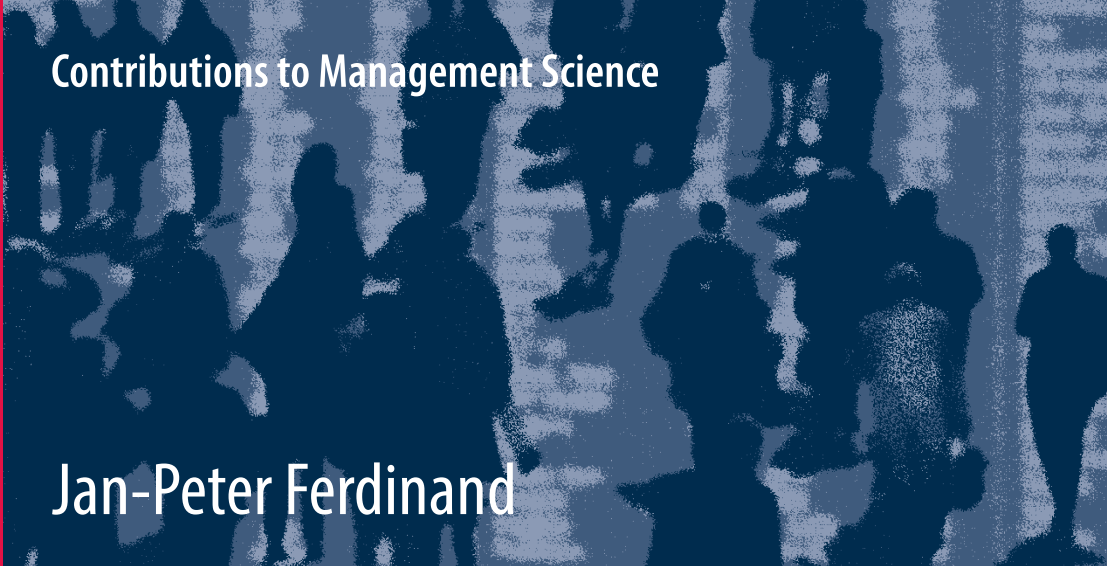

Contributions to Management Science

Jan-Peter Ferdinand

Entrepreneurship in Innovation Communities

Insights from 3D Printing Startups and the Dilemma of Open Source Hardware

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Contributions to Management Science

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Insights from 3D Printing Startups and the Dilemma of Open Source Hardware

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Zugl.: Berlin, Technische Universität, Diss., 2017 u. d. T. Innovation Communities & the Dilemma of Entrepreneurship - Insights from the Field of Desktop 3D Printing.

ISSN 1431-1941 ISSN 2197-716X (electronic)
Contributions to Management Science
ISBN 978-3-319-66841-3 ISBN 978-3-319-66842-0 (eBook)
DOI 10.1007/978-3-319-66842-0

Library of Congress Control Number: 2017950333

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

It is easy to fall in love with the idea of people making something for the greater good, but how much of that is just a naive view of reality? How much are we living in denial, blind to the fact that things might work differently? Some lovers might show a face to you and lie, but most of the times you aren't ready to ask the right questions, mostly because you might not be willing to hear the truth. (David Cuartielles 2014)

Acknowledgements

This book originates from the research I conducted during my PhD project at Technische Universität Berlin. It would not have been possible without the financial support of the German Research Foundation (DFG) and its funds for the Graduate School "Innovation Society Today—The reflexive creation of novelty," which provided the best of all possible environments to get this work done. In addition, the scholarship granted by the German Academic Exchange Service (DAAD) enabled my studies abroad in Berkeley that influenced the story of this book a lot.

Talking about persons, first I want to thank the 3D printing entrepreneurs, RepRap community members, and advocates of Open Source Hardware, who participated in my empirical research, for their openness and kind support. Furthermore, I am especially indebted to Prof. Arnold Windeler, chair for the Sociology of Organizations at Technische Universität Berlin, who was always willing to share his scarce time and rich knowledge to encourage me and my work. I am also very grateful for the essential advice of Prof. Leonhard Dobusch, Department of Organization and Learning at Universität Innsbruck, who was the smartest second supervisor I can imagine. Another big "Thank you!" goes to my fellow colleagues, especially Uli Meyer, Julian Stubbe, Fabian Schroth, Uli Petschow, Robert Jungmann, Valentin Janda, and Robin Tech for their feedback, cooperation, and friendship.

Nobody has been more important to me and the success of this endeavor than the members of my family. My loving wife Sonja and our adorable children Clara and Ellen are the infinite source of my inspiration and motivation. Last but not least, I want to thank my parents Ingelore and Hans, whose love and encouragement are with me in whatever I pursue.

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Chapter 1
Believe Me, Don't Believe the Hype

It is easy to fall in love with the idea of people making something for the greater good, but how much of that is just a naive view of reality? How much are we living in denial, blind to the fact that things might work differently? Some lovers might show a face to you and lie, but most of the times you aren't ready to ask the right questions, mostly because you might not be willing to hear the truth. (David Cuartielles 2014)

Abstract This introductory chapter raises the book's guiding question: How do the institutional idiosyncrasies of innovation communities affect entrepreneurship in the field of desktop 3D printing? It also gives first insights on the emerging issue of open source hardware and illustrates the conceptual, theoretical, and practical perspectives applied in this work.

When I started out with this PhD project, I was eager to tackle the topic of 3D printing, which at the time was the next big thing in tech. Similarly to the impacts of desktop publishing in the late 1980s, 3D printers were envisioned as means to "spur a manufacturing revolution" (Vance 2010, *New York Times*) that enable everyone to have a private "factory on [his or her] desk" (*The Economist* 2009). Although admittedly impressed by the medial buzz and the bright promises that accompanied the technology, my personal interest in 3D printing from the beginning focused more on the organizational and cultural contexts, in which the technology gained its initial momentum. Indeed, as 3D printers represent the major case of the relatively new phenomenon of open hardware (OH) or interchangeably open source hardware (OSH), these contexts emphasized decentralized and non-commercial modes of community-based developments as exciting new approaches for the ideation and innovation of tangible products.

While open source principles already proved their evidence as promising means for innovation in contexts of collective software developments, the present research project emphasizes the adoption of related practices like open knowledge exchange, intellectual property (IP) refusal, or the non-commercial provision of outcomes

J.-P. Ferdinand, *Entrepreneurship in Innovation Communities*, Contributions to Management Science, DOI 10.1007/978-3-319-66842-0_1

within the originally patent-based realms of hardware-based product development. However, before I dig into this endeavor more deeply, I want to outline why I conceive these related topics as a worthwhile contribution to the current body of knowledge on innovation dynamics.

In contemporary western societies, innovation has become a dominant paradigm to drive technological, economical, as well as societal change (Hutter et al. 2011). Under this ubiquitous banner, modes of action and organization that nurture the path of ongoing innovations have become increasingly multifaceted. One of these new facets for doing innovation captures the capabilities of decentralized patterns of knowledge creation that, under some circumstances, are likely to outcompete established routines of firm-based research and development (R&D), for example. The guiding motif behind this perspective might be summed up by a renowned quote from Sun Microsystems' co-founder Bill Joy, which subsequently spread as "Joy's law," stating that "no matter who you are, most of the smartest people work for someone else" (see Lakhani and Panetta 2007, 97).

Indeed, Joy's law refers to a key feature of innovation in the digital age. As digital technologies enable the low-threshold creation and distribution of knowledge and skill among an extensive network of heterogeneous actors, capacities to leverage innovations become increasingly diverse. Consequently, it is almost impossible to fetch digitally dispersed expertise within spatially as well as temporarily bounded organizations, what potentially lowers the relevance of focal enterprises and forces them to engage in rather scattered exchange processes with actors outside their firm boundaries. In the multiple contexts of innovation studies, strands of research that address these topics refer to concepts of open innovation or open business models (Chesbrough 2003, 2006), democratized or user-based innovation (von Hippel 1988, 2005), as well as the already mentioned patterns of open source software development (DiBona et al. 1999; Raymond 2001; von Hippel and von Krogh 2003). While each of these strands somehow discusses interfaces between distributed forms of knowledge creation, none of them adequately defines the conceptual idiosyncrasies of the corresponding modes of organization and coordination (O'Mahony and Lakhani 2011).

In order to enter this void, I introduce the concept of *innovation communities* as an offer to grasp informal modes of collective but distributed innovation. Innovation communities represent sets of actors that collectively engage in the development, improvement, or application of novel goods and services. They are based on the imperative of openness and accessibility of knowledge and therefore delineate an alternative way of doing innovation that lacks central guidance and does not primarily create knowledge for commercial purposes. To elaborate my notion of innovation communities and corresponding processes of community-based innovation (CBI), I draw on insights from the New Institutionalism in sociology as well as field theory. I believe that this approach helps to single out the structural as well as institutional features that enable (and restrict) community-based types of innovation. In this regard, a particular focus of this book draws on the matter of entrepreneurship, a critical practice that reveals principal frictions within innovation communities. Applied to the context of 3D printing, which represents my empirical field of investigation, the merger of the general perspective of innovation communities on the one hand and the particular focus on entrepreneurship on the other informs the guiding question of this book: *How do the institutional idiosyncrasies of innovation communities affect entrepreneurship in the field of desktop 3D printing?*

Against the background of my general research question, the upcoming sections of this introduction present the scope of related perspectives (Sect. 1.1), introduce the empirical context of 3D printing (Sect. 1.2) and finally give an overview over this book's agenda (Sect. 1.3).

1.1 Scope of Perspectives

The present work aims to enrich the body of knowledge on innovation communities and the corresponding modes of community-based innovation. It therefore compiles a triad of conceptual, theoretical, and practical contributions that form the cornerstones of this book and complementary address the state-of-research on open and distributed innovation (1), the theoretical discussions at the intersection of institutions and fields (2), as well as the findings derived from my empirical investigation (3).

1.1.1 Conceptual Perspective

My conceptual framework for this project draws on the generic assumption that innovation has become increasingly diverse. Consequently, while early innovation scholars predominantly emphasized the dominant paradigm of industrial R&D (Arrow 1962; Freeman 1982; Levin 1988), related research foci subsequently expanded in order to grasp more multifaceted patterns like, for instance, innovation systems (Nelson 1993; Freeman 1995; Lundvall 2010) or inter-organizational networks (Robertson and Langlois 1995; Powell et al. 1996; Sydow and Windeler 1998). In the contemporary age of digital innovation, the tendencies towards increased decentralization and intensified collaboration among heterogeneous actors also spurred discussions on communities and crowds, which represent alternative types of coordination based on informal ties especially prevalent in the digital realm (Brabham 2008; West and Lakhani 2008; Dobusch et al. 2013).

Although I believe that the loosely coupled and diffuse interactions, which characterize crowds, can drive idea exploration and leverage the "cognitive surplus" of digitally networked actors (Shirky 2010), they also represent rather random forms of social organization that lack capacities for collective, mutually aligned actions. Communities, however, have recently gained increasing interest as a governance mode for collective action, one which expands the big three of market, hierarchies, and networks (Lave and Wenger 1991; von Hippel 1988; Adler 2001;

Gläser 2001; Seidel and Stewart 2011). However, work on the topic either underemphasizes the structural and theoretical foundations of community-based modes of coordination or barely elaborates on their potential as distinct settings for innovation. As I will point out, the specific institutional background of innovation communities constitutes social contexts that on the one hand promote advantageous means for collective exploration and knowledge creation, but on the other hand restrain entrepreneurial opportunities that intend to exploit related efforts in commercial ways.

Within such communities, exploration typically resembles an open, generalized exchange of knowledge and expertise among the participating actors. However, since such collectives are surely capable of generating large and diverse amounts of new and potentially innovative ideas, diffusing or exploiting these may be more difficult for innovation communities to accomplish. Since the collectively created knowledge nevertheless offers promising entrepreneurial opportunities, it is occasionally appropriated by external companies or members of the innovation community spinning-out associated startups. In each case, the actors that develop ambitions to appropriate community-based innovations face a dilemma—they are caught between the symbolic and practical foundations of the community on the one hand and rather entrepreneurial rationalities on the other. Elaborating the principal contradictions that accompany the entrepreneurial dilemma represents my approach to refining the concept of innovation communities and delineating the corresponding dynamics of CBI.

1.1.2 Theoretical Perspective

In most general theoretical terms, I conceive of (innovation) communities as a phenomenon located at the meso-level of social order, in which actors engage with one another on the basis of shared understandings and collective rationalities that constitute a common *issue* of interest and thus reproduce a particular *field* as a distinct social system. This general notion allows me to integrate the discussion of communities within some of sociology of organization's most influential theoretical strands. Indeed, while the links to theories of fields (DiMaggio and Powell 1983; Bourdieu and Wacquant 1992; Hoffman 1999; Fligstein and McAdam 2012) are obvious, a second theoretical reference point for this book is the concept of institutional logics, which recently (re-)gained considerable momentum within the body of literature associated to the New Institutionalism (NI) in organizational analysis (DiMaggio and Powell 1991; Friedland and Alford 1991; Thornton et al. 2012). Since I consider the features and characteristics that distinguish one field from another merely as a matter of specific institutional arrangements, merging the two theoretical perspectives helps me to capture the idiosyncrasies of innovation communities analytically.

However, to understand the dilemma of entrepreneurship in the context of community-based innovation, an exclusive focus on the particular logics that inform innovation communities is insufficient. Instead, the entrepreneurial ambitions, which motivate community members to become founders of commercial ventures, usually reflect business logics as well. Hence, the symbolic contradictions and practical frictions that emerge between the poles of collective exploration and individual exploitation also reflect the contradictory relationships between different institutional logics – logics that either emphasize values of openness and non-proprietary knowledge exchange or support instead pragmatic orientations towards economic gain and business viability. According to my analytical emphasis on the field level, I assume that the practical implications associated with the dilemma of entrepreneurship play out at arenas, which emerge between distinct meso-level orders and thus intersect the effects of different institutional logics.

Since entrepreneurs for community-based innovation reside at the intersection nexus of community- and market-based fields, they face potentially contradictive references for appropriate action. What is considered as legitimate in the one context may be conceived is inappropriate in the other. Hence, these actors need to become knowledgeable for the particular understandings and rationalities that constitute each of these settings. Tracing the strategies they use to navigate through the jungle of institutional ambiguities thus offers general insights on the particular impacts of different logics and their overall relevance in the broader context of nested and multifaceted field structures.

1.1.3 Practical Perspective

Regarding the practical contribution of the book, it is worth mentioning that although the concept of innovation communities is principally versatile and applicable to many facets of collective action that promotes potentially innovative outcomes, it so far mainly resonates within the digital sphere and related processes of open source software development (OSS, Raymond 2001; Kogut and Metiu 2001; Dahlander and Magnusson 2005). Indeed, because digital innovative outcomes such as software applications reveal properties of nonrival goods, trading them as community-governed commons represents a viable way to sustain and reproduce interaction within the community-based fields (Benkler 2006; Lessig 2006).

