management controls, contracts, gatekeeping, and intellectual property rights (i.e., what is special about coopetition in an open-source settings?).

To finalize our review of results communicated in dissertation article 6, which addresses the RQ1 and the RQ4 research questions of the main dissertation and uses data from both the OpenStack and CloudStack open-source cloud computing infrastructures, we here outline a set of the most interesting findings:

- OpenStack was revealed to be a very complex ecosystem. By 24 November 2016, OpenStack counted with 65.116 developers and 645 supporting companies from 187 different countries[30]. The project had more than 20 million lines of source-code. We noted also a high inclusiveness of the OpenStack ecosystem to third-party contributors (e.g., hobbyists, academic researchers). OpenStack was not solely developed by the biggest firms backing it financially; instead, contributions were highly distributed across a number of individuals and organizations in a very transparent way.

- As pointed out earlier, by pure serendipity, we ended up investigating cooperation among competing ecosystems (i.e., OpenStack vs. CloudStack). Citrix, in a surprise move, and citing the lack of OpenStack interoperability with Amazon cloud systems, acquired Cloud.com in July of 2011 and donated the overall code-base to the Apache Foundation[31]. Citrix was hoping that customers of Amazon cloud computing services[32] would adopt CloudStack for their private clouds as its API integrates more closely with Amazon's public cloud. This move raised conflict within the OpenStack community where Citrix was a top contributor from the beginning. Citrix claimed to make peace with OpenStack on 21 April 2015 by announcing that it had become a corporate sponsor of the OpenStack Foundation. To sum up, Citrix divested from OpenStack and created a competing Amazon compatible open-source infrastructure, but

[30] Data retrieved from `http://www.openstack.org/community/`.

[31] The Apache Foundation has a very good reputation within the open-source community. After all, the Apache HTTP Server, colloquially called Apache, is the world's most used web server software.

[32] Please note that Amazon Web Services' Elastic Compute Cloud (EC2) is the world's most popular public cloud. It is the most profitable division of Amazon.

after four years of much conflict and tension, it engaged with OpenStack once again.

- During such period of tension between Citrix and the OpenStack community (July 2011 to April 2015), and by mining both OpenStack and CloudStack repositories with SNA, we found out that 10 developers contributed both to OpenStack and CloudStack. Six of these developers were affiliated with Citrix. While Citrix's contributions were recurrent, the contributions of the other four were sporadic. In other words Citrix was a regular contributor to the two competing cloud computing infrastructures – the 3D visualization Figure 4.6 aims to capture such behavior.

- While taking Citrix as focal firm embedded in two competing cloud computing infrastructures, and by looking at the source-code with social network analysis over time (i.e., longitudinal analysis), we found that Citrix's developers always kept recurrently contributing to OpenStack; this is surprising as Citrix's managerial actions pushed for CloudStack. By looking at the timing and pace of the contributions, we can argue that Citrix committed code in both directions (i.e., Citrix bridged a flow of knowledge and resources across two competing infrastructures). The OpenStack community did not appreciate Citrix's actions for some time.

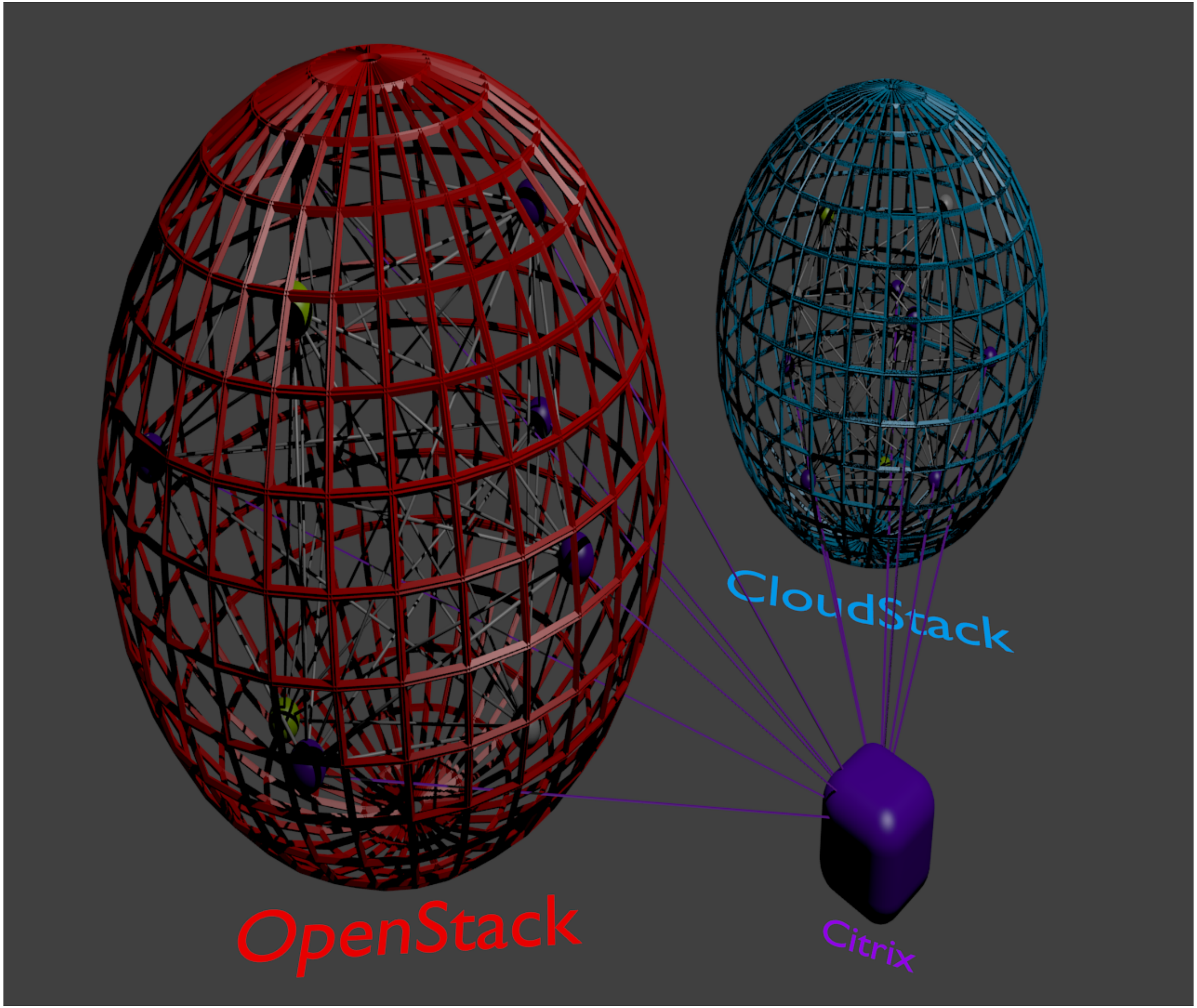

Figure 4.6: Modeling the role of Citrix in cooperation among competing ecosystems

5 Analysis and discussion

After presenting the empirical results, I interpret and discuss their significance to the current body of theoretical knowledge. Even if I emphasize contributions toward the current body of theoretical knowledge, I also discuss the significance of this research for practice.

The contributions are organized by their derivation. More concretely, I outline the most relevant lessons learned that derived from (1) our literature review efforts, (2) conducting our multiple-case study of mobile platforms that integrate OSS components in different ways, (3) the WebKit case, (4) the OpenStack case, Even if, in the original articles, I and my coauthors extensively employed the platforms and the ecosystem constructs, here, I employ the infrastructure construct for more precisely defining the theoretical boundaries of this doctoral dissertation.

As pointed out by Carillo and Bernard (2015) in a recent critical review of IS literature on FLOSS, the OSS phenomenon has been theorized within very broad and abstract theoretical boundaries. Prior OSS projects have been conceptualized as instances of "virtual organizations," "open innovation communities," "virtual teams," "knowledge firms," "global distributed collectives," "online collaborative networks," "communities of practice," "online communities," "peer production communities," and "organized volunteering forms," among others.

Upon my own literature review efforts, and by contrasting Information Systems and Software Engineering research on FLOSS, I do perceive that scholars within Information Systems often argument on possible generalizations to very wide and encompassing constructs at in (Carillo and Bernard 2015). This contrasts with generalization of open-source software in Software Engineering where social theory plays a smaller but well-recognized role, generalization beyond the open-source arena is infrequent. In such perceived situation, generalization issues should be taken very carefully. In this doctoral dissertation, I establish the boundaries of the claims to what we had figured out that we have been studying: (1) open-source software and (2) digital infrastructures.

Within this analysis and discussion chapter, the FLOSS research community and the IS research community are targeted. A more general audience is targeted later in the concluding chapter.

5.1 Contributions from the literature review

The concept of openness was revealed to be quite problematic and controversial within high-networked contexts. During the literature review efforts, both I and my coauthors have faced difficulties in understanding what openness actually means within high-networked settings such as platforms, ecosystems, and infrastructures (see Gacek and Arief 2004; Stallman 2009; Tkacz 2012, for prior works pointing out little reflection on what openness actually means). As open-source traveled far beyond the sphere of software artifacts and licenses to wider domains such as hardware and artistic and cultural works, it gets "harder and harder" to understand what openness really means within a particular context (cf. Balka et al. 2010; Coleman 2004; Perens et al. 1999).

To grasp this problem, and to leverage the literature review efforts, we proposed a framework that views openness along with six different sociotechnical aspects. More specifically, its was proposed that openness can be better understood along with the aspects of architecture (hardware and software), compliance with standards, transparency and inclusiveness of governance, market policies on the distribution of third-party complements, lock-in mechanisms, and intellectual property (see Section 4.1.2 and dissertation article 2).

As pointed out earlier, as the societal and technological systems become increasingly networked (Ciborra 2000), understanding openness in high-networked production setting becomes increasingly relevant. The proposed six different aspects of openness should be useful to scholars and practitioners by enabling a greater understanding of the open-source software phenomenon in a platforms/ecosystems setting. Furthermore, the proposed conceptual framework on openness has utility for:

- Analyzing large platforms, ecosystems, and infrastructures (among other high-networked production environments).
- Understanding and explaining its development/production.
- Guiding inquirers on particular set of questions to ask when exploring them.

- Guiding the development of future measurements and typologies of openness.
- Juxtaposing infrastructures and platforms.[1]

5.2 Contributions from the mobile platforms case

A plenitude of this dissertation efforts were geared toward a better understanding of the implications of the OSS phenomenon to the competitive mobile platforms market. To better understand such implications, I and my coauthors (1) addressed more concretely what open-source software components were integrated by Apple, Google, and Nokia into their mobile platforms; (2) investigated the open-source platform-based strategies employed by Apple, Google, and Nokia (i.e., how they integrate OSS into their platforms); and (3) assessed how third-party application developers were coping with the strategies announced by the three platform providers – such efforts related with RQ4 research question on "Why do firms follow open-source platform-based strategies? Why do they contribute to open-source infrastructures? What are the motivators?” Based on our results (see Section 4.1.3 and dissertation article 3), we must point out that firms that committed themselves to co-create value jointly with the open-source community (i.e., that engage with OSS community) are now the leaders of the mobile-devices industry (e.g., Google and Apple). Conversely, the players that less committed to co-create value jointly with the open-source community now have reduced sales and are accumulating losses within the mobile-devices industry (e.g., Nokia and Microsoft). Given the relevance of the mobile-devices industry, we must find that existing literature associating OSS with the "alternative low cost" can be misleading [2].