When applied to contexts of physical value creation, studies in the context of user innovation offer first hints that the community model is stretched to its limits when the corresponding practices require monetary investments in raw materials, tooling, prototyping, and manufacturing (Franke and Shah 2003; Hienerth 2006; Baldwin et al. 2006). Thus, the transformation from collectively generated ideas to tangible outcomes accompanies a switch between collective- and individual modes of action that usually causes practical friction (Brinks and Ibert 2015). Consequently, although the conceptual framing of innovation communities is similar in both contexts of digital and tangible value creation, the actual effects of CBI are likely to differ among its particular contexts of application.

Against this background, open source hardware offers an empirical setting in which these contrasts play out evidently. While the blueprints that document the designs, built-in components, and construction manuals of OSH resemble commons-based knowledge similar to the source code of OSS, the tangible devices produced based on these blueprints resemble the properties of private goods. This hybrid nature of OSH also affects the contexts of its creation, which therefore offer a worthwhile starting point to investigate the principle opportunities and roadblocks of community-based modes of innovation that increasingly enter the physical world.

Besides, the empirical context of OSH is particularly useful when studying the dilemma of entrepreneurship and its actual implications on community members that become founders of OSH startups. On the one hand, these constellations reflect the strong, value-based bonds that shape the entrepreneurs' social background in innovation communities. On the other hand, the market criteria that these actors need to adapt in order to create viable business models partly contradict the community principles. In the course of my empirical investigation, I will particularly focus on the tensions that fuel the dilemma of entrepreneurship in OSH and trace the practices and strategies that actors apply to cope with them.

1.2 Setting the Scene: Open Source Hardware, 3D Printing, and Entrepreneurship

Although relatively young, the scope of particular topics that together constitute the phenomenon of open source hardware already offers a considerable variety in terms of technologies, applications, and purposes. Hence, the general issue appears too broad to define an appropriate starting point for research on the particular properties of innovation communities. In order to narrow this variety down to a field that for instance allows a targeted access to reliable empirical data, I decided to focus on the more immediate context of 3D printing as the most developed and well-known application of open source hardware. In the next paragraphs, I will nevertheless outline the general backgrounds and basics of open source hardware before I introduce the field of 3D printing as the particular case for my research.

Generally, OSH refers to the development of material devices in terms of "hardware hacking" as a practice that opens up black boxes of consumer electronics to enable the creation of novel devices with new functionalities (A. Powell 2012). In this regard, the so-called "Homebrew Computer Club" (HCC), which started in 1975 as a group of engineers and technicians in a two-car garage in Silicon Valley's Menlo Park, serves as the first and most iconic example of such practices, even before ideas of open source software first came up. According to Levy's description of the early HCC days, "they [the founding members] discussed what they wanted in a club, and the words people used most were 'cooperation' and 'sharing'" (Levy 1994, 202). Based on their passion and fascination on technology hacking, the Club constituted a growing community of user innovators who regularly met to exchange their latest takes on microcomputers. The first Apple computers, which later gained a considerable impact on the history of personal computing, also originated at least partly from the fertile atmosphere of the HCC. Steve Wozniak, who was among the early HCC members, describes this initial phase of development as follows:

> The Apple I and II [personal computer] were designed strictly on a hobby, for-fun basis, not to be a product for a company. [. . .] There was a lot of showing off to other members of the club. Schematics of the Apple I were passed around freely, and I'd even go over to people's houses and help them build their own. [. . .] It's very motivating for a creator to be able to show what's being created as it goes on. (Wozniak no year)

Retrospectively, it is hard to determine to what extents either Wozniak' background in the HCC or his employment at Hewlett Packard shaped the motivation to found the Apple Computer Inc. together with Steve Jobs. Nonetheless, the history of Apple resembles one example for the many HCC-related ventures that initially "were looking for a way to finance their avocation of playing with electronics" (Levy 1994, 202), subsequently outgrew their former hacker community, and then continued to shape the commercial tech industry to the present day.

Thriving on a growing "maker movement" and the renaissance of "do-it-yourself" (DIY) as a personalized mode of production (see Anderson 2012) the development approach of OSH has very recently increased its popularity as well as its potential applications. Furthermore, the whole concept also matured in terms of definitions, which describe OSH as "hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design"(Open Source Hardware Association 2015). Besides the similarities to the open source software realm (the hardware blueprints essentially resemble a pendant of open source software code), OSH's distinction from OSS is obvious, too. Since OSH needs to be materialized by production, related devices like 3D printers, (media)artistic equipment (like e.g. sampling machines or synthesizer), micro-controllers, and unmanned aerial vehicles ("drones") do not share the nonrival properties of information-based goods like software. Instead, they reveal a hybrid nature, which on the one hand adopts the radical approach of OSS by freely revealing product blueprints within innovation communities, and on the other hand requires considerable investments in the production processes that usually result in tradable goods. Because of these financial investments, the transformation of commons-based blueprints into tangible products also accompanies a switch from a common/community-based into a private/market-based domain.

To narrow down the scope of OSH applications as well as the corresponding communities, I focus my investigation on the context of 3D printing. Although the initial idea behind 3D printing, which basically refers to layer-wise creation of any physical object, has existed since the invention of early rapid prototyping methods like stereolithography in the 1980s (Jacobs 1992), associated promises of the "freedom of creation" or "a new industrial revolution" emerged only during the last decade (Hopkinson et al. 2006; Pine and Korn 2011). One of the main reasons for increased interest in 3D printing is its adoption by non-professional users, which has transferred industry-scale 3D printing into low-threshold applications of "desktop" 3D printing.

The *RepRap* community has been a major driver in this changing dynamic; this community started in 2004 as a project to develop an affordable and easy to use *rep*licating *rap*id prototyping device. Adrian Bowyer, who at this time worked as an academic in the fields of mathematics and engineering at the University of Bath in Great Britain, launched this idea with the aim to invent a self-replicating machine that is able to print most of its components itself (in this case "most" essentially refers to anything that can be made from plastics). Since the beginning, this literally evolutionary approach to technology development was accompanied by strong accounts to free and open access to any of those knowledge-based resources (hardware blueprints, firmware etc.) that are required to rebuild and further develop RepRap 3D printers (see Bowyer 2006b).

Against this background, RepRap started as an open-source and community-based project that tried to include as many people as possible to spread both the constitutive idea as well as the actual printers (Jones et al. 2011). In the beginning, the RepRap community mainly consisted of tech savvy geeks who were particularly interested in the RepRap's engineering topics. With the rise of the maker movement and the growing appreciation of hacker-culture, the idea of 3D printing in general and RepRap's low-cost and DIY-friendly approach in particular have become of wider interest to a broader scope of DIY enthusiasts—as well as to commercial actors identifying new market opportunities. In this extended scope of interests, heterogeneity in terms of both technical applications and related guiding visions became generally high. Besides all this heterogeneity, a general tendency associated with the community's further development delineates shift from the initial idea of self-replication to a sense that 3D printers might be used more generally, to print objects not necessarily linked to their own components (Söderberg 2014).

In line with these dynamics, many actors that were more or less involved in the RepRap community identified opportunities to align with and even nurture the emerging 3D printing hype by selling affordable, open source 3D printers to people that were less interested in building the devices on their owns but wanted to use the technology for reasons other than self-replication. Since this rather new peer group for 3D printing grew significantly after 2010, not only the technology but also the social (and organizational) contexts that initially enabled its proliferation have changed dramatically in recent years. Indeed, in the shadow of RepRap's rise, the number of startups that emerged from the community also increased notably. Among them, a company called "Makerbot industries", co-founded by one of RepRap's former core developers, was supposed to become the role model of a successful company that really bridged the gap between open source ideals and business viability.

This period was also when I developed a deeper personal interest in the topic of open source hardware and the general dynamics that accompany the transformation of open source principles to physical contexts. Shortly after I defined the research project that motivated the present book, I headed to NYC in order to attend the 2012 edition of the Open Source Hardware Summit, the world's first comprehensive conference on open hardware. However, only one week before, Makerbot, which at this time was already the proud operator of a Brooklyn based company that employed over 150 people, decided to stop sharing their blueprints but rather become at least partly proprietary instead. This step was a true shock to the RepRap community as well as the entire open source hardware world, which not only caused a considerable controversy at the Summit, but also changed the empirical circumstances for the narrative of my research.

In the beginning, I was excited by the fact that a community- and commons-based approach to hardware innovation was actually capable of withstanding the dominant routines of proprietary and patent-regulated product development prevalent in the commercial realm. Indeed, the emphasis on openness and decentralization that shaped the ideation and development of 3D printing resonated well with complementary phenomena from the nascent fields of education (see e.g. David's 2007 or Fecher and Friesike's 2014 work on "open science") or related participatory tendencies in politics (Hague and Loader 1999; Cornwall and Coelho 2007). Taken together, all these notions suggested a general bottom-up dynamic that promoted innovative niches preparing to disrupt the established structures of the pre-digital age.

However, Makerbot's decision to leave the open hardware track did not fit my vision of a ubiquitous grassroots revolution, nor my initial plan to tell this story for the case of innovation communities in the context of 3D printing. Nonetheless, the resulting emphasis on the frictions and irritations that accompany community-based innovations is still valuable both conceptually and theoretically. From this point of view, the topics at stake in this book add evidence for the increasing number of (institutional) references that affect today's general conditions for "doing innovation" (Hutter et al. 2011). Thus, in order to understand the idiosyncrasies of innovation communities and explain the dilemma of entrepreneurship in open source hardware, the analytical heuristics applied to my research emphasize notions of conflict between certain institutional logics (Friedland and Alford 1991) and the struggles over relevance between distinct fields (Bourdieu and Wacquant 1992; Fligstein and McAdam 2012). In the next subchapter, I will outline the contents that finally resulted from this re-definition of my initial research perspective.

1.3 Agenda of the Book

To approach the institutional tensions that affect innovation communities, Chap. 2 starts out with a reception of the existing body of research in connection with common-pool resources. While initial interpretations of the commons emphasized their implicit vulnerabilities and thus revealed rather tragic notions, especially Ostrom's insights on self-organized governance instead propose ways in which collective groups that jointly provide common-pool resources can guard themselves against free-riding and private appropriation.

Discussions, which link insights on the commons to knowledge-based resources, suggest that communities promoting the open and non-proprietary exchange of information may even reveal advantageous properties in terms of value creation. These advantages particularly play out within digital realms, e.g. when source code is freely provided in order to spur joint software developments. To elaborate the linkages between commons, communities, and innovation further, Chap. 2 proceeds with the state of research associated with topics of open and distributed innovation. My review of related work selectively focuses on available conceptions of the community form as well as the corresponding patterns of "doing" community-based innovations. It is shown that since innovation communities mainly draw on value-based bonds that appreciate openness and accessibility of knowledge as common ground for interaction, any attempt to exploit related outcomes commercially leads to friction. Hence, actors who intend to carry out the entrepreneurial opportunities that emerge from community-based innovations face a dilemma that stems from the ambiguous and potentially contradictive guidelines for appropriate action, either prevalent in community or business realms.

Chapter 3 connects directly to these conceptual findings and theorizes the macro-, meso-, and micro-perspectives on CBI by discussing its institutional foundations, its implementation in the context of fields, as well as its practical implications in terms of agency and entrepreneurship. Aiming to root innovation communities at the intersection of different institutional orders, I draw on Friedland and Alfords' concept of institutional logics. Although their emphasis on diversity and potential conflicts between different logics offers a good perspective for my research setting, the symbolical and practical implications of how institutional logics shape the conditions for action remain rather vague in their theoretical approach. I therefore draw on the concepts of rationality and legitimacy to sharpen the analytical scope of the institutional logics perspective and discuss the potential tensions that affect innovation communities as a phenomenon that results from overlaps between the institutional orders of capitalism and science.

These refinements thus converge in my attempt to grasp innovation communities as a distinct type of meso-level order. Here, the general conflicts that have already shaped the institutional foundations of CBI play out in the context of gradually settled fields, where community and business logics compete over the legitimate ways to approach the particular innovation at stake. Consequently, the resulting fields reflect an ambiguous institutional environment that affects not only the general conditions under which innovation communities create and develop potentially innovative artifacts (like 3D printers), but also the particular opportunities and struggles that accompany corresponding approaches for commercial exploitation. As the dilemma of entrepreneurship in open hardware usually refers to community members that develop entrepreneurial ambitions to commercialize community-based innovations, Chap. 3 also emphasizes the micro level of individual actors and their agentic capacities to relieve tensions within a complex and potentially contradictive institutional environment.

In Chap. 4, I merge the conceptual and theoretical insights that inform this work in order to operationalize the analytical framework, which I apply to explain how the institutional idiosyncrasies of innovation communities affect entrepreneurship in the field of desktop 3D printing. Additionally, I outline my methodological approach as well as the data sources my analysis draws on. In the context of my empirical investigation, I apply a triangulation that allows me the describe the evolution and change of the 3D printing field, delineate shared understandings on how this issue should be approached appropriately, and finally synthesize the actors' practical responses to the dilemma of entrepreneurship.

Backed by my analytical framework and the three-folded methodological approach, Chap. 5 finally tackles the actual setting of desktop 3D printing. I start my empirical investigation with a description of emergence and change within the 3D printing field. I analytically distinguish three different phases of transformation and trace their particular impacts on the field's structure and its constituting issue. Indeed, especially the case of Makerbot and its decision to abandon the open source approach from their business model caused a stir in within the field. I therefore draw on this particular incident and the resulting controversies as a data basis to capture the general attitudes and evaluations that RepRap members and open source hardware advocates yield towards the commercialization of community-based innovations. I thus derive a taxonomy of opposing codes that delineates community and business stances within the dilemma of entrepreneurship. In order to explore the practical responses of actors that face this dilemma, I analyze interviews that I conducted with founders of 2nd generation community spin-offs, which already took the consequences of the Makerbot controversy into account to inform their own business strategies. It turns out that these actors are highly aware of the challenging contexts for their entrepreneurial efforts and thus try to incorporate aspects from both community and business realms within the business models of their RepRap-related startups.

In Chap. 6, I discuss the insights of my empirical research in conceptual and theoretical terms. With regard to the institutional entanglements that shape the 3D printing field and the corresponding conditions for entrepreneurial action, I emphasize the interfaces between different layers of social order. Hence, I trace the particular macro institutional implications on the meso-level order of the field and its subpopulations as well as the field's impacts on individual agency. Against the discussion of institutional effects and the corresponding idiosyncrasies of community-based innovation, I redefine the dilemma of entrepreneurship as a phenomenon that not only shapes the individual actors' scope of action but also the overarching meso-level context of innovation communities, which are potentially threatened by their members' entrepreneurial efforts as well. Additionally, I reconsider the essential differences between the exemplary case of open source software and the empirically observed context of open source hardware. In this regard, the matter of materiality turns out to be a crucial variable in determining the means and ends for community-based innovation. Moreover, the physical transformation of commons-based knowledge into tangible OSH devices like 3D printers generates multiple opportunities for entrepreneurship and thus heats up the disruptive tendencies associated with the dilemma of entrepreneurship.