So far, prior literature in computer-based platforms (mostly derived from the PC industry), as well as more contemporary work in mobile platforms, often see open-source as "an alternative with reduced market share" (Lanzi 2009). As tables turned (i.e., companies integrating OSS to a large extent are now the leaders of the market), generalizations from previous theory on "platform wars"

[1] After all, earlier research points out that infrastructures are more open than platforms (see Hanseth and Lyytinen 2010; Tilson et al. 2010).

[2] See (Davis et al. 2006; Economides and Katsamakas 2006; Lanzi 2009; Niederman et al. 2006; West 2003) among other works that associate OSS with low-cost alternatives to monopolistic software.

to a more recent context of mobile platforms should be taken cautiously. We also noted a convergence between the PC and mobile industries: (1) many of the players within the PC market are now within the mobile-devices market (e.g., Apple and Microsoft); (2) much of the technology that powered PCs is now powering mobile devices and vice-versa (e.g., Bluetooth and IEEE 802.11b); and (3) PCs and mobile devices often integrate with each other as vendors often seek complementarity, coherence, and compatibility between their own PC and mobile offer (see Mikkonen et al. 2016, for a related discussion). This convergence between industries (i.e., PC and mobile) remains largely unexplored by academia. Interesting research questions dealing with the implications of such convergence remain unexplored, such as, "Should firms concentrate on one ’platform war’ or run several ’platform wars’ in parallel?” It is also not clear if OSS plays an important role in such convergence.

5.3 Contributions from the WebKit case

The research efforts on mining the WebKit repository with social network analysis were initially intended as a study on collaboration. However, as pointed out earlier (see Section 4.1.4), I and my coauthors noticed that much of the collaboration was among competitors (i.e., software developers affiliated with competing firms co-edited the same source-code files). This motivated us to engage with coopetition theory (and other related interorganizational theory dealing both with cooperation and competition) and to search for other cases of coopetition in the open-source arena. Our outline sampling known cases of coopetition within the same OSS project (see Table 4.3 or dissertation article 6), shows that the "open-coopetition" phenomenon, even if recent spans across different industries (e.g., web, cloud, mobile, and 3D printing technologies). However, even if cooperation among competitors and OSS are phenomena with recognized impact on how value is created, explored, and exploited in networked settings, there are very few studies addressing how rival firms simultaneously cooperate and compete in the open-source arena (Germonprez et al. 2013; Teixeira et al. 2015).

From a practitioner’s viewpoint, this is unfortunate because naïve assumptions concerning "work with competitors" and "open-source work" can lead in practice to opportunistic behavior, unintended spillover effects, and loss of reputation and trust among software development partners. A deeper understanding of the phenomena would help practitioners to balance competition and cooperation in open-source ecosystems. Given the scarcity of empirical studies addressing this new phenomenon, we call for more empirical research on "How do competitors cooperate in open-source ecosystems, and why?” Therefore, we warn both FLOSS and IS scholars that little is known about how competitors cooperate in open-source ecosystems. Hopefully we, or others, will conduct future research along these lines.

As captured in Table 4.3 (page 60), cooperation among competitors in open-source arena (or "open-coopetition," as coined in dissertation article 2) is a quite heterogeneous phenomenon. It is visible across different industrial domains (e.g., GENIVI in automobile and Android in mobile devices), older and newer industries (e.g., OpenEMR in medical and Dronecode in Unmanned Aerial Vehicles). Furthermore, it is practiced by established high-tech leaders (e.g., Apple and Google in WebKit) and start-ups (e.g., Prusa and Kossel in 3D printing). Companies like IBM, VMware, and RedHat recurrently cooperate with competitors across multiple cases (e.g., RedHat is highly involved in the development of Linux, Docker, and Xen); they maintain portfolios of alliances with firms that are direct competitors. As evidenced in Table 4.3, we can argue that the phenomenon of cooperation among competitors in the open-source arena started with the commercialization of Linux – we could argue Linux as the fist case of "open coopetition." The phenomenon started in the software industry (e.g., operating systems and Internet browsers), but it is now also visible in other industries (e.g., automotive and financial).

Besides calling for future research bridging coopetition theory (and other related interorganizational theory dealing both with cooperation and competition) with open-source software, and coining the term open-coopetition (a neologism to describe collaboration between competitors in the open-source arena), our analysis of the WebKit project also highlighted the power of the open-source fork concept as a nexus enabling both features of competition and collaboration. Prior research suggests that code forking is an increasingly common occurrence within OSS communities, it is a topic that nonetheless has seen limited academic study (Robles and González-Barahona 2012). As a key output of this doctoral research, we attempt to theorize on the concept of fork by integrating it with coopetition theory (i.e., theory related to cooperation among competitors).

Forking was an essential event shaping the WebKit community[3]. First of all, the WebKit project started as a fork of two other open-source projects. When Apple decided to enter the Internet browser market, it decided to fork the KTML and KJS projects, inheriting a valuable code-base for further development in accordance with their own strategy. Later on, after Apple's WebKit debut and successful entrance into the mobile devices market, the overall project was once again forked in 2010, leading to the creation of the WebKit2 project for a more platform-independent version (pushed by Nokia and other mobile device vendors). More recently, in April 2013, Google announced that it had forked core components of WebKit to be used in future versions of its own browsers[4].

The findings, discussed in dissertation article 4, highlight open-source fork as a mechanism enabling both features of competition and collaboration. A fork may split a previously united community in two, and the simple existence of a threat of a fork has significant implications within a cohesive community. As a form of schism, all developers have the freedom of leaving the community, with a copy of the existing code base, to further develop the project on its own. As earlier proposed by Nyman et al. (2011), fork serves as an invisible hand of sustainability ensuring that the code base can remain open and best fulfills the needs of the community it lives on. Indeed, recent research has shown that even large-scale forks can achieve sustainability (Gamalielsson and Lundell 2012,1). The occurrence of several forks on the initial WebKit codebase is better understood with prior work from Nyman and Mikkonen (2011) that identifies the need of porting a program to a new hardware or software architecture as a driver of forking.

In the case of WebKit, the preexistence of a code base reduced the barriers to entry for firms that wanted to integrate Internet browsing technologies into their offering (e.g., mobile phones and personal computers). The initial WebKit code base was forked several times as an increasing number of firms become interested in porting the "program" into other hardware/software stacks. On the other side, the threat (or danger) of fork stimulated a collaborative sense of community (Lakhani and Wolf 2005) and the setup of shared norms and values (Bergquist and Ljungberg 2001) that unify the community against possible break-up forces. All this within a scenario of pooled R&D where costs and governance are shared

[3] See Figure 1 within dissertation article 4.

[4] Please note that both Google Chrome and the Android mobile devices have a very significant market share in their respective markets.

within a collaborative community (see West and Gallagher 2006).

Even if the initial goal of this research was to study collaboration in the WebKit project, fork also enables a set of competition features. At first, even if fork facilitates the commoditization of technology that can be copied and ported to architecturally different products, in the WebKit case, this only concentrated a small effort of the "whole product" offering for many of the involved firms. Firms relying on WebKit source of innovation (e.g., Apple, Google, Samsung, Adobe, and Nokia, among others), kept differentiating both while porting it to their own architectures and in other areas of their computer-based platform/ecosystem. Moreover, firms exhibited competition in the WebKit multifork scenario, when recruiting talented open-source developers or when sourcing from open-source service providers (e.g., iGalia). Besides competing for talented labor needed for developing such a large-scale open-source fork, firms also compete for abortive capacity (Cohen and Levinthal 1990; West and Gallagher 2006), technological learning (Bonaccorsi et al. 2006) and organizational learning (Bonaccorsi et al. 2006; Huntley 2003). As fork reduces barriers to entry, there is also an increased risk of free riding (Eisenmann 2007). Innovators must master the open-source community project for better guiding its development according to their own interests while being aware that "copycats" can always fork their contributions.

In Figure 5.1 we sensitize on the fork concept as a nexus (i.e., a mechanism) enabling both features of competition and collaboration[5]. On the collaboration side: 1) the danger of a fork unites the community on an established project; 2) the initial forking momentum might enhance cohesiveness in an initial post-fork phase and 3) working on the commons stimulates cooperation. On the other side, fork is related to competition as well: 1) the freedom of forking allows easier barrier to entry; 2) the freedom to fork enables technological and organizational learning from other derived projects; 3) it allows easier integration for differentiation on the "whole product"; 4) it shapes the access to talents, skills, and resources; and 5) the freedom to fork is always there, allowing anyone to create divisive derivative works.

[5] If reading this dissertation using software, please note that the figure is included as Scalable Vector Graphics – readability can be increased by zooming in.

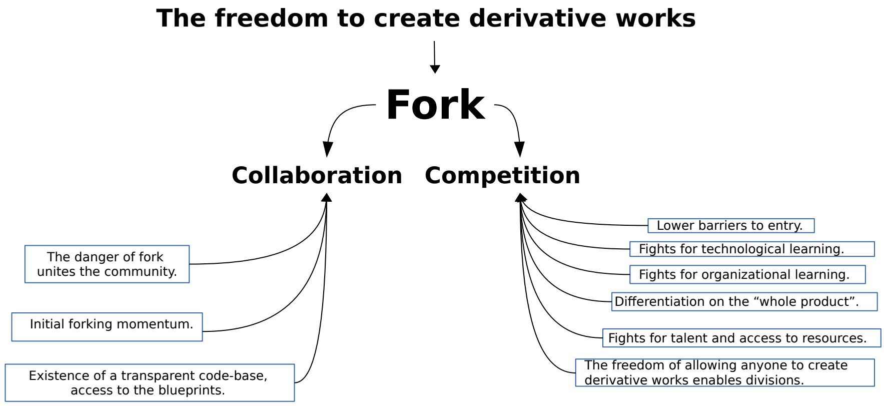

Figure 5.1: Open-source fork as an enabler of collaborative and competitive features.

5.4 Contributions from the OpenStack case

Based on our investigation of the OpenStack infrastructure for big data with social network analysis, we found out that the expected social tendency of developers to work with developers from same firm (i.e., social homophily) did not hold within the OpenStack case (see Section 4.1.5). This adds to social network theory that tested and confirmed the social principle of homophily in multiple settings. Our nonconfirmatory findings reinforce open-source software as a phenomenon that challenges the current body of established theoretical knowledge – new theories are therefore required to better understand open-source software (see Hinds 2008; Howison and Crowston 2014).

One of the most fundamental characteristics of social network theory in social sciences is the focus on relationships among actors as an explanation of actor and group outcomes (Borgatti et al. 2014; Borgatti and Halgin 2011). The principle of social homophily (i.e., that actors tend to establish ties with similar others in a group) is, therefore, central to social network theory. Such positive relationship between the similarly of two actors in a group and the probability of a tie between them was one of the first features early noted by social network analysts (Freeman 1996).

Research on the patterns of homophily is remarkably robust over various types of relations (Kossinets and Watts 2009; McPherson et al. 2001). Evidence of the homophily tendency crosses domains, in scientific fields (e.g., physics and biochemical networks) the same tendency is known as assortative mixing (Croft et al. 2008; Newman 2003; Peng 2015). Particularly in social sciences, evidence was found that "similarity breeds connection" with regard to many characteristics such as gender, ethnicity, age, religion, education, occupation, social class hierarchy, geography, family, organizational affiliation, network positions, attitudes, abilities, beliefs, and aspirations, among others (see Brass et al. 2004; McPherson et al. 2001, chapter 6 in Croft et al. 2008 and chapter 4 in Easley and Kleinberg 2010 for exhaustive reviews).