Chapter 7 starts with a brief summary of this book's findings. Furthermore, it wraps up its key contributions in conceptual, theoretical, and practical terms. The final section concludes with an outlook on how the principles of community-based innovation extent their reach to processes that foster hardware innovation in rather competitive business realms. Drawing on two related examples, I reconsider how my analytical concept of innovation communities can nurture a more elaborated understanding of open and distributed innovation.

Chapter 2
Linking Commons, Communities, and Innovation

Abstract To approach the institutional tensions that affect innovation communities, this chapter starts out with a reception of the existing body of research in connection with common-pool resources. While initial interpretations of the commons emphasized their implicit vulnerabilities and thus revealed rather tragic notions, especially Ostrom's insights on self-organized governance instead propose ways in which collective groups that jointly provide common-pool resources can guard themselves against free-riding and private appropriation.

To elaborate the linkages between commons, communities, and innovation further, this chapter proceeds with the state of research associated with topics of open and distributed innovation. My review of related work selectively focuses on available conceptions of the community form as well as the corresponding patterns of "doing" community-based innovations. It is shown that since innovation communities mainly draw on value-based bonds that appreciate openness and accessibility of knowledge as common ground for interaction, any attempt to exploit related outcomes commercially leads to friction. I conceive of these frictions as the "dilemma of entrepreneurship".

This chapter aims to enrich the conceptual basis for my understanding of innovation communities, associated modes of interaction and exchange, as well as related notions of the dilemma of entrepreneurship. It therefore starts with applying the perspective of common-pool resources to potentially innovative knowledge (Sect. 2.1). As I will show, corresponding approaches, which are for instance prevalent in contexts of open source software or user innovation, entail high degrees of openness and accessibility that indeed enable strong dynamics for exploration and knowledge creation (Sect. 2.2). The social contexts for related modes of innovation usually link to communities that sustain strong value-based bonds for interaction and thus need to develop appropriate means to guard themselves against commercial exploitation. However, since innovation communities usually lack capacities to diffuse their developments e.g. by launching them on markets, prospective entrepreneurs seize latent opportunities for commercialization, which subsequently impose challenges for them personally as well as the communities they are embedded in Sect. 2.3.

J.-P. Ferdinand, *Entrepreneurship in Innovation Communities*, Contributions to Management Science, DOI 10.1007/978-3-319-66842-0_2

2.1 The Actually Not-So-Tragic Tragedy of the Commons

The spirit of capitalism, according to Weber's famous interpretation, lies in the everlasting accumulation of wealth for its own sake, or as he described it: "Man is dominated by the making of money, by acquisition as the ultimate purpose of his life" (Weber 2005b [1930], 18). This dominant trait of social action resonates with the institution of capitalism and related logics that spur the means of "accumulation and commodification of human activity" (Friedland and Alford 1991, 248). In traditional economic theory, associated attempts of converting all actions and goods into commodities that have a monetary price and can thus be traded in terms of market exchange usually refer to the "homo economicus". This idealized model of economic action based on formal rationality and self-interest seeks and reflects key motifs of maximizing individual utility or increasing economic profit (see Simon 1955 for critical reception of the concept). Although this sketch of capitalism certainly cannot meet the complexity of the economic sphere, it clearly emphasizes some key aspects for the reproduction of its logic and sets up an essential background to address the controversy at stake in this chapter.

With his paper on "The Tragedy of the Commons", Hardin (1968) conceptualized existential problems that arise at the intersection of an increasing human population and the principal scarcity of natural, common-pool resources like e. g. oceanic fishing grounds, meadows and cropland, or national parks that are open to everyone. Although Hardin originally addressed ecological theory and environmental issues such as sustainability, his article in *Science* caused quite a stir in economics because his argumentation heavily draws on assumptions of rational choice and game theory. The tragedy of commons envisions a common-pool resource (CPR) like a pasture, which is open to everyone and therefore used by all herdsmen who have an interest to access it. To sustain the pasture as a CPR, each herdsman would be conscientiously obliged to limit the number of cattle to a degree that is compatible to the joint interest of all herdsmen to share the pasture and make collective use of it. The tragedy enters with a behavioral tendency grounded in the spirit of capitalism, which enforces the immanent pursuit of maximizing individual gain, or as Hardin described it rather dramatically:

> [...] the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another; and another... But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit--in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all. (Hardin 1968, 1244)

Hardin's interpretation of this problem leads him to a defeatist view on humanity that, under the conditions of a high-density population, will overexploit natural resources as long as they are free to access. He therefore suggests to abandon the commons and either transform them into private (capitalist) property or to apply regulative forms of coercion, e.g. through compulsory taxes (ibid, 1247f.).

Ostrom opposed this pessimistic and rather conformist perception by emancipating herself from mainstream theories of rational choice. Instead of grounding her findings on synthesized models that simulate rational decision-making, Ostrom favors an empirical approach that actually explores real life practices of actors who are directly engaged in the management of CPR. In her volume on "Governing the Commons", she develops an empirically supported theory of self-organizing forms of collective action that are likely to solve the tragedy of the commons:

> What one can observe in the world, however, is that neither the state nor the market is uniformly successful in enabling individuals to sustain long-term, productive use of natural resource systems. Further, communities of individuals have relied on institutions resembling neither the state nor the market to govern some resource systems with reasonable degrees of success over long periods of time. (Ostrom 1990, 1)

Although Ostrom agrees that individual rationalities may lead to outcomes that are not rational from a communities' perspective, she disagrees that these situations generally give rise to tragic consequences. She therefore contradicts the interpretation of the tragedy of the commons by labelling constellations that are likely to involve CPR related problems such as freeriding explicitly as social dilemmas. These dilemmas can be solved by individuals who do not make decisions exclusively by rational self-interest, but rather contribute to decentralized approaches of *self-government* by adopting mutually aligned strategies that reduce the sub-optimality of outcomes and change the rules-in-use that affect the structure of the CPR situation (Ostrom et al. 1994, 17).

As a precondition for self-organizing communities to foster creative and constructive solutions for common-pool problems, Ostrom emphasizes the necessity of direct interaction and therefore focuses entirely on "small-scale CPRs" like inshore fisheries, smaller grazing areas, groundwater basins, irrigation systems, or communal forests that are located within one country and consist of a limited number of potential appropriators (ibid. 26). In situations in which actors know each other and communicate repeatedly, Ostrom assumes that individuals will develop and agree upon rules that organize provision and appropriation in ways that support a common interest in the usage of the CPR. This bottom-up coordination will thus lead to the emergence of institutionalized structures that enable "that they can learn whom to trust, what effects their actions will have on each other and the CPR, and how to organize themselves to gain benefits and avoid harm" (ibid. 184).

As another important part of their work on the commons, Ostrom and colleagues also clarify the conceptual basis for the analysis of CPR related problems by integrating them in a general classification of goods that is widely acknowledged in the economic realm:

> Common-pool resources share with what economists call 'public goods' the difficulty of developing physical or institutional means of excluding beneficiaries. [...] Second, the products or resource units from common-pool resources share with what economists call 'private goods' the attribute that one person's consumption subtracts from the quantity available to others. (Hess and Ostrom 2003, 120)

In economic analysis of CPR, the literature accordingly addresses constellations where the exclusion of potential appropriators is difficult and the output of the resource system is subtractable, i.e. one person's use reduces the benefits available to another (Ostrom et al. 1994, 6). Because Ostrom's stresses the features of local settings, clearly defined boundaries, and face-to-face interaction as key preconditions for self-organizing CPRs, it initially appears inappropriate to apply this perspective to immaterial and *non*subtractive entities like information and knowledge. Nevertheless, Ostrom and colleagues consider them as a matter of CPR because the social dilemmas associated with the provision, circulation, and appropriation of knowledge are pretty much the same as in the original contexts of natural commons (Hess and Ostrom 2003, 2007).

In order to increase the applicability of their insights for more general uses in connection with information-based resources, the physical features of natural CPR need to be substituted by rather immaterial notions of *knowledge commons*. However, this switch also alters the narrative of why these resources need to be guarded against private appropriation. In this respect, Ostrom and colleagues apply a rather normative approach against excessive restrictions of free and open access to information that may cause an underuse of knowledge-based resources:

> Information that used to be 'free' is now increasingly being privatized, monitored, encrypted, and restricted. The enclosure is caused by the conflicts and contradictions between intellectual property laws and the expanded capacities of new technologies. It leads to speculation that the records of scholarly communication, the foundations of an informed, democratic society, may be at risk. (Hess and Ostrom 2003, 112)

Although the authors identify a certain variety in enclosing threats that undermine free access to public, scientific, and government information, the general logic behind these restrictions is "one of privatization, the haves versus the have-nots, the elite versus the masses" which, again, is obviously aligned with the guiding visions of capitalism (Hess and Ostrom 2007, 13). Compared to the preconditions that enable bottom-up modes of governing natural CPR, the prevalence of fuzzy boundaries, multiple layers of coordination, and decentralized provision make attempts of self-organizing the knowledge commons even more challenging.

To elaborate conditions for the maintenance of knowledge commons and detangle their components, Hess and Ostrom introduce the distinction between the ideas, artifacts, and facilities that capture the various forms and facets of knowledge (Hess and Ostrom 2003): *Ideas* constitute the creative visions and intangible contents that are captured by *artifacts* like books, files, databases or any other discreet and observable representation; *facilities* such as libraries, the internet, or other knowledge repositories build the resource system that collects and stores artifacts and thus makes them accessible. Indeed, the value of this distinction becomes evident when the social dilemmas that potentially affect knowledge commons are taken into account. In order to sustain common knowledge pools it becomes a key challenge to ensure the open accessibility of the artifacts and facilities that embody the knowledge commons:

> An infinite amount of knowledge is waiting to be unearthed. The discovery of future knowledge is a common good and a treasure we owe to future generations. The challenge of today's generation is to keep the pathways to discovery open. Ensuring access to knowledge is made easier by examining the nature of knowledge and identifying the ways in which it is a commons. (ibid. 7)

Indeed, I share the opinion that the extent to which the provision, circulation, and appropriation of knowledge is performed as a common depends upon the degree of *openness* captured in the specific constellations of ideas, artifacts, and facilities. Consequently, any effort that contributes to the self-government of knowledge commons needs to strengthen the practical, normative, and regulative frameworks that sustain open access to knowledge and prevent knowledge commons against proprietary enclosure.

2.2 The Promise of Commons-Based Peer Production

The ideas making up the "knowledge commons" mentioned above also represent the core units in play in Benkler's concept of *commons-based peer production* (CBPP, Benkler 2006, 60). Considering the rise of information- and communication technologies (ICT) and the emergence of digital forms of organization that together favor decentralized and networked modes of coordination, Benkler describes CBPP as a new mode of value creation, which is "radically decentralized, collaborative, and nonproprietary; based on sharing resources and outputs among widely distributed, loosely connected individuals who cooperate with each other without relying on either market signals or managerial commands" (Benkler 2006, 60).

Benkler turns the supposed vulnerability of the commons, namely the fact that they lack possibilities to structure rights to access, use, and control over them (Hardin 1968), into a promising precondition for his notion of peer production as a viable alternative to property-based market mechanisms:

> The result is a flourishing nonmarket sector of information, knowledge, and cultural production, based in the networked environment, and applied to anything that the many individuals connected to it can imagine. Its outputs, in turn, are not treated as exclusive property. They are instead subject to an increasingly robust ethic of open sharing, open for all others to build on, extend, and make their own. (Benkler 2006, 6)

So, Benkler opposes Hardin's pessimistic interpretation of the commons with a rather bright and normative vision of "Commonsism" (Bauwens 2010), which breaks with the logic of capitalism and treats "individuals, who interact with each other socially, as human beings and as social beings, rather than as market actors through the price system" (Benkler 2006, 6). This assumption becomes reasonable when the specifics of production within the sphere of digital information are taken into account. Other than Ostrom and colleagues, who consider knowledge commons to potentially reveal traits of private goods at least in their artifact- and facility-based occurrences, the flow of goods in Benkler's take on the information sector appears even more "nonrival." Because these intangible goods remain digital without e.g. being printed as books, consumption by one person does not decrease chances for consumption by another—their marginal cost, once produced, is zero (ibid. 36). From a society's point of view, any ambition to apply copyrights or similar forms of intellectual property protection would lead to an inefficient under-utilization of the protected information. Benkler does not generally challenge the right of private companies to produce proprietary information e.g. in terms of commercial research and development (R&D) nor does he challenge artists' or authors' permissions to protect their intellectual outcomes. Instead, he particularly adds his nonmarket notion of peer production as a "subset of commons-based production practices [which] refer to production systems that depend on individual action that is self-selected and decentralized [. . .]" (ibid. 62).

With the triad of personal computers as production device, the internet as communication infrastructure, and commons-based flow units like information or knowledge being ubiquitously accessible for a large group of people, the barriers to participate in contexts of CBPP are quite low. This inclusive nature also fosters new types of collaboration between dispersed but networked individuals who decide on their own whether to participate in collective processes of peer production. Because these emergent groups are capable of integrating the talents and skills of many people who team up situationally, they are supposed to challenge conventional modes of R&D established in firm-based settings (Tapscott and Williams 2006). Indeed, some examples from the realm of digital, information-based value creation show evidence that CBPP can lead to viable and even disruptive outcomes.

In the broader context of Web2.0 applications that together show the increased impact of individuals on digital media and its collective creation (see Shirky 2008), *Wikipedia* is certainly the most ideal-type example of CBPP. Generally, the concept of peer production applies because on the one hand, individuals self-selectively decide to become authors and create articles, and on the other hand, the broader wiki-framework serves as facility, which lacks hierarchical decision-making and proprietary control:

> With nothing more than the effort of volunteers, the most used, and perhaps the most useful encyclopedia ever written has been created through millions of uncoordinated instances of collaboration. (Lessig 2006, 243)

Although users who would probably lack formal access writing conventional encyclopedias generate most of the content within Wikipedia, the quality of articles is quite high.[1] This quality has also be considered as a specific outcome of a commons-based knowledge provision that also includes acts of peer revision "to frame a piece neutrality" (Lessig 2006, 143) as well as to defend the common good against maliciousness in terms of contributors intentionally publishing the untruth.

Another prominent example of CBPP is the collective development of *free-* respectively *open source software*. Although the concerning body of knowledge is

[1]Indeed, Giles' (2005) analysis of a random set of collected entries from Wikipedia and the Encyclopedia Britannica shows that the number of errors included does not vary significantly between both mediums.

quite sophisticated (see e.g. DiBona et al. 1999; Raymond 2001; Moody 2001; Weber 2004), I use the upcoming subchapters to sketch out the key aspects of these issues from my own perspective. This is not only exciting because the history of OSS is full of good stories, but also necessary for me because of the already existing insights on OSS represent a key reference for my explanation of OSH which follows later in this book. Since perspectives on OSS have become increasingly complex during the last decades, it then seems expedient to entangle its ideological backgrounds (Sect. 2.2.1) from the associated practices of value creation (Sect. 2.2.2).

2.2.1 The Ideological Foundation of Free Software

Tackling the former first, a retrospective look at the early days of OSS gives some striking insights. When the first computers were installed at universities like the Massachusetts Institute of Technology (MIT) in the middle of last century, their adoption by researchers was heavily affected by tinkering and pushing the boundaries of existing applications. This ingenuous style of engaging with the new technology implicitly yielded into what Levy calls *hacker ethos*: “a philosophy of sharing, openness, decentralization, and getting your hands on machines at any cost—to improve the machines, and to improve the world” (Levy 1994, 7). The term “hacker”, which was mainly used as a category of self-description back then, generally refers to people who do “hacks” in the sense of undertaking projects “not solely to fulfill some constructive goal, but with some wild pleasure taken in mere involvement” (ibid. 23). Because access to information is the key precondition for either improving things or creating new solutions, the claim for open systems, both in terms of hardware and software, reflected the imperative for hackers right from the start. The creed promoting free exchange of information thus shaped the approach to computing for the upcoming generation of IT scholars.

During the 1980s, significant hardware improvements, the development of versatile software applications, and the degression of prices for computers together spurred an ICT revolution that was accompanied by increased market relevance and a growing commercial interest to foster associated intellectual property rights. Because these dynamics noticeably affected the hackers and their particular practices, Richard Stallman, who was one member of the new generation of MIT computer programmers, felt a special responsibility to oppose these restrictive tendencies. Stallman took on this endeavor in a hacker-typical hands-on manner, namely by creating an entirely free operating system, which he labelled GNU. In addition to this practical attempt, he also added some considerable political momentum by founding the Free Software Foundation (FSF) and publishing a manifesto that explicates the hacker ethos he was implicitly socialized with (see Stallman 2010). The manifesto mainly clarifies his vision about how “free software” should be:

> 'Free software' is a matter of liberty, not price. To understand the concept, you should think of 'free' as in 'free speech', not as in 'free beer'. Free software is a matter of the users' freedom to run, copy, distribute, study, change and improve the software. (ibid. 3)

It is obvious that the open, public, and non-proprietary features of free software oppose the building blocks of proprietary software from commercial vendors like Microsoft or Adobe that explicitly prohibit modifications, reproductions, improvements, or redistributions by users. Stallman thus contested established legal structures like copyrights, licenses, or patents, which together protect the commercial regime, with the "General Public License" (GPL) he attached to the GNU operating system. The GPL, also associated with the paradigm of "copyleft", applies to defend both the ideological intents and practical foundation of developers engaged this particular pattern of software development as it guarantees high degrees of freedom implied in commons-based code:

> The goal of copyright is to restrict unauthorized use, copying, distributing, modifying, and performing. The goal of copyleft is to allow these same activities, but to restrict proprietary appropriation. Unlike software in the public domain, works derived from software licensed under the GPL cannot be made proprietary. With this self-perpetuating clause, the GPL not only establishes a commons [...], but a fence that protects that commons. (O'Mahony 2003, 1186)

The strong political momentum embodied in free software thus fostered a whole movement of programmers who shared Stallman's anti-capitalist vision—as well as his ambition to undercut the monopolies of commercial software vendors: "Stallman created in the GNU GPL a kind of written constitution for the hacker world that enshrined basic assumptions about how their community should function" (Moody 2001, 27). The practical building blocks derived from this ethos thus address an approach to joint problem solving via open sharing of ideas, free access to all contributed software, and ongoing interaction lacking central guidance (Lakhani and Panetta 2007, 107).

2.2.2 The Practical Transformation of Open Source Software

The ideological backgrounds that motivated GNU and GPL slightly mitigated when a group of well appreciated free software enthusiast met in 1997 to discuss how their particular approach to programming might grow out the strict political agenda of the FSF (Williams 2002, 194pp.). Although this group of people supported Stallman's accounts to openness and freedom, "they were concerned that the Free Software Foundation's anti-business message was keeping the world at large from really appreciating the power of free software" (DiBona et al. 1999, 9). Seeking a less-biased term, the group agreed on *open source* as a new description to highlight the practical implications of the processes that create software. Although it is hard to appraise the extent to which this terminological variation actually affects the discourse on free and open source software, respectively, a shift in discussion can indeed be observed.

The main reference for the conceptual turn towards open source software thus refers to Eric Raymond's well acknowledged paper "The Cathedral & the Bazaar" (see Raymond 2001, 19pp.), which emphasizes the particular organizing patterns that constitute open source development processes. Drawing on a heuristic that distinguishes between linear and diffuse modes of coordination, Raymond, who by the way also attended the meeting mentioned above, influentially informed the general discussion on collaboration and the division of labor in the context of software development. While the cathedral model resembles a centralized organizing approach embracing focal authorities that divide and supervise tasks carried out by executing workforce, the bazaar style clearly indicates a collaborative mode of peer production in which "each person is free to choose what he wishes to work on or to contribute" and "no consciously organized or enforced division of labor" takes place (S. Weber 2004, 62).

Although the cathedral represents a metaphor mainly associated with formal organizations like business corporations, also the creation of the GNU operating system revealed properties of a rather linear endeavor carried out and supervised by Stallman and the FSF as central authorities. Therefore, the terminological and conceptual turn from free to open source software was also accompanied by the replacement of GNU as the most referential case for non-proprietary programming. Instead, Linus Torvalds' Linux project became the prime example of OSS approaches that clearly support the bazaar model of coordination:

> GNU programs were 'cathedrals', impressive, centrally planned monuments to the hacker ethic, built to stand the test of time. Linux, on the other hand, was more like 'a great babbling bazaar', a software program developed through the loose decentralizing dynamics of the Internet. [...] Where Stallman served as the classic model of the cathedral architect-i.e., a programming 'wizard' who could disappear for 18 months and return with something like the GNU C Compiler-Torvalds was more like a genial dinner-party host. [...] From the Torvalds' perspective, the most important managerial task was not imposing control but keeping the ideas flowing. (Williams 2002, 194)

Although Williams's quote points the differences between GNU and Linux out quite sharply, I want to elaborate on the development practices of Linux a little more because they still represent the most prevalent organizing principles underlying OSS. Compared to Stallman, Torvalds represented a new generation of hackers, which already adopted PC machines, communicated via internet-enabled newsgroups, and could draw on comparatively broad references of existing software. Against this background, Torvalds started his project in a rather pragmatic fashion, using already available source code as scaffold for developing his own operating system called Linux. What really boosted Linux was Torvalds' decision to encourage interested people from his newsgroups to participate in the project from the beginning—be it in terms of expressing suggestions for further developments or contributing directly to the project by joining the complex debugging- and programming processes (Moody 2001, 42). To emphasize the open and inclusive nature of his project, Torvalds also applied the GPL to Linux. It turned out that the pragmatically decentralized development approach together with the implied degrees of openness suited the task pretty well and together served as a fruitful framework to scale up the impact of Linux rapidly:

> By the end of the year [1991, when Torvalds first announced Linux], nearly 100 people worldwide had joined the newsgroup. [. . .] Through 1992 and 1993, the community of developers grew at a gradual pace. [. . .] In 1994, Torvalds released the first official Linux, version 1.0. The pace of development accelerated through the 1990s. By the end of the decade, Linux was a major technological and market phenomenon. [. . .] By the middle of 2000 Linux ran more than a third of the servers that make up the web. (S. Weber 2004, 55)

As indicated before, the success of Linux is substantially based on widely dispersed contributions of thousands of people that self-selectively take over modular tasks that together compile the operating system as a joint effort. To participate in the project, interested people only need to sign up for the Linux mailing list, which serves as "the rendezvous point for technical discussions of the features being developed by contributors [who] report and fix bugs, contribute and modify code, and discuss the technical evolution of the kernel." (Lakhani and Panetta 2007, 99)

Although Linux originates from hacker and open source communities, its increasing relevance led to an incremental and mutual inclusion of private corporations that seek to aid and improve the project. Today, a share of about 88% of developers that contribute to the central component of the Linux operating system, the Kernel, have a corporate background (Corbet et al. 2015, 3). The transformation of Linux from a rather straightforward project supported by a small group of like-minded people into a joint endeavor of heterogenic actors nurturing the project for various purposes considerably affected the constitution of the related developer community. While some researchers interpret this as "a harbinger of an end to the current dominance of a proprietary, closed source software model" (Fitzgerald 2006a, 587–588), others identify opportunities to leverage mutual benefits. Thus, corporate companies that operationalize them for commercial purposes increasingly adopt the functional properties of open source development practices:

> Members of the open-source movement were motivated to expand the scope of open source software and felt they could benefit from the resources firms could provide. In turn, as open-source projects took hold among users, firms were motivated to tap an emerging market, giving open-source projects some leverage to engage their participation. (O'Mahony and Bechky 2008, 432)

To sum up the points of the previous paragraphs, the examples of Wikipedia and OSS indicate that commons-based knowledge and ICT together constitute a framework that enables modes of collective value creation, which differ from established modes associated with markets and hierarchies in their various aspects. Since participation lacks formal authority as well as centralized guidance, the coordination of distributed action as well as the provision of related outcomes can be best understood in terms of self-organization. Besides the functional aspects that keeps OSS communities working, notions of commons-based peer production also imply a certain set of shared values supporting the open and nonproprietary features, which in turn sustain related outcomes as commons-based goods.

2.3 Idiosyncrasies of Innovation Communities

I discussed the topic of the commons to outline how and under which circumstances their specific properties can enable collaborative modes of knowledge creation. Furthermore, the motif of commons-based peer production suggests various links to the broader topic of "innovation", but without capturing conceptual implications systematically. Nevertheless, the exemplary case of OSS in particular motivated an entire research perspective within the field of innovation studies. While this stream of research coincides in its focus on distributed processes that exceed the boundaries of focal firms, it internally differs in the ways that openness, commons, and communities are emphasized. Indeed, one can roughly contrast two streams of research: the one promotes open business models and the relevance of external stimuli for corporate value creation (Chesbrough 2003, 2006) and the other emphasizes more decentralized modes of innovation taking place without guidance of a focal firm (von Hippel 1986, 2005).

Chesbrough's foundation of *open innovation* refers to the rise of ICT and ubiquitous networking among heterogeneous actors—companies among themselves, companies with research institutes, companies with customers, companies with communities etc.—and corresponding approaches for corporates to engage in co-operative knowledge creation. In this context, he labelled his take on open innovation as a "paradigm shift" and "the new imperative for creating and profiting from technology" (Chesbrough 2003). Chesbrough suggests that firms should expand their internal R&D approaches by acquiring potentially innovative ideas, patents, products, etc. from outside their boundaries to generate additional value:

> Companies must structure themselves to leverage this distributed landscape of knowledge, instead of ignoring it in the pursuit of their own internal research agendas. [...] The new logic will exploit this diffusion of knowledge, rather than ignore it. [...] Instead of restricting the research function exclusively to inventing new knowledge, good research practice also includes accessing and integrating external knowledge. (ibid. 51)

Although Chesbrough boldly states that "the new logic of innovation turns the old assumptions on their head" (ibid), it definitely does not break with the capitalist logic of private profit maximization. Instead, the proclaimed mode of open innovation essentially expands its scope as commercial appropriation of potentially innovative ideas as it blurs the boundaries of focal firms and fosters corporate strategies to seize external knowledge.

Regarding conditions of low appropriability, for instance when potential financial benefits are considered as insufficient to spur private corporate investments in R&D, von Hippel emphasizes the evidence of *user innovation* and their dissemination to others as an alternative way of creating valuable innovations (von Hippel

1988; Bogers and West 2012). Instead of being centrally supervised by profit-seeking firms, user innovation often resembles a widely distributed process between different actors who are interconnected in communities via information transfer links that involve face-to-face, electronically-mediated or other types of communication and provide sociability, support, information, a sense of belonging and collective identity (von Hippel 2005, 96). What distinguishes von Hippel's argument from the common sense of (economic) literature on innovation is the strong emphasis on openness and free access to knowledge as constitutive elements for these communities. Since participation in innovation communities typically lacks monetary incentives, hierarchical authority, or formal membership, the hallmark of open knowledge and access to it is critical for most actors who join these voluntarily assembled, informal groups.

Comparing the sketched-out approaches, my own research rather embraces von Hippel's notion of user innovation, as it also emphasizes the bottom-up dynamics that spur innovations in community contexts. However, the issues I aim to tackle in this book demand a more well-elaborated understanding of the idiosyncrasies that constitute communities as a unique context for "doing innovation" (Hutter et al. 2011). To comply with this ambition, I will first discuss the reception of community concepts within the existing and nuanced body of literature on distributed innovation (Sect. 2.3.1) before I focus on how communities are supposed to shape the innovative practices of their members thereafter (Sect. 2.3.2). Finally, this chapter wraps up the gained insights by evaluating the general means for exploration and exploitation within settings of community-based innovation.

2.3.1 Communities as Organizational Contexts for Innovation

Concurrent with the rise in studies on open- and user innovation, communities have become a growing topic within the analysis of innovation processes, too (West and Lakhani 2008). While the strand of open innovation literature merely draws on communities as sources for complementary assets (Dahlander and Wallin 2006), research in the field of user innovation generally emphasizes their capabilities to spur innovation outside of firm-boundaries (von Hippel 2005, 96). Although innovation scholars increasingly acknowledge the relevance of communities, attempts to define innovation communities still lack conceptual maturity. In the following paragraphs, I will nevertheless present related approaches eclectically rather than extensively in order to derive a common ground for my own definition of innovation communities.[2]

[2]Please note that this chapter mainly refers to the state of knowledge in the context of innovation research. In Chap. 3, especially Sect. 3.2, I approach the matter of communities from a rather theoretical point of view.

Literature on *communities of practice* (CoP) constitutes one of the initial foundations for thinking about innovation communities. It was also von Hippel who first identified phenomena of “the extensive exchange of proprietary know-how by informal networks of process engineers in rival (and non-rival) firms” (von Hippel 1987, 291). These informal networks connect actors across single firms and foster the exchange of knowhow between professionals who share similar fields of work. The direct process of knowledge-trading relies on a reciprocal ratio of inbound and outbound transfers that stabilizes trustful relationships and offsets the imperative for secrecy to varying degrees: “No explicit accounting of favors given and received is kept in instances studied to date, but the obligation to return a favor seems strongly felt by recipients—‘. . . a gift always looks for recompense’” (ibid. 292).