The pattern of homophily, which has heterophily as the usual antonym, gathered particular interest from social scientists studying adolescence, crime, and terrorism from a network perspective. Homophily was confirmed in outcomes that are perceived as positive such as marriage, friendship, and school achievement (Berndt and Keefe 1995; Kandel 1978; South and Messner 1986; Tolson and Urberg 1993), as well as in outcomes that are negatively perceived such as crime, rape, and terrorism (Blau and Blau 1982; Long 1990; Stohl and Stohl 2007; Young 2011). More recently, with the emergence of compressive, large datasets capturing virtual interaction among individuals (e.g., e-mail, instant messaging, and social networking websites) and with the advancement of computational social science the pattern of homophily has been further confirmed for large populations.

Both classical and computational social science studies[6] recurrently confirmed that homophily bounds social networks (Aral et al. 2009; Bakshy et al. 2015; Colleoni et al. 2014). We are therefore surprised by our nonconfirmatory results (see dissertation article 5). In a more recent study that followed ours, Linåker et al. (2016) investigated the Hadoop – open-source distributed storage and processing technologies for big data jointly developed by an extensive network of participants (e.g, Cloudera, Yahoo!, Facebook, Twitter, LinkedIn, Jive, Microsoft, Intel, and Hortonworks, among others). The results pointed out that developers affiliated with competing firms collaborate as openly as the ones affiliated with nonrivaling firms do. Once again, the theoretically expected homophily regarding company affiliation was not observed in open-source communities as in other social networks[7]. This difference between the patterns

[6]See Lazer et al. (2009) for a discussion on the emergence of data-driven "computational social science" in general and Lindberg et al. (2013) on its application to open-source in particular

[7]As a side note, another related study exploring gender bias in open-source software development was recently pre-archived by Terrell et al. (2016). By mining by GitHub and Google+, they

of homophily in open-source communities and the patterns on homophily in other social networks merits further examination.

As put by Gallivan and Ahuja (2015), who confirmed homophily in the coauthorship networks of research published in top IS journals[8], the effect of homophily is also interesting by its contradictory effects. On the one hand, creating new knowledge relies on recombining ideas (Fleming et al. 2007) across diverse areas of the knowledge possessed by the team (West 2002). On the other hand, team members are required to be comfortable working with each other (e.g., Guimera et al. 2005; Taylor and Greve 2006). A better understanding of the dynamics of homophily can lead to more effective reward structures and more creative collaboration structures (Gallivan and Ahuja 2015).

Our nonconfirmatory findings give force to prior findings that quantitative tested well-established theories (e.g., Social Network Theory, Social Capital Theory, Work Group Effectiveness, Communities of Practice, and Networks of Practice, among other social theories that look at social structure) within the context of open-source software (see Hinds 2008). As evidenced in the following quote, and contrary to theory-based expectations, results derived from the analysis of open-source software repositories did not confirm what have been proposed so far – as early acknowledged by von Krogh and Spaeth (2007), open-source software is filled with theoretical tension (i.e., it challenges previously established theories).

> "Successful project groups exhibited low levels of closure and that the levels of bridging and leader centrality were not important factors of success. These findings suggest that the creation and use of open-source software may represent a fundamentally new socio technical development process which disrupts the team paradigm and which triggers the need for building new theories of collaborative development. These new theories could point toward

found out that when a woman's gender was not obvious from her name or photo in the GitHub profile, her patch would be slightly accepted more often than a patch (i.e., code contribution) from a man. However, as the study was not yet published in a peer-reviewed outlet, we opted to not build upon it.

[8] As a raw empirical note, leading IS academic conferences are sites where the homophily pattern can also be observed – we can often depict groups for professors, groups of youngsters, groups of qualitative researchers, German-speaking, Scandinavians, graduates from the same university, editors of the same journals among other attributes that bound scholars together in the IS community.

> the broader application of open source methods for the creation of knowledge-based products other than software" – (Hinds 2008, pp8)

Furthermore, besides testing the social principle of homophily within a novel context, our findings from the OpenStack study also highlight the value of coopetition theory to both understand and explain the evolution of the OpenStack infrastructure for big data. Some results were somewhat surprising for the established body of theoretical knowledge in coopetition (see dissertation article 5 and dissertation article 6). Also from a more practical perspective, our results also call for the development of code-collaboration metrics and visualizations as a valuable complement to established software development metrics emphasizing code size, code quality, and productivity.

In addition, when seeing the OpenStack case from the lenses of theory in open-source software and user-innovation[9], and based on our finding from the OpenStack case I argue for following two propositions:

Theoretical Proposition 1 – *Within an R&D context where multiple organizations co-develop open-source software, the inclusiveness of open-source ecosystems stimulates both cooperation and user-innovation.*

Theoretical Proposition 2 – *Within an R&D context where multiple organizations co-develop open-source software, the transparency of open-source ecosystems also facilitates the transfer of information and resources among partners.*

By the same token and from another theoretical perspective, when seeing the OpenStack case within the theoretical background of strategic networks, ecosystems, and portfolio of alliances (as in dissertation article 6), we propose that development transparency and weak intellectual property rights (i.e., characteristics of open-source ecosystems) allow a focal firm to transfer information and resources more easily between multiple alliances – this should interest scholars with interest in coopetition and portfolios of alliances. Therefore, in dissertation article 6,we discussed the following theoretical proposition:

[9]A thorough review of user innovation can be found in von Hippel (1988, 2005).

Theoretical Proposition 3 – *Within an R&D context where a focal firm is engaged in multiple alliances, development transparency and weak intellectual property rights allow an easier flow of information and resources between alliances.*

Finally, when seeing the OpenStack case within the theoretical background of digital infrastructures, and by scrutinizing the evolution of the social structure of OpenStack in relation to its competitive environment endogenously and exogenously (see fig. 4.5), following especially the evolution of Citrix's competitive-cooperative actions and discourse (see Figure 4.6), we propose the following two theoretical propositions on the evolution of digital infrastructures:

Theoretical Proposition 4 – *Infrastructure evolution is influenced by the competing infrastructures. Competitive and cooperative behaviors within a infrastructure are influenced by the dynamics of competing infrastructures.*

A focal organization can be engaged in the development of multiple and competing infrastructures. The competitive-cooperative behavior of the focal organization within and among infrastructures influences their evolution. In other words, competitive-cooperative behavior that can occur at the interindividual, interorganizational, and interinfrastructure levels influences the evolution of infrastructures.