The concrete concept of communities of practice was subsequently coined when von Hippel’s arguments were adapted and generalized in terms of “organizational-” (Brown and Duguid 1991) respectively “situated learning” (Lave and Wenger 1991). Providing contexts for learning through practice, CoPs constitute “an intrinsic condition for the existence of knowledge” (ibid.) as well as “significant sites of innovating” (Brown and Duguid 1991, 41). According to Lave and Wenger, the community-term “[does not] imply necessarily co-presence, a well-defined, identifiable group, or socially visible boundaries. It does imply participation in an activity system about which participants share understandings concerning what they are doing and what that means in their lives and for their communities” (Lave and Wenger 1991, 98). The defining feature of CoP thus refers to communal practices that convey a common body of knowledge and know-how and thereby reproduce shared identities of the community members involved (Brown and Duguid 2001, 202).

With the CoP approach becoming increasingly popular among organizational scholars, the initial focus on intra-firm constellations providing contexts for learning through practice has expanded considerably and has now transformed into a “new organizational form [. . .] that promises to complement existing structures and radically galvanize knowledge sharing, learning, and change.” (Wenger and Snyder 2000, 139). This new scope also embraces actor-relationships outside and across focal firms that expand the initial notion of tightly-knit groups towards radically dispersed and individualized “knowledge collectivities” rather unlikely to develop anything like cohesive identities and mutually shared understandings (Lindkvist 2005).[3]

[3]While I will mainly draw on the organizational aspects of community-based innovation, a prominent stream of research addresses the individual motivations of people that contribute to such joint endeavors. For instance, Wasko and Faraj (2000) focus on the reasons why members of internet newsgroups generate, maintain, and exchange knowledge within these “electronic communities of practice”. They find evidence that related knowledge flows are motivated by moral obligation and community interest rather than by narrow self-interest. In their content analysis of 342 open-ended responses from participants of IT-themed newsgroups (described as “self-organizing, electronic forums where issues associated with the topic of the newsgroup are discussed”,

Sharing the aim of broadening the firm-biased notions of CoP, Lee and Cole develop a general community-based model of knowledge creation by contrasting its principles with traditional, firm-based modes of knowledge creation (Lee and Cole 2003). Drawing on the case of Linux, the authors show that OSS communities break with three core assumptions of firm-based organizing. Neither the locus of organizational action takes place at the level of a firm or a set of firms, nor does physical proximity support the development of trust through repeated interactions, nor does knowledge creation take place under conditions of authority and hierarchy. Instead, the community-based creation of OSS is shaped by individuals that are organizationally as well as locally dispersed, lacks central authority, which regulates the behavior of community members, and is mutually stabilized by trust that stems from the collective assignment of IP (ibid. 635).

This broader notion of CoP also informs the community-concepts applied in studies of open and distributed user innovation. In their related study on sports communities, Franke and Shah contextualize the innovative practices they observe in terms of CoPs forming around the topics of sailplaning, canyoning, snowboarding, and handicapped cycling. They observe that either the communities as a whole or certain subgroups of community members reproduced intense exchange of information, assistance, and personal contacts in order to create potentially innovative goods:

> Without exception, the innovating community members we surveyed do not innovate in isolation or secrecy; they receive important advice and assistance from other community members. Assistance is provided to innovators for free and innovators generally share their innovations to the community for free—although the levels of free support and access diminish somewhat as competitive pressures grew higher. (Franke and Shah 2003, 158)

Franke and Shah found that economic exchange and monetary profit reflect minor motivations for either the innovators or those who assisted them. Instead, they rather "cite having fun and viewing the giving of innovation-related assistance to community members as a social norm as the strongest factors influencing their decision to assist innovators" (ibid.). Although these forms of exchange of information, assistance, and outcomes may lack efficiency (at least from an economic

ibid. 162), the majority of comments (42%) are associated with the specific facets of community-based interactions. These include strong desires to engage in communities of practice not primarily for social reasons but the open and reciprocal exchange of practice related knowledge within a group of like-minded members: "People in these communities feel that sharing knowledge and helping others is 'the right thing to do,' and people also have a desire to advance the community as a whole. However, giving back to the community in return for help was by far the most cited reason for why people participate. [...] People feel that the community provides access to knowledge rather than just information, and becomes a valuable forum to receive feedback on ideas and solutions" (Wasko and Faraj 2000, 169). Contrasting the community-based notion of collectively owned and maintained knowledge with a market-based perspective of treating knowledge as a private good proprietarily owned by single organizations, the authors suggest that "knowledge flows best when seekers and experts are considered members of the same community and thus share the same values, codes, and narratives" (ibid. 170) and further conclude that "the end result is increased knowledge flows and innovation within the community" (ibid. 171).

point of view), their free and open exchange though unfolds self-reinforcing potentials for innovation that incorporate improvements by others sustains the means for prospective acts of sharing knowledge (ibid. 172).

Brinks and Ibert propose a slightly different terminology in their concept of *interest communities*, defined as "a group of individuals, who share enthusiasm about a particular concern or topic and/or who are strongly affected by a particular problem" (Brinks and Ibert 2015, 1). Compared to what was sketched out in terms of CoP, communities of interest do not primarily constitute themselves around a particular set of practices, which guide the learning and identification processes of the actors involved, but around an increased enthusiasm for particular objects, topics, or activities shared by all actors of their members. Since these actors mainly represent "sophisticated users, highly skilled enthusiasts and dedicated hobbyists," (ibid.) the whole concept matches pretty well with the broader perspective of user innovation. Indeed, the authors find that communities of interest, which in the cases of the study gather around fingerboarding and geocaching, create sources for innovation as "a social context within which actors are mainly intrinsically motivated to contribute to a common knowledge pool and willing to share their ideas freely" (ibid. 9). Comparing the insights from communities of interest with Franke and Shah's application of CoPs in the field of novel sports (see above), it becomes obvious that besides either being constituted around practices or interests, the defining features between both concepts appear heavily entangled and can hardly be distinguished analytically.

Generalizing her insights on user innovation in terms of a broader understanding about a community-based model of innovation, Shah (2005) especially emphasizes the stark contrast to the proprietary model as it relies neither on exclusive property rights, nor on hierarchical managerial control (ibid. 339). Instead, innovation communities are assumed to embrace "the open, voluntary, and collaborative efforts of users" (ibid. 339). This particular approach to product design and knowledge transfer allows users to tinker with and improve upon a given product or service without any commercial or legal restrictions. The practices of making information and innovation accessible also resembles a self-organized approach to preventing third parties, like commercial firms or other non-members of the community, from appropriating community-based outcomes and therefore sustains the community-members' freedom to modify, improve, and actually build the community-based innovations (ibid. 345).

Adding another facet, Dobusch and colleagues develop their understanding of online communities (e.g. associated with Wikipedia or Linux) by distinguishing them not from commercial firms but instead from the crowd model, which represents a nascent but obviously different approach to grasp collective dynamics on the internet (Dobusch et al. 2013). While crowds consist of unconnected users who individually contribute to definite, centrally organized tasks, community members need to coordinate themselves to achieve the common, interdependent goal. Additionally, unlike crowds, which involve little or no interaction among the individuals involved, community members reproduce high levels of interaction and thus self-organize the means of decentralized control that sustain their constituting objectives.

My own understanding of innovation communities builds on various aspects derived from the literature sketched out in the prior paragraphs. While the CoP-related approaches emphasize the connection between common identities and shared practices, their applications in contexts of open source- and user-innovation reveal openness and accessibility as the fundamental qualities that accompany related processes. Merging these strands, I define innovation communities as *non-commercial actor constellations that consist of self-selected members, who engage in the collaborative development, improvement, or application of novel entities, like e.g. certain products or software programs. The actors involved then share the outcomes of their efforts back to the common body of knowledge and thus sustain the ground for collective interaction*. I believe that this definition captures both the practical and normative features, which constitute the distinct context for community-based modes of innovation.

2.3.2 "Doing Innovation" in Community Contexts

To approach the idiosyncrasies of community-based innovation, one might relate them to what Murray and O'Mahony call "cumulative innovation": process that build on already existing ideas of others to create new ones (Murray and O'Mahony 2007). Regarding the conditions that enable cumulative innovation, the authors share the emphasis on disclosure and access and add the aspect of rewards, which explicitly imply monetary as well as non-monetary rewards such as reputation or credit (ibid. 1009). Besides drawing on the general bottom-line of open knowledge exchange, another aspect that enables cumulative innovation consists of a functioning mode of crediting single contributions by the means of collective appreciation. In the instance of communities in open source software, these antecedent conditions for cumulative innovation play out as follows:

> Open-source contributors tend to be motivated more by recognition than reward. [...] But motivation for recognition is not enough to spur contributions. It is only with open access to a community's source code and development process that contributors can make accumulative contributions. (Murray and O'Mahony 2007, 1008)

Other examples refer to scientists, whose research findings become well recognized within their particular peer communities, or single user innovators, who receive positive or constructive feedback upon a project, for which they provided all relevant information to the relevant community.

Regarding the mode of interaction prevalent in the user communities observed by Franke and Shah (see above), the authors found evidence that "in these communities both assistance and access to completed innovations are freely shared" (Franke and Shah 2003, 171). This adds another facet to processes of community-based innovation as not just the generation of knowledge but also iterations and further developments on the functionality or the design of innovations are subjects of cumulative and collective effort. Interpreting their findings, Franke and Shah thus conclude that "these patterns suggest that generalized, rather than restricted, exchange behavior governs the exchange of information and assistance within these communities" (ibid.). Although they do not elaborate on the concept of generalized exchange more deeply, it seems to me a worthwhile approach to describing the distinct notion of reciprocity as stabilizing condition for collective communal agency.

Social exchange theory generally traces social relationships in terms of reciprocity within either restricted or generalized exchange processes. Restricted exchange reflects direct reciprocity between two actors who exchange resources with each other: "[. . .] the resources that one actor gives are directly contingent on the resources that the other gives in return. If A gives to B, B is the person who would reciprocate to A" (Takahashi 2000, 106). Examples for restricted exchange, like market transactions or employment relationships, are the most prevalent form of exchange in the economic realm. In contrast to these dyadic structures, generalized exchange generally applies in collective constellations that involve more than two parties: "each actor gives benefits to another and eventually receives benefits from another, but not from the same actor" (Molm et al. 2007, 206).

In the reception of Lévi-Strauss' work on that topic, Molm and colleagues also suggest that while restricted exchange potentially involves tensions that arise from "quid pro quo" situations, in which self-interested actors negotiate over the fairness of direct exchange, generalized exchange usually embraces high levels of *solidarity* (ibid. 208). Solidarity is defined as "the integrative bonds that develop between persons, and between persons and the social units to which they belong. Solidarity is potentially composed of both behavioral and affective components" (ibid. 207). It is thus characterized by a set of associated components, which include "trust (the belief that the exchange partner will not exploit the actor), affective regard (positive feelings for, and evaluations of, the partner), social unity (perception of the relationship as a social unit, with actors united in purpose and interests), and feelings of commitment to the partner and the relationship" (ibid). Although the authors discuss related implications in terms of networks generally, the promoted notion of solidarity particularly applies to community settings that typically consist of affectual ties among actors that engage in collective processes of value creation (see definition above). I will therefore adapt the concept of generalized exchange in order to describe the knowledge flows apparent in innovation communities.

This perspective gains further evidence when the downsides of generalized exchange are taken into account. Takahashi in particular focuses on the vulnerabilities that accompany the characterizing features of unilateral resource-giving and the high levels of trust that maintain constellations based on indirect reciprocity:

> [. . .] unilateral resource giving is an invitation to exploitation [. . .] Rational self-interested members will be better off if they do not give resources to others. However, members who think that others will not give are unlikely to give away their own resources, and generalized exchange may never be established. (Takahashi 2000, 1107)

Against this background, the concept of generalized exchange obviously links the social dilemmas that affect the governance of common-pool resources with the challenges at the core of innovation communities. In this view, the analogy between the provision of commons on the one, and unilateral sharing of novel and potentially innovative knowledge on the other hand, matches pretty well.

As exemplified in the context of cumulative innovation before, ideal-typical modes of community-based innovation require established means and ends to accomplish the exploration, dissemination, and appreciation of novel entities (like source code or knowledge). In constellations, in which any of these facets is realized within a particular community, members of that community would certainly be able to self-organize themselves in order to maintain the constitutive practices of generalized exchange without serious irritations. However, situations, in which the collective provision of knowledge commons is echoed by attempts of private appropriation from actors that seek to approach the particular community externally, throw the community-constitutive means of indirect reciprocity out of balance.

Indeed, according to the general thoughts presented in the discussion on the commons earlier in this chapter, the particular nonrival properties of knowledge commons alongside their rather unlimited accessibility especially imply latent risks of freeriding behavior from actors that intend to approach a community's resources without contributing to their collective provision (ibid.). Against this background, establishing practices that guard their constitutive commons against private appropriation represents a key precondition for innovation communities to protect themselves against threats in connection with external commercial exploitation or corresponding attempts to transform open into proprietary knowledge. Again, insights from the OSS realm show evidence that innovation communities are capable to develop means to maintain the constitutive principles of openness and generalized exchange proactively and withstand potential struggles.

As outlined before, the terminological switch from "free" to "open source" software also affected the prevailing visions and attitudes within the related communities. The normative bonds, which motivated the inception of the free software movement, mitigated the participants' increased ambition to strengthen the competitive position of the open source approach against proprietary software. Although free- and open source software are united in their emphasis on open and freely available source code, the pragmatic turn towards OSS broke the reluctance of free software to team up with commercial actors and changed the attitude towards firms noticeably.[4]

[4]To exemplify these tendencies for the case of Linux, Lakhani and Panetta point out that the surrounding "commercial ecosystem" was expected to reach "about $35 billion in 2008 with installations in more than 43 million computing devices ranging from PCs and servers to cell phones, routers, and super computer clusters" (Lakhani and Panetta 2007, 99). The commercial potential of OSS thus differs from the proprietary software model as not the actual products but the service of consulting and support are sold. As Kogut and Metiu describe for the case of RedHat, which is the biggest and most recognized company that provides a version of Linux along other

From the point of proprietary firms, there are various reasons to engage in OSS communities. Some consider related investments as strategic move to trigger the creation of new knowledge and generally amplify their innovative capacities (von Hippel and von Krogh 2003; Rolandsson et al. 2011). Besides, collaborations with OSS communities may offer sources of efficiency gain as they intensify exchange processes with potential users which concurrently participate in debugging and design of a particular piece of software (Kogut and Metiu 2001). Additionally, West identifies firms' strategies to release source code to OSS communities in order to expand its adoption and attract potential developers to contribute to the particular project (West 2003). Others argue that firms invest in OSS because they intend to gain legitimacy by using the resulting software and also try to influence the direction of its further development by paying their employees to occupy critical positions within the communities (Dahlander and Wallin 2006). Independent of the particular goal that a firm aims to accomplish, the general divergence of rationales between communities and companies imposes principle organizational challenges in every interaction:

> OSS communities are outside the hierarchical control of the firms, and there are no contractual agreements between the firm and the contributing community members. Even more importantly, the basic idea of exploiting the financial value of jointly developed software runs against the core values of the entire OSS movement, in which the code is protected from being appropriated by commercial firms through the use of legal and normative mechanisms. (Dahlander and Magnusson 2005, 482)

This quote points towards a rather general issue of community-based innovations. Constellations, in which the collective outcomes imply potentials for commercial exploitation, will certainly attract private actors seeking to gain additional value from them. From the perspective of a community, which needs to provide modes of generalized exchange in order sustain the collective creation of commons-based knowledge, these strong imperatives toward commercial exploitation by private companies impose serious challenges for their internal cohesion:

> To remain open and publicly available, it [OSS] must be protected from proprietary appropriation. Thus, open source and free software appear to be joint in supply, but are in fact vulnerable to usage that would threaten its availability to all. Use of the software will not diminish in the present, but the future stream of benefits is at risk. (O'Mahony 2003, 1182)

In her study of community managed OSS projects, O'Mahony identifies a set of rather technical tactics that related communities develop to stay open and sustain their constituting commons (ibid. 1183pp). The most powerful approach to guard the commons is the adoption of formal licenses like copyleft, which legally restrict the proprietary appropriation of open source software code. Another opportunity relates to the inception of collectively-managed non-profit organizations like the

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open source applications, companies that build their business models on OSS usually compete on the basis of customer service, instead of ownership of the intellectual property (Kogut and Metiu 2001, 252).

Free Software Foundation, which are able to allocate resources to actually enforce these licenses. Although these approaches somehow neglect the affective and normative aspects sustaining the social bonds and associated feelings of belonging, they offer a sophisticated toolkit to defend the core contents of innovation communities engaged in OSS development. As outlined in Sect. 2.2, these advancements build on a rich heritage of ideological engagements, organizational creativity, and strategic turn that together helped to make OSS the success story it is today.

While some of the insights on community-based innovations from the field OSS are eligible for generalization, others are not. For instance, since it is very likely that profit-seeking actors with a capitalist spirit try to engage in any innovation communities as soon as they create valuable outcomes, any of such collectives needs to figure out how their outcomes may be protected against proprietary appropriation. However, compared to the specific case of OSS, most of those constellations lack similar degrees of sophistication and institutionalization to guard their constituting commons. For instance, the study by Baldwin et al. (2006) draws on the case of rodeo kayaking communities to derive a programmatic model for the transformation of tangible user innovations into commercial products. The model concludes that in early phases, free-revealing communities are highly beneficial in exploring novel designs, as these collective activities are more efficient than innovators acting in isolation. Regarding the latter phases of exploitation, the authors thus emphasize the increasing relevance of professional manufacturers entering in the final stage of the innovative process. Since "too much competition" will certainly decrease the community's viability (ibid. 1307), the commercial exploitation of user innovation by private actors entails the threat that related communities will eventually lose control over their constituting commons.

Summing these insights up, it becomes obvious that CBI represents a collective effort of knowledge creation and dissemination by the means of open, accessible, and generalized exchange. This particular mode of "doing innovation" thus adds a performative facet to my definition of innovation communities presented above. Yet, situations in which corporate actors join these settings to engage in processes of community-based innovation are socially challenging—particularly because commercial strategies to appropriate collective commons are potentially critical for generalized exchange. Although it is generally possible that corporate companies, which appreciate and support the principles of CBI, engage positively in related settings, innovation communities still need to protect themselves from unilateral commercial exploitation and sustain the solidarity and reciprocity that constitutes their immanent interactions.

2.3.3 Exploration and Exploitation in Innovation Communities

Any of the constellations of scientific, digital, or physical value creation that have been interpreted in terms of non-commercial community-based innovation before might also entail latent occasions for critical friction between the means of collective innovative action and the ends of private/corporate appropriation. As shown in the beginning of this chapter, the classical economic perspective roots related tensions in a certain tragedy of the commons, which conceives of collective action as infused by the spirit of capitalism and assumes a rational actor seeking to maximize his or her private profit. Applied to the context of innovation communities, such a behavior at some point would disrupt the bottom lines of generalized and commons-based knowledge exchange. Although the spirit of capitalism surely constitutes an important orientation for human action, Ostrom's analysis of common-pool resources already reveals communities' abilities to self-organize collective provision *and* utilization in sustainable ways. Empirical evidence from the contexts of open source software or open science adds further evidence for alternative modes of collective action that actively embrace open and accessible knowledge-flows to maintain the reciprocity within communal, non-proprietary relationships.

Accordingly, communities that reproduce generalized modes of exchange rely strongly on the collective commitment to disclosure and the practical imperative of sharing potentially innovative knowledge. The extensive implementation of these community principles represents the key preconditions for the mutual perception of reciprocity between the otherwise decoupled actors involved, thus spurring associated feelings of solidarity and a certain sense of belonging. Although the introduced cases from the field of OSS reveal how communities become able to guard their constitutive commons as well as the structures of collective contribution by the means of specific licenses, most innovation communities lack similar legal resources and therefore rely even more on the symbolical and practical implementation of common values.

Although it is, in principle, possible that community-based innovations are created, developed, and disseminated exclusively within the boundaries of a particular community, it is not very likely. Existing research from related contexts suggests instead that communities provide applicable and even advantageous settings to create novel knowledge collectively. While these processes foster a rich environment for serendipity, related outcomes too often fail to capture its monetary value adequately. This is especially the case when patterns of community-based innovation are applied in the context of tangible product innovations. Such constellations leave the realm of digital, nonrival information as they imply the need to turn common ideas into physical goods. While the collective creation and exploration of ideas and designs can surely be accomplished by community interaction, the matter of material production usually requires resources that can hardly be provided by the means of generalized exchange.

From a capitalist point of view, any potentially innovative idea that fails to become an actual product reveals an instance of economic under-exploitation. Since innovation communities indeed lack capacities for market exploitation, they often generate entrepreneurial opportunities for actors seeking to appropriate community-based innovations in commercial ways. In this context, Harhoff and Mayerhofer (2010) envision general conditions that would enable well-balanced collaboration between communities and firms (here: "manufacturers") as a hybrid source of innovation as follows:

> We argue that such hybrid forms will be sustainable only if the parties involved receive a sufficiently high benefit from the relationship and as long as the norms of the community, in particular with regard to sentiments of fair treatment, are not violated. [. . .] The relationship between the community and manufacturer must display some fairness, in that users receive a return in kind from the manufacturer's appropriation of the innovation. (Harhoff und Mayerhofer 2010, 141)

Furthermore, studies on the commercialization of user innovation also reveal that efforts to exploit community outcomes do not necessarily stem from external actors like firms or professional manufacturers but are also pursued by user entrepreneurs, who found community spin-offs from within innovation communities (Shah and Tripsas 2007; Baldwin and von Hippel 2011). Yet, I consider any such entrepreneurial ambitions as socially challenging, since as a rule, commercial strategies to appropriate collective outcomes contradict community principles. Even if entrepreneurial actors contribute to collective processes of knowledge exploration, the fact that they individually engage in exploitation tips the balance that sustains reciprocal generalized exchange. It is essentially this dilemma between the entrepreneurial ambitions to exploit the commons and the community-based foundations to guard them, which motivates my empirical research.

For the entrepreneurs, the *dilemma of entrepreneurship* usually translates into a paradoxical relationship between the symbolic and practical foundations of innovation communities on the one hand and the economic rationalities that extend the means and ends of community-based innovation by providing guidelines for commercial exploitation on the other. Since any attempt to capture the economic value of CBI requires monetary investments and competitive business models, entrepreneurs necessarily need to adapt practices from business realms that stand in contradiction to modes of open and generalized exchange. However, this may also become a problem for the particular innovation communities, too, as the inability to capture the entire (and especially: economic) value of their outcomes reveals a shortcoming that can decrease the integrity of their members. While the current state of research widely lacks analytical toolkits to explain related frictions, I will draw on insights from the sociology of organizations in order to explain the social dilemma at the intersection of innovation communities and entrepreneurship more profoundly.

Chapter 3
Theorizing Innovation Communities

Abstract This chapter connects directly to the current state of research on innovation communities and discusses their institutional foundations, their implementation in the context of fields, as well as their practical implications in terms of agency and entrepreneurship. Against this background, I attempt to grasp innovation communities as a distinct type of meso-level order. Here, the general conflicts that shape the institutional foundations of collective innovation play out in the context of gradually settled fields, where community and business logics compete over the legitimate ways to shape the particular innovation at stake. Consequently, the resulting fields reflect an ambiguous institutional environment that affects not only the general conditions under which innovation communities create and develop potentially innovative artifacts (like 3D printers), but also the particular opportunities and struggles that accompany corresponding approaches for commercial exploitation. As the dilemma of entrepreneurship in open hardware usually refers to community members that develop entrepreneurial ambitions to commercialize community-based innovations, Chap. 3 also emphasizes the micro level of individual actors and their agentic capacities to relieve tensions within a complex and potentially contradictive institutional environment.

Various aspects that I discussed in connection with the current state of research on innovation communities suggest that their specific modes of non-proprietary and non-commercial value creation differ considerably from related practices within business settings. If, for example, corporate actors approach open-source or user communities, they might encounter ideological as well as practical differences, which are difficult to align with their business routines. The distinct modes that coordinate social interaction within markets and communities might provide explanations for this. While markets emerge from mainly competitive business relations, communities essentially rely on reciprocity and trust among their members. Besides, practices of trading, financing, or employing, which are prevalent in markets, are constituted by direct exchange and pricing of tradable values like e.g. money, goods, investments, or workforce. In contrast, generalized exchange of commons-based values like knowledge or assistance within communities relies on indirect reciprocity (Takahashi 2000) and mutual perceptions of solidarity (Molm et al. 2007).

J.-P. Ferdinand, *Entrepreneurship in Innovation Communities*, Contributions to Management Science, DOI 10.1007/978-3-319-66842-0_3

This broad scope of facets touches some of sociology's key issues that range from multiple rationalities and associated types of social action (Weber 1978), over the constitution of fields as meso-level orders (Fligstein and McAdam 2012) to the mutual relationships between actors and the institutionalized structures they are embedded in (DiMaggio and Powell 1991; Giddens 1984). I will tackle these issues in the course of this chapter by first grounding the inherent differences between communities and markets in distinct *institutional logics* that differentiate the society's general systems of order (Sect. 3.1). Although these macro references can hardly be neglected, I believe that the institutional tensions, which affect my research case, mainly occur on the meso-level of social order. I will therefore introduce various sociological notions of *fields* and their corresponding assertions on the constitution of meso-level orders. In particular, I derive a theoretical framework that captures the distinct institutional environment in which actors who engage in community-based innovations are embedded (Sect. 3.2). Finally, the foundation of the micro-level focuses on the individual capacities that constitute the actors' *agency* against the ambiguous institutional background that shapes the field structure they are embedded in (Sect. 3.3).

3.1 Institutional Foundations

The sociological analysis of institutional tensions within the context of community-based innovation needs to emphasize some general traits of social action as well as their broader structural references. To elaborate this key issue in sociological theory, I will first and mainly take the perspective of the New Institutionalism (NI), which emphasizes the mutual relationships between actors and the institutional environments they are embedded in (DiMaggio and Powell 1991; Scott 2001, 2013). Within this theoretical framework, the particular scope of institutional settings refers to various levels of social order that may either address global structures (Meyer et al. 1997; Meyer 2010), the functional separation of a society's most important institutional spheres (Friedland and Alford 1991), fields (or more precisely: organizational fields, DiMaggio and Powell 1983) as well as the context of single organizations (Zucker 1983).

Against this multifaceted background, one common denominator of institutionalist perspectives suggests that these institutional environments represent aggregated contexts beyond the scope of single actors' agency. They are supposed to shape individual or collective action by the latent presence of shared cultural schemas, normative expectations, or regulative rules:

> Institutions comprise regulative, normative, and cultural-cognitive elements that, together with associated activities and resources, provide stability and meaning to social life. (Scott 2013, 56)

These structural elements form a continuum of conditions for action moving "from the conscious to the unconscious, from the legally enforced to the taken for granted" (Hoffman 1997, 36, cited from Scott 2001, 51). Moreover, the distinguishing feature of the "New" Institutionalism refers to what DiMaggio and Powell describe as "cognitive turn" (DiMaggio and Powell 1991, 22). Accordingly, the mutual relationships between institutions, cognition, and action form a triad, which represents the pivotal focus of NI-related perspectives.[1] In doing so, new institutional theory highlights the cultural influences on decision-making and organizational structures:

> It [institutional theory] holds that organizations, and the individuals who populate them, are suspended in a web of values, norms, rules, beliefs, and taken-for-granted assumptions, that are at least partially of their own making. These cultural elements define the way the world is and should be. (Barley and Tolbert 1997, 93)

However, since such institutional environments "can vary in the degree to which acts in them are institutionalized" (Zucker 1977, 728) and "only exist to the extent they are institutionally defined" (DiMaggio and Powell 1983, 148), tracing the actual links between institutions, cognition, and action remains an analytical challenge.

Insights from the previous chapter suggest that the general tensions associated with the dilemma of entrepreneurship point more specifically to the intersection of different institutional contexts. While notions of commons-based, generalized exchange resemble open source ideals that originate from the scientific realm (see Sect. 2.2.1), the commodification and monetization of CBI via the means of restricted exchange are instead linked to economic spheres. In the theoretical context of NI, this assumption refers to Friedland and Alford's (1991) attempt to develop a conception of society as a potentially contradictory interinstitutional system: "Institutions cannot be analyzed in isolation from each other, but must be understood in their mutually dependent, yet contradictory relationships" (ibid. 241). Central to this endeavor is the concept of *institutional logics*, which serves as an approach to add aspects of differentiation between distinct societal spheres to the body of new institutionalist theory:

> Each of the most important institutional orders of contemporary Western societies has a central logic—a set of material practices and symbolic constructions—which constitutes its organizing principles and which is available to organizations and individuals to elaborate. (Friedland and Alford 1991, 240)

According to the authors, the interinstitutional system of contemporary Western societies consists of five major institutional orders with each reproducing a dominant logic: The institutional logic of capitalism is shaped by the accumulation and

[1] In the additional notes to the introductory chapter of "The New Institutionalism in Organizational Analysis", DiMaggio and Powell specify their understandings on both, cognition and action as follows: "By cognition we refer to both reasoning and the preconscious grounds of reason: classifications, representations, scripts, schemas, production systems, and the like. [...] We use the term action throughout to refer to social behavior, without any of the muscular, rational, or individual reductionist connotations that some have associated with this term." (DiMaggio and Powell 1991, 35).

commodification of human activity. The institutional order of the state is accompanied by the logic of rationalization and regulation of human activity by legal and bureaucratic hierarchies. The order of democracy, by the logic of participation and popular control over human activity; the order of the family by its associated logic of community and the motivation of unconditional loyalty to its members.[2] Finally, the institutional order of religion (respectively: science) is transcendental (or, for the case of science: objective or "mundane") truth and the symbolic construction of reality within which all human activity takes place (ibid.).