Theoretical Proposition 5 – *Openness increases interactions among digital infrastructures. Characteristics such as development transparency, distributed control, and weak intellectual property rights enable competitive-cooperative interactions among different infrastructures.*

A focal organization can be engaged in the development of multiple and competing infrastructures. If such infrastructures are open-source (versus proprietary) it is more likely that a focal organization will engage in competitive-cooperative interactions among infrastructures.

The last proposition is especially paradoxical. On one hand, theory suggests that such relational interactions can drive potential synergies (Gnyawali et al. 2010; Gnyawali and Park 2011). On the other hand, theory suggests that the same relational interactions can also lead to opportunistic behaviors, unintended spillover effects, and undermining of trust (see Chen and Miller 2015; Fernandez et al. 2014).

Considerable attention has been paid to the evolution of digital infrastructures (Henfridsson and Bygstad 2013). It is known that infrastructures are embedded within other sociotechnical systems and shaped by social practices and conventions of practice (Star 1999; Star and Ruhleder 1996; Vaast and Walsham 2009). Many embraced tension and paradox to explain digital infrastructure evolution uncovering some of the many mechanisms behind it (Eaton et al. 2015; Hanseth et al. 1996; Tilson et al. 2010). Our findings suggest that infrastructures co-evolve with the competing infrastructures. Understanding infrastructure requires an especially astute awareness of the competitive landscape. Research addressing the evolution of digital infrastructures should therefore acknowledge that infrastructures entangle with other infrastructures, even with competing ones.

6 Conclusion

In this last chapter, after presenting the results (see Chapter 4) and discussing its implications (see Chapter 5), I conclude this dissertation with an attempt to succinctly pinpoint theoretical and managerial contributions to a broad audience.

6.1 Contribution to theory

Besides testing knowledge from the last decades on computer-based platforms (Gawer and Cusumano 2008; West 2003) and multi-sided platforms (Hagiu and Wright 2011; Rochet and Tirole 2003) within emergent scenarios, this study aimed to provide scholars with rich descriptions of real-world issues faced by corporations following open-source based platform strategies (i.e., corporations that integrate open-source technological components within platforms to a great extent).

Both from combining multiple case studies and research approaches and from bridging theoretical constructs across different disciplines, we propose a cross-disciplinary framework to analyze the manifestations of open-source platform-based strategies within emergent industries (i.e., mobile and cloud computing). Our findings, bounding with the concepts of platform, ecosystem, and infrastructure, also matter to practitioners by increasing the understanding of how corporations follow an open-source based platform strategy – or in other words, describing on how corporations integrate OSS technological components from the open-source domain into their own computer-based platforms.

We started by investigating the mobile industry with a strong focus on cooperation in the joint development of computer-based platforms. We argued that open-source software should no longer be associated with alternative low-cost products (see Economides and Katsamakas 2006; Lanzi 2009) and that the freedom of ”forking” (see Gamalielsson and Lundell 2014; Robles and González-Barahona 2012) acts as a nexus enabling both features of competition and collaboration. I later narrowed the theoretical inquiry to ”how competitors cooperate" in the joint development of such platforms. At the same time, we also expanded our empirical boundaries from the mobile devices industry to the cloud computing industry as we noted that collaboration among competitors in the open-source arena is an expanding phenomenon with cross-industrial impact – after all, both the demand from consumers and the offer from suppliers of OSS are increasing across industries in today's high-networked economy (see Table 4.3 for a number of evidences).

Even though we started with a theoretical background in open-source and platforms, we moved on to explore other cross-disciplinary concepts, such as ecosystem (Adner and Kapoor 2010; Iansiti and Levien 2004; Moore 1996) and infrastructure (Hanseth and Lyytinen 2010; Henfridsson and Bygstad 2013; Tilson et al. 2010). We braced coopetition theory from the fields of Marketing and Strategic Management within exploratory case studies. Our cases confirmed much of the established literature on coopetition. The need for external resources is a main driving force behind the establishment of long-term cooperative relationships (Kock 1991). Through cooperation, two companies can gain access to each other's unique resources or share the cost of developing new, unique resources (Bengtsson and Kock 2000). Within an open-source scenario, it is an open (i.e., open for contributions from everyone) and networked community (i.e., integrating firms and independent developers) that fulfills the need for external resources. Moreover, according to Bengtsson and Kock (2000), individuals within a firm can only act in accordance with one of the two logics of interaction at a time –that is, either compete or collaborate. Hence, the two logics either have to be divided between individuals within the company or need to be controlled and regulated by an intermediate organization such as a collective association. Within an open-source scenario, it is the infrastructure community that plays the role of such an intermediate organization. Developers must identify themselves with the infrastructure community in order to be able to collaborate with rivals.

Our research also found discrepancies with some of the prior literature on R&D coopetitive networks, which address alliances in a form of either joint ventures, consortia, or other arrangements where access is only granted to a few select partners (see Dagnino et al. 2008; Gnyawali and Madhavan 2001). In our open-source community case, everyone is welcome to contribute to the project, and everyone is allowed to copy, sell, and distribute outcomes from the project. Moreover, the classical coopetition literature also argues that coopetition activities take place far from the customer; *"competitors* *cooperate with activities far from the customer and compete in activities close to the customer"* (Bengtsson and Kock 2000). However, in the open-source infrastructures, coopetition can also occur very close to the market and customers; in the terms of user-innovation (Lakhani and von Hippel 2003; von Hippel 2009)[1]. In the WebKit and OpenStack cases, some of the end customers (e.g., the ones purchasing mobile devices powered by WebKit or public clouds running OpenStack) contributed occasionally to the infrastructure. Our research data from open-source ecosystems revealed many nonaffiliated developers and end-users contributing with coding, bug fixing, testing, localization, documentation and translation efforts, enabling user-innovation on the studies projects.