Generally, this five-folded differentiation of institutional orders does not represent a comprehensive list but a rather eclectic array, which, according to the authors, reflects the macro-institutional landscape of Western societies in the twentieth century. Additionally, since the reach of institutional logics is latently contested and hence fluid, the authors suggest that each of the corresponding logics "should be observable in patterns of material and symbolic practice" (ibid. 262). Accordingly, the notion of *material practices* refers to "patterns of human activity by which individuals and organizations produce and reproduce their material subsistence and organize time and space" (ibid. 243). The notion of *symbolic constructions* thus emphasizes "symbolic systems through which they [individuals and organizations] categorize that activity and infuse it with meaning" (ibid. 232).

The background, then, is one of simultaneously symbolic and material aspects of distinct institutional logics, which struggle for relevance within the broader scope of an interinstitutional system. Friedland and Alford believe that only the emphasis of institutional contradictions between such logics is vital to restore meaning in social and especially NI-related analysis. This nuanced perspective thus offers a good starting point to elaborate on the different accounts of agency and consciousness contained in the initial formulations of NI:

> Under some conditions, [actors] are artful in the mobilization of *different* institutional logics to serve their purposes. Sometimes rules and symbols are internalized and result in almost universal conformity, but sometimes they are resources manipulated by individuals, groups, and organizations. (Friedland and Alford 1991, 254, italics added by authors)

Hence, while I appreciate the approach of a nuanced institutional logics perspective, I criticize its application to the explanation of social action. Moreover, I attempt to fill gaps in the authors' understanding of how institutional logics and related sets of material practices and symbolic constructions can be traced analytically (or even: empirically). Therefore, I consider it worthwhile to relate two of Friedland and Alford's vague notions—material practices on the one hand and symbolic constructions on the other—to two of sociology's basic categories: rationality and legitimacy (Sect. 3.1.1). Afterwards I will apply the sharpened perspective on institutional logics to the general topic of innovation by emphasizing

[2] As I have shown before and will elaborate further later (see Sect. 3.2), this traditional notion of community differs considerably from my understanding of communities as distinct contexts for innovation.

the particular effects of scientific and capitalist logics on innovative action (Sect. 3.1.2).

3.1.1 Capturing the Conflicts Between Logics

Friedland and Alford claim that institutions can hardly be analyzed in isolation from each other, but must be understood in their mutually-dependent relations: in doing so, they point towards the friction that occurs when the practical and symbolical implications of distinct institutional logics clash in immediate contexts of social action. Besides stating that each logic contains certain sets of material practices and symbolic constructions that actors can draw on to align their actions with a certain institutional order, the authors remain rather fuzzy in explicating how these practices and constructions can be delineated in the context of empirical research. I believe that while distinct material practices derived by a certain logic predominantly aggregate patterns of rationality that link the actors' ideas, intents, and actions in specific ways, symbolic constructions mainly affect their valuations and evaluations on legitimacy and morality.

3.1.1.1 Material Practices and Rationality

In one of his more recent papers, Friedland (2013) explicitly emphasizes the close linkage between the institutional logics perspective and Weber's theory of value spheres. Like the initial conceptualization of institutional logics, value spheres also represent an approach to distinguishing between relative autonomous and potentially contradictive domains of action. Instead of Friedland and Alford, who conceive of five dominant institutional orders and associated institutional logics, Weber distinguishes between six value spheres: religion, economy, politics, aesthetics, the erotic, and intellectualism (Oakes 2003, 28). Independent of the actual number, value spheres, too, offer an analytical structure to separate a society's macro order into different institutional scopes, with each representing a distinct "locus of value rationalization" (Oakes 2003).[3]

[3]In Weber's theoretical corpus, *Rationalization* describes historical processes of systematization, in which ideas (containing certain values and worldviews) transform into relative persistent capacities which influence social action, or, as Swidler (1973) puts it, "the process by which ideas develop their own internal logic" (ibid. 36). Rationalization therefore rather resembles a general and processual pattern, which can occur in many different spheres of life without being restricted to any unique types of institutions or modes of social action: "There is, for example, rationalization of mystical contemplation, that is of an attitude which, viewed from other departments of life, is specifically irrational, just as much as there are rationalizations of economic life, of technique, of scientific research, of military training, of law and administration. Furthermore, each one of these fields may be rationalized in terms of very different ultimate values and ends, and what is rational from one point of view may well be irrational from another." (Weber 2005, xxxvii–xxxix).

Like institutional logics, value spheres define a space of rationalized principles and value positions that claims a certain validity and legitimacy, or, as Townley puts it: "[...] each value sphere has patterns of action and ways of life that are defended as 'rational'" (Townley 2002, 146). As such, each value sphere endows individuals with interpretative capacities "to deliberately take a position on the world and ascribe a meaning to it" (Weber 1949, 81 cited from Oakes 2003, 28)

The particular connection between actors, their cognitive capacities for agency and the distinct sets of meaning that inform their actions directly leads to Weber's popular concept of *rationality*. Weber explicates general modes of how actors link ideas, intents, and action and thus attach meaning to their day-by-day practices (Swidler 1973). According to Kalberg (1980) four types of rationality can be derived from Weber's work: practical, theoretical, substantive, and formal (ibid. 1151pp., see also Townley 2002, 165).

- Practical rationality embraces tacit guidance for pragmatic actions in the course of daily routines. Practical rational actors accept the given realities unquestioned and apply "the most expedient means of dealing with the difficulties they present" (Kalberg 1980, 1152).
- In sharp contrast, theoretical rationality captures rather reflective modes of action that are based on abstract concepts and sophisticated understandings of how the world works.
- Substantive rationality resembles practical rationality as it directly orders action in coherence to an actor's immediate preferences. Unlike its practical notion, substantive rationality thereby relates not to pragmatic means-end evaluation but to "valid canons" of values or value postulates that ascribe meaning to action without referring to any prospect of success.
- Finally, formal rationality also draws on means-end calculations but grounds them in conscious evaluations of available options depending on their ability to aid in achieving a certain goal. It informs formal rational-choice approaches to action and therefore mainly relates to the economic realm and the bureaucratic form of domination (ibid. 1158).

In contrast to rationalization as the general process that establishes differentiated value spheres, or the distinct but universal modes of rationality that provide analytical patterns to grasp linkages between ideas, intents, and action, Weber's fourfold *typology of action* represents basic capabilities of human individuals that play out in their day-by-day actions (Kalberg 1980, 1148). According to Weber, social action can either be affectual, traditional, value-rational, or means-end-(resp. instrumentally-)rational. Regarding related degrees of consciousness, Weber generally considers affectual and traditional action as unthinking or taken-for-granted because they are shaped by habit or emotion. Instead, the latter types are rational because, in the case of instrumentally-rational action, "the end, the means, and the secondary results are all rationally taken into account and weighed" (Weber 1978, 26). Value-rational action finally participates in the "clearly self-conscious formulation of the ultimate values governing the action and the consistently planned orientation of its detailed course to these values" (ibid. 25).

Linking value spheres, rationality and the corresponding types of social action in an empirical study on the introduction of business planning and performance measures in cultural organizations, Townley (2002) distinguishes between cultural and economic value spheres. She finds that "the four dimensions of rationality are apparent in both value spheres [. . .] although differently weighted and with different meanings" (ibid. 176). By analyzing actual organizations in their respective environments, Townley thus leaves the macro sphere of social order and clearly relates the concept of value spheres to meso-level structures and the immediate patterns of action that claim for a certain type of rationality in the particular sphere. Although I generally criticize this implicit switch between different analytical layers, I nevertheless appreciate Townley's empirical proof of what already appeared reasonable from a theoretical point of view: "Two types of rationality inform the rational action familiar to organization theorists: substantive rationality informs value-rational action, and formal rationality informs instrumentally rational action." (Townley 2002, 165)

Picking up again Friedland and Alford's concept of institutional logics and its intellectual affinity to Weber's value spheres, I believe that linking Weber's general modes of rationality with particular types of action helps to develop a nuanced approach to analyze the ways in which actors connect their ideas and intents to distinct modes of action. This perspective thus expands the original notion of material practices as "patterns of human activity by which individuals and organizations produce and reproduce their material subsistence" (Friedland and Alford 1991, 243). Tracing the particular values and intents, which inform these patterns thus offers a good starting point to elaborate on the actual relationships between immediate action and its institutional references in distinct, potentially contradictive logics. Conflict between different institutional logics thus appears because of the incompatibility of dominant practices, which differ from each another principally because of the conscious meanings and values that heterogeneous actors attach to them.

3.1.1.2 Symbolic Construction of Legitimacy

Generally, stressing the notion of symbolic construction in terms of "symbolic systems through which [actors] categorize [. . .] activity and infuse it with meaning" (Friedland and Alford 1991, 232) addresses a couple of sociology's well renowned topics. In the context of NI-related literature, for instance, symbolic construction reminds one of the cultural-cognitive aspects of institutions: "the shared conceptions that constitute the nature of social reality and the frames through which meaning is made" (Scott 2001, 57; see also DiMaggio 1997). In a similar way, Brunsson's conceives of ideology as sets of ideas that "define not only what is perceived as fact but also which facts appear important" and thus facilitate action and decision-making through mere symbolic references, myths, or strategies (Brunsson 1982, 38; see also Meyer et al. 2009, 5pp.) Last not least, the notion of symbolic constructions resonates well with Weber's premise that subjective meaning is a fundamental precondition for social action, what essentially links it back to the domain of material practices (see prior chapter).

These references are obviously too broad to sharpen an analysis that draws on the logics concept. I therefore suggest narrowing the notion of symbolic constructions down to what Meyer and Rowan (1977) describe as "rationalized myths" and their premier influence on the *legitimacy* of formal structure. Starting from the rather uncontested standpoint that rationalized formal structures such as hierarchies reflect processes of institutionalization in term of "rulelike status in social thought and action" (341), the authors interpret their symbolical outcomes in terms of rationalized myths:

> Such elements of formal structure are manifestations of powerful institutional rules which function as highly rationalized myths that are binding on particular organizations. (Meyer and Rowan 1977, 343)

The relationship between rational myths and their adoption within a particular organization is two-fold: on the one hand, this relationship depends on taken-for-granted understandings on "legitimated" organizational structures spreading through isomorphistic tendencies, on the other hand, it also accompanies structural inconsistencies such that "formal structures that celebrate institutionalized myths differ from structures that act efficiently" (ibid. 355). In each case, the authors interpret the organizational implications of rationalized myths in terms of institutional pressures that stem from wider cultural frames. These frames essentially represent a bounded set of symbolic constructions of how organizations are structured appropriately: "Organizations that incorporate societally legitimated rationalized elements in their formal structures maximize their legitimacy and increase their resources and survival capabilities." (Meyer and Rowan 1977, 351)

I refer to this line of arguments because I believe that legitimacy, defined as "a generalized perception or assumption that the actions of an entity are desirable, proper, within some socially constructed systems of norms, values, beliefs, and definitions" (Suchman 1995, 574), is mainly a matter of *symbolic construction* rooted in the specific cultural-cognitive settings of particular institutional spheres. Focusing on organizational legitimacy in particular, Meyer and Richard Scott (1983) relate it "to the degree of cultural support for an organization—the extent to which the array of established cultural accounts provide explanations for its existence, functioning, and jurisdiction, and lack or deny alternatives" (201). In this view, legitimacy is tightly related to "rational cultural accounting systems" assessing the "adequacy of an organization" (ibid.). While Suchman (1995) also describes legitimacy as socially constructed because "cultural definitions determine how the organization is built, how it is run, and, simultaneously, how it is understood and evaluated" (575), he raises questions about the extent to which organizations are capable to actively seek for such benevolent dispositions:

> [...] I consider cultural environments to be fundamentally constitutive of organizational life, and I adopt a somewhat skeptical attitude toward the autonomy, objectivity, and potency of managers. Managers do enunciate supportive myths and prescribe culturally

> congruent rituals; however, managers rarely convince others to believe much that the managers do not believe themselves. (Suchman 1995, 577)

While I am also cautious about overemphasizing an actor's ability to select pieces from the cultural repertoire in order to construct legitimate lines of action intentionally, I believe that especially in ambiguous cultural settings, actors are indeed capable of considering which of the symbolic constructions that are apparent in their aggregated institutional environments suits them best to justify their actions as legitimate practice. What tips this balance remains an empirical question recursively dependent upon an actor's cultural embeddedness and the particularly institutionalized criteria for legitimate action.

3.1.2 Institutional Logics and Innovation

In Western societies, the subject of innovation is traditionally grounded within the economic sphere and the corresponding institutional order of capitalism. According to Friedland and Alford, the associated logic promotes the accumulation and commodification of human activity, which in the case of innovation mainly refers to contexts of research, development, and the exploitation of novel goods or services. Accordingly, the material practices concerned with commercial innovation generally address issues of ownership and appropriability—economic actors only invest in potential innovations if they believe they can make a profit from this commercial exploitation.

Indeed, the core aspect that distinguishes the most established economic ways of dealing with innovation from what I have described as common practice in terms of community-based innovation in the previous Chap. 2 is that "information will frequently have an economic value, in the sense that anyone possessing the information can make greater profits than would otherwise be the case" (Arrow 1962, 614). Although this is certainly true for every variable that affects competitiveness and market equilibria, it is particularly pivotal when it comes to novel knowledge that has the potential for commercial innovation. Schumpeter already embraced the relevance of innovations as the most immediate sources of economic gains (Schumpeter 1939, 104). Moreover, innovations provide the main stimuli for what he popularly called "creative destruction": a disruptive dynamic of economic change that represents the "essential fact about capitalism" (Schumpeter 2003, 83). Consequently, the constant and intended creation of knowledge as the main trigger for innovation is one of the key criteria that legitimate enterprises in the economic realm (Hutter et al. 2011).

In order to build creative capacities for sustaining innovativeness as default mode for their business practices, firms in knowledge-driven sectors of the economy often implement R&D units, engage in inter-organizational networks, or apply open innovation strategies to foster the exploration of innovative knowledge. Each of the related practices is likely to catalyze knowledge as commodities that serve as a promise for future revenues:

> In the most general terms, private profit-seeking agents will plausibly allocate resources to the exploration and development of new products and new techniques of production if they know, or believe in, the existence of some sort of yet unexploited scientific and technical opportunities; if they expect that there will be a market for their new products and processes; and, finally, if they expect some economic benefit, net of the incurred costs, deriving from the innovations. (Dosi 1988, 1120)

Dosi's quote also indicates another important feature: the high relevance of appropriation within in the economic sphere. Innovation endeavors that seek to explore opportunities for innovation always focus on possible applications that improve a company's performance on the market. Therefore, outcomes from corporate R&D units are either immediately transformed into tradable products or services, or are appropriated to generally increase a firm's competiveness in the capitalist system. Thus, firms engaged in knowledge-driven markets usually seek to keep their R&D outcomes secret or apply patents to secure their intellectual property: "With suitable legal measures, information may become an appropriable commodity" (Arrow 1962).