Based on the theoretical integration of our findings, we propose the novel notion of open-coopetition, originated but deviating from prior knowledge on coopetition, to explain the development of complex and highly networked R&D projects in the open-source arena. All of this is geared toward a ”plug-in” theory that should explain collaboration among rival firms in an open-source way: coopetition in the public domain where nobody needs to ask for permission to contribute or innovate; and in an open intellectual property regime where everyone is allowed to modify, copy, sell, and distribute community-driven innovations.

Overall, the use of the selected social theories (e.g., coopetiton, homophily) was revealed to be valuable to explain our empirical results. We found, however, nonconfirmatory findings (aka theoretical anomalies) when applying established social theories within the particular context of this study. As remarked earlier, the open-source phenomenon is filled with theoretical tension as it challenges previously established theories (see von Krogh and Spaeth 2007). Newer and more encompassing theories are therefore required to better understand open-source software in general (see Hinds 2008; Howison and Crowston 2014). More particularly, future research is required to understand why certain theoretical aspects of coopetition and homophily do not hold within the particular context of open-source software.

[1] Such results are in line with parallel discussions in value co-creation in the Marketing discipline (see Grönroos 2012; Lessem and Palsule 1997) and in value co-production in the Strategic Management literature (see Huemer 2006; Ramirez 1999).

6.2 Contribution to practice

We believe that our research has important implications for the overlapping practices of R&D Management, Information Systems, and Software Engineering. Moreover, a better understanding of coopetition in the open-source arena informs the regulatory practice on how rival firms collaborate and compete in the open-source arena[2].

From the set of previously discussed contributions to practice (see chapter 5), we would like to emphasize the potential of our approach (i.e., longitudinal Social Network Analysis with emphasis on the visualization of cooperative activities) to support stakeholders of high-networked open-source projects. First of all, and from a project governance perspective, our Social Network Analysis metrics and visualizations can help different stakeholders in assessing their interfirm network positions for better decision making regarding internet-worked strategic alliances; see (see Teixeira 2014a). The interpretation of such visualizations, which can be combined with traditional software engineering metrics (see Figure 6.1), empowers projects' decision makers. Second, and from the producer's perspective, software developers are empowered with novel code-collaboration analytical tools, providing rich information that can lead to improvements in the software development process. Third, and from the consumer's perspective, users, adopters, and integrators can better grasp project's social structure evolution and dynamics. They can then make thorough assessments of its sustainability when reacting to exogenous events in the industry. Fourth, investors are also provided with a complementary analytical tool for clarifying network dynamics, improving the forecast of product attractiveness and future growth (see Teixeira and Lin 2014b; Teixeira et al. 2015).

Finally, and besides the methodological approach, our theorizing of "open-coopetition" (Teixeira and Lin 2014a), derived from our recent research efforts at a very preliminary stage, provides guidance on the management of high-networked R&D activities in a more open-source fashion: namely, minimizing the need for gatekeepers, lawyers, and complex intellectual property arrangements, while maximizing development transparency, sense of community, and value co-creation beyond the organizational boundaries as illustrated in Fig-

[2] Economists recognize that competition, while harming some participants, benefits the overall society. However, on the other hand, firms naturally seek noncompetitive behaviors (e.g., the establishment of monopolies and cartels). Regulation entities should orchestrate how firms balance cooperation and competition toward the interests of the overall society.

ure 6.2. Much future research is needed toward a better understanding and explanation of open-coopetition.

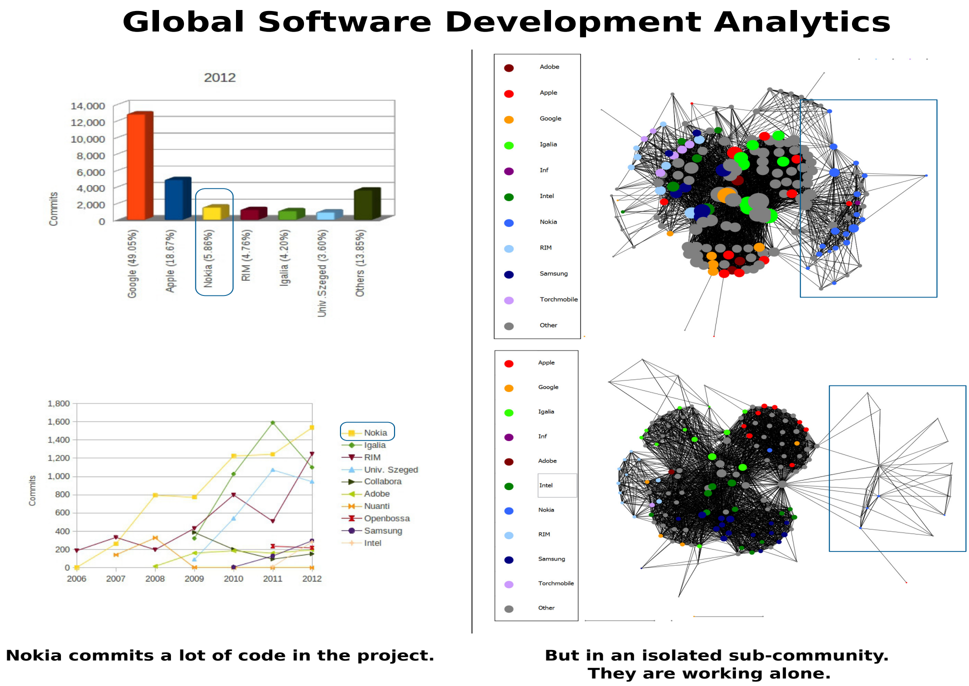

Figure 6.1: Combining code-driven metrics with social network visualizations.

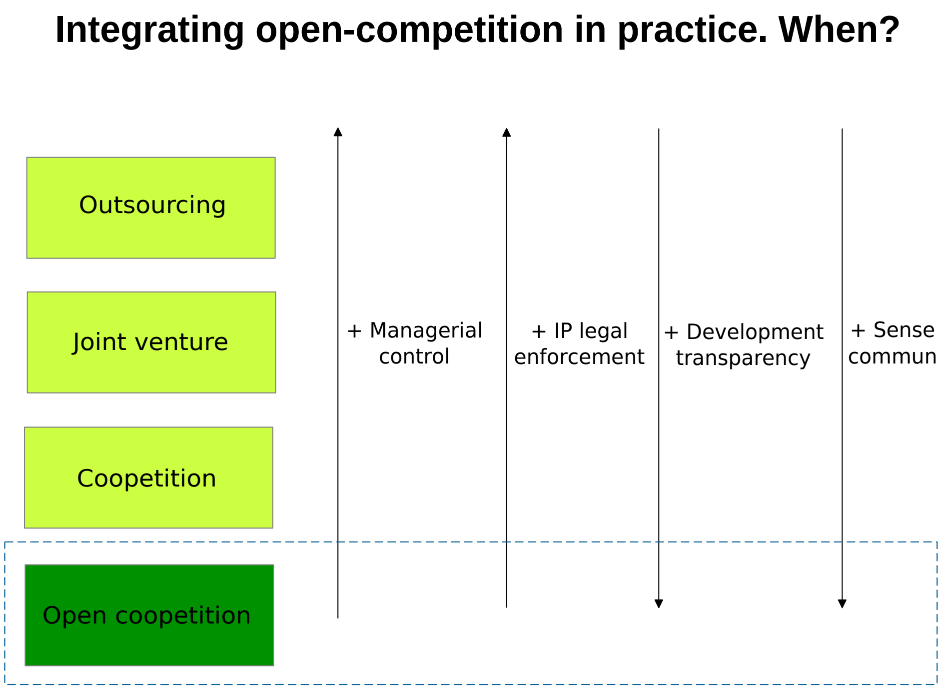

Figure 6.2: The open-coopetition theory in practice.

Part II

Original articles

The original articles, as well as the presentation website supporting the defense of this doctoral dissertation, are available under the open-access terms at the author personal website at `http://www.jteixeira.eu`.

Article 1

Addressing **What do we know about open-source and computer-based platforms?**

. . . .

Teixeira, Jose and Baiyere, Abayomi. Crafting a systematic literature review on open-source platforms, *Proceedings of the 10th IFIP WG 2.13 International Conference on Open Source Systems (OSS 2014)*. San Jose, Costa Rica, May 6-9, 2014, Springer.

. . . .

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Publicly available at `www.jteixeira.eu/pub/phd-article1.pdf`.

Article 2

Initially addressing **What do we mean by ’openness’ of computer-based platforms? How to measure it?**

. . . .

Teixeira, Jose. On the openness of digital platforms and ecosystems, *In Proceedings of the 11th International Symposium on Open Collaboration (OpenSym 2015)*. San Francisco, USA, August 19-21, 2015, ACM.

. . . .

. . . .

Publicly available at `www.jteixeira.eu/pub/phd-article2.pdf`.

Article 3

Initially addressing **What are the open-source software technological components integrated by the mobile-devices vendors?**

. . . .

Mian, Salman and **Teixeira, Jose** and Koskivaara, Eija. Open-source software implications in the competitive mobile platforms market, *Proceedings of the 11th IFIP WG 6.11 Conference on E-business, E-services, and E-society, I3e 2011*, Kaunas, Lithuania, October 12-14, 2011, Springer.

. . . .

. . . .

Publicly available at `www.jteixeira.eu/pub/phd-article3.pdf`.

Article 4

Initially addressing **How rival platform-vendors collaborate in the open-source arena?**. Also addressing **How do rival firms collaborate in open-source infrastructures? How does the collaboration evolve over time? How is collaboration affected by exogenous events in the surrounding industrial market?**

. . . .

Teixeira, Jose and Lin, Tingting. Collaboration in the open-source arena: The WebKit case, *Proceedings of the 52nd ACM SIGMIS Computers and People Research (CPR 2014)*, Singapore, May 6-9, 2014, ACM.

. . . .

. . . .

Publicly available at `www.jteixeira.eu/pub/phd-article4.pdf`.

Article 5

Initially addressing **How rival platform-vendors collaborate in the open-source arena?**. Also addressing **Is there a tendency towards sub-grouping in open-source infrastructures? With whom developers tend to work with? Are there different sub-communities within the infrastructure's community?** and **How competition for the same revenue model (e.g., Rackspace vs. HP on public clouds, Citrix vs. VMware on virtualization technologies, Google vs. Apple in web-browsers) affect collaboration in open-source infrastructures?**

. . . .

Teixeira, Jose with Robles, Gregorio and González-Barahona, Jesús Lessons Learned from Applying Social Network Analysis on an Industrial Free/Libre/Open Source Software Ecosystem, Published after 3 revisions at *Journal of Internet Services and Applications*, Springer.

. . . .

. . . .

Publicly available at `www.jteixeira.eu/pub/phd-article5.pdf`.

Article 6

Initially addressing **How rival platform-vendors collaborate in the open-source arena?**. Also addressing **Why companies follow open-source platform-based strategies?**

. . . .

Teixeira, Jose with Mian, Salman and Hytti,Ulla . Cooperation among competitors in the open-source arena: The case of OpenStack, *Proceedings of the 37th International Conference on Information Systems (ICIS2016), Dublin, Ireland, 11-14 December, 2016, AIS.*

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Publicly available at `www.jteixeira.eu/pub/phd-article6.pdf`.

The presentation slides supporting this dissertation defense are also publicly available at the author personal website at `http://www.jteixeira.eu/presentations/diss/`.

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