While all of the practices of exploration and exploitation associated with the dominant capitalist logic reveal the key features of Weber's formal rationality and exemplify associated types of instrumentally rational action, the original organizing principles that enable "innovation" in science present quite different properties. The pivotal precondition that sustains innovative action as means for the collective expansion of scientific knowledge is what Merton (1973) describes in terms of "'Communism,' in the nontechnical and extended sense of common ownership" (ibid. 273).[4] This principle of scientific communism suggests that the very idea of scientific knowledge creation and circulation heavily draws on a non-proprietary approach to knowledge as a common. Indeed, common ownership exemplifies some of the key features of scientific practices:

- First, since each novel discovery and finding builds upon a body of existing knowledge, scientists are constantly embedded in a cultural heritage that reveals the "essentially cooperative and selectively cumulative quality of scientific achievement" (ibid. 275).
- This directly leads to a second implication, namely that "the institutional conception of science as a part of the public domain is linked with the imperative for communication of findings. Secrecy is the antithesis of this norm, full and open communication its enactment" (ibid. 274).
- Consequently, "the scientist's claim to 'his' intellectual 'property' is limited to that of recognition and esteem which, if the institution functions with a modicum

[4]Besides his notion of communism, Merton explicates three other imperatives—universalism, desinterestedness, and organized skepticism—in order to demarcate specific sets of institutionalized values and norms widely legitimized in scientific communities.

of efficiency, is roughly commensurate with the significance of the increments brought to the common fund of knowledge" (ibid. 273).

Because the ongoing scientific search for and recognition of novel knowledge makes up a quite complex, diffuse, and persistent endeavor, it is tackled collectively by almost every single member of the scientific community. Necessarily, researchers narrow down their area of work by engaging in particular disciplines, focus on topics that cover their individual research interests, and publish in books and journals well-recognized in their specific peer groups:

> Each active member of the research community is engaged upon his own research programme which is always, in some respects, distinct from other such programmes. Nevertheless, all researchers make use of provided information by other members of the community and attempt, more or less regularly, to communicate their results to other interested scientists. (Mulkay et al. 1975, 188)

Although usually employed in universities, scientists and researchers are only slightly guided by these formal organizational structures. Studies in the sociology of science propose instead a more decentralized mode of coordination, based on the "mutual adjustment of independent initiatives—of initiatives which are coordinated because each takes into account all the other initiatives operating within the same system" (Polanyi 2000, 2). By interpreting the mutual alignment of independent contributions as "the most efficient possible organisation of scientific progress" (ibid, 56), Polanyi delineates a particular mode of self-organization that not only applies to explorative processes of knowledge creation but also to scientists' ambition to sustain knowledge as a commons-based resource. In contrast to the instrumental means and ends of innovation in the economic realm, the ways scientists create and disperse novel knowledge entail value-based accounts to substantial rationality. These capture and reproduce the core principles derived from the ethos of science: "An essential, defining feature of modern science thus is found in its public, collective character, and its commitment to cooperative inquiry and free sharing of knowledge" (David 2007, 6).

Applying the previously developed analytical perspective to the ideal-typical contrasts between the capitalist and scientific ways of "doing innovation" thus suggests the juxtaposition of exemplary material practices and symbolic constructions depicted in Table 3.1.

The conceptual emphasis on contradictory relationships between distinct institutional logics thus becomes evident, when the ideal typical principles of capitalist and scientific innovation merge within hybrid settings for interaction. Indeed, recent trends in business models emphasize a company's ability to exploit external knowledge by e.g. tapping into scientific realms.[5] Together with complementary tendencies in academia, which for instance spur increased numbers of university industry partnerships or the rising implementation of technology transfer offices,

[5]Cohen and Levinthal first coined this approach in terms of "absorptive capacity", defined as "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilities" (Cohen and Levinthal 1990, 128).

Table 3.1 Material practices and symbolic constructions shaped by the institutional logics of capitalism and science

	Capitalist logic	Scientific logic
Material practices	• "Doing innovation" to increase private profits • Trading knowledge as a proprietary commodity • Firm-based coordination	• "Doing innovation" to expand the body of existing knowledge • Sharing knowledge as a common among peers • Community-based coordination
Symbolic constructions	• Innovation as key driver for economic change and market competiveness • Commercial success decides upon value of innovative knowledge	• Individual contributions as part of scientific communism • Peer evaluations decide upon value of innovative knowledge

constellations in which actors from different domains collaborate in joint innovation endeavors gain in empirical evidence.

Due to the specific rationalities and cultural surroundings that shape their particular "sets of material practices and symbolic constructions," firms usually consider commercial approaches, which monetize scientific research and capitalize external knowledge from scientific communities, as a legitimate business strategy. In contrast, scientific actors may frame the same constellations quite differently, as they represent the increasing commercialization of academic research (David 2007).[6] It becomes obvious that the clash of rationalities and cultures irritate the scientific ideals of self-organized, open, and accessible knowledge creation to a considerable degree:

> These disagreements can be related to the differences in the ways in which 'ownership' is attributed in the university research and commercial activity. Whereas the origin or 'ownership' of ideas in science has traditionally been indicated by credits given to colleagues, the more formally defined intellectual property rights indicate ownership in business. In business, property ownerships convey to the owner both the exclusionary right, that is, the right to exclude others from using his or her property, and the right to appropriate economic returns. (Knuuttila 2012, 840)

From the perspective of scientific communities, these contradictory attitudes towards ownership and the related implications for openness and accessibility reflect key challenges in the governance of knowledge-based commons. Even if some individual scientists might benefit from the commercialization of scientific knowledge (at least in monetary ways, e.g. by acquiring private funds or starting their own spin-off businesses), it is likely to harm the reproduction of scientific communities committed to an ongoing search for new knowledge. However, recent discussions in connection with "open science" also reflect that scientific actors devote increasing efforts to sustain the common principles that reproduce the

[6]It has to be mentioned that other interpretations assess the entanglement of capitalism and science consider related implications less critical. Especially authors like Etzkowitz acknowledge that "[academia] has become entrepreneurial" (Etzkowitz 2003, 109) emphasize the upside of these tendencies in terms of "a significant productive force of economy" (Etzkowitz 2003, 552).

scientific communities they are embedded in: “[Open science] is accompanied by a vivid discourse that apparently encompasses any kind of change in relation to the future of scientific knowledge creation and dissemination; a discourse whose lowest common denominator is perhaps that science in the near future somehow needs to open up more.” (Fecher and Friesike 2014, 17).

Linking the institutional logics perspective to these hybrid contexts for innovation reveals that it is reasonable to associate distinct patterns of material and symbolic practices with a particular logic in order to elaborate on the contrasts between them. However, the actual conflicts whose investigation is supposed to “restore meaning into social analysis” (Friedland and Alford 1991, 240) essentially play out in very specific fields of action. Analyzing them therefore requires a focus on meso-level orders as arenas, in which the actual impacts of institutional conflict become empirically traceable. Here, institutional complexity and conflict translate into contradicting practices, as well as ambiguous criteria for legitimacy that individuals need to elaborate as soon as they become actors in a certain field.

Aligning these insights with the topics of this study, I locate incidences of community-based innovation on the meso-level of social order. Innovation communities furthermore resemble most of the features that characterize communities in science, as e.g. the exemplary case of community-based innovation in the context of free and open source software directly links to the scientific realm, too. Indeed, it is hard (if not impossible) to understand the institutionalization of OSS communities without linking them to the heritage of the particular scientific logic that motivated Richard Stallman to create GNU or the FSF (see Sect. 2.2.1). Additionally, the conflicts that accompany the dilemma of entrepreneurship are also rooted in the general incompatibilities that arise when material practices and symbolic constructions derived from the capitalist logic spur commercialization and commodification within otherwise commons-based fields of innovation communities.

3.2 Innovation Communities and Fields

Besides the advantages the institutional logics perspective offers, one clear shortcoming results from the fact that Friedland and Alford widely neglect the existence and multiple effects of meso-level orders. Though they criticize for instance Granovetter’s work on social networks for not considering the interests, values, motives, and beliefs in his concept, they also fail to elaborate how the “content—that is, the distinctive categories, beliefs and motives created by a specific institutional logic” of social relations guides the behavior of organizations and individuals (Friedland and Alford 1991, 252).

Nevertheless, one of the main theoretical contributions of the NI establishes (organizational) fields as a level of social order “bounded by the presence of shared cultural-cognitive or normative frameworks or a common regularity system so as to ‘constitute a recognized area of institutional life’” (Scott 2001, 84; see also DiMaggio and Powell 1983, 148). While institutional logics are clearly rooted in the macro-level of the most important institutional orders, their actual implications for social action affect any level of institutional settings that links individual action with broader, more or less institutionalized structures. Thus, the meso-level order of fields reflects an analytical scope, through which the "organizing principles" of institutional logics are brought into immediate effect.[7] Since fields often imply references from various logics, they constitute meso-level layers of diffraction that re-shape and re-assemble distinct, often heterogeneous institutional environments and therefore reflect a fine-graded perspective for analyzing the institutional dynamics that emerge below and across a society's dominant orders.

3.2.1 Theories of Fields

Against the background that each institutional logic consists of a rather coherent set of material practices and symbolic constructions, the general assumption of inherent conflict between them suggests that merging these distinct sets on the meso-level of usually heterogeneous fields potentially leads to institutional frictions. Yet, by introducing the motifs of "institutional isomorphism and collective rationality," DiMaggio and Powell's (1983) seminal article widely neglects this assumption. Instead, the authors conclude that the processes of institutional field definition, which for instance include increasing interaction and mutual awareness among involved actors as well as the emergence of structures of interorganizational domination, entail coercive tendencies leading to the homogenization and structural alignment of these organizations.

This is particularly noteworthy as the authors' concept of organizational fields is, among others, also informed by Bourdieu's understandings of fields (Greenwood and Meyer 2008, 261).[8] Regarding the general structural properties that affect social action within his notion of fields, Bourdieu heavily draws on the analogy of a game: there are certain *rules*, although not explicit and codified, that shape the capacities for action; there are also *stakes*, which represent objectives of the competition between players:

> In a field, agents [. . .] constantly struggle, according the regularities and the rules constitutive of this space of play (and, in given conjunctures, over those rules themselves), with various degrees of strength and therefore diverse probabilities of success, to appropriate the specific products at stake in the game. Those who dominate in a given field are in a position

[7]Although Thornton and Ocasio's effort to expand the institutional logics framework often remains vague in terms of definitions, references and applications, they explicate pretty clear that "institutional logics do not emerge from organizational fields—they are locally instantiated and enacted in organizational fields" (Thornton et al. 2012, 119).

[8]Indeed, DiMaggio and Powell's definition of organizational fields as consisting of "those organizations that, in the aggregate, constitute a recognized area of institutional life" resembles some of Bourdieu's thoughts about fields and its boundaries: "The limits of the field are situated at the point where the effects of the field cease." (Bourdieu and Wacquant 1992, 100).

> to make it function to their advantage but they must always content with the resistance, the claims, the contention [. . .] of the dominated. (Bourdieu and Wacquant 1992, 102).

In contrast to DiMaggio and Powell's emphasis on emergent isomorphism, Bourdieu's view on action and social relations within fields embraces the influence of a particular social structure, which stems from the relative power positions that field actors occupy. Instead of a certain settled structure, fields resemble spaces of potential and active forces that challenge this structure: "[. . .] the field is also a field of struggles aimed at preserving or transforming the configuration of these forces" (ibid. 101, italicized by author). These struggles thus reveal tendencies of class conflict as the relations between positions are objectively defined by the distribution of power (tightly linked to what Bourdieu considers in terms of capital[9]), whose possession directly shapes the actor's opportunities to approach the objectives at stake in the particular field.

Accordingly, the intents that motivate action differ across the positions that actors occupy in their field. If they are incumbents that already possess power and capital, they are likely to act in order to maintain the particular field structure. If they act from low-power positions, they instead resemble challengers that attempt to strategically contest the given field structure.[10] Depending on the degree to which the field structure affects the practical sense and subjective interpretation of the participating actors, their objective position in the field also shapes the rationalities and understandings, which inform their actions and evaluations:

> Each field calls forth and gives life to a specific form of interest, a specific *illusio*, as tacit recognition of the value of the stakes of the game and as practical mastery of its rules. Furthermore, this specific interest implied by one's participation in the game differentiates itself according to the position occupied in the game (dominant vs. dominated or orthodox vs. heretic) and with the trajectory that leads each participant to this position. (Bourdieu and Wacquant 1992, 117, italicized by authors)

While Bourdieu's notion of illusio as "tacit recognition of the value of the stakes of the game" and "practical mastery of its rules" constitutes the symbolic and practical framework in which field interaction takes place, the immediate enactment of illusio usually implies conflicts between actors that occupy varying positions in the field. However, Bourdieu's dominant application of the field concept generally captures broader social contexts like the artistic, intellectual, religious, juridical, or scientific fields, which rather address macro spheres than more immediate settings for empirical research.

Therefore, recent receptions of field theory draw on references from both Bourdieu and NI to found a general perspective on fields that clearly emphasizes

[9]Bourdieu generally distinguishes between three "fundamental guises" (Bourdieu 2010 [1986], 82): economic capital like e.g. money or property rights, cultural capital like educational qualifications, and social capital acquired by formal titles or nobility.

[10]See also Bourdieu's references in the Marxist notion of class struggles reflecting unequally distributed power in the context of capitalist labor (Marx 1973 [1887]) as well as in Weber's conceptualization of markets as power arenas (Weber 1968).

the rather concrete, yet more fluid meso-levels of social order, which include both organizations and individuals as relevant actors. For instance, Hoffman's approach of *issue-based fields* represents such an approach that resonates well with Bourdieu's field concept. Working from the idea that fields generally represent networks of interaction, Hoffman suggests that not certain industries or technologies but instead common *issues* constitute a field: "Issues define what the field is, making links that may not have previously been present" (Hoffman 1999, 352).

Although Hoffman's conception coincides with Bourdieu's emphasis on the relevance of relational structures within fields, he discusses notions of struggles between contesting field members in terms of negotiations over issue definitions, their interpretation, and related forms of appropriate engagement. Thus, the institutional life within issue-based fields mainly refers to actors that constantly negotiate over appropriate definitions of the particular issue at stake or legitimate practices to approach it. In this regard, Hoffman seizes the idea of *collective rationalities* in a way that differs from its initial meaning in the context of DiMaggio and Powell's work: "The notion of collective rationality is to be seen not as an argument of strict environmental determinism but rather a choice among a bounded set of legitimately available options" (Hoffman 2001, 134).[11]

Fligstein and McAdam's (2012) theory of strategic action fields (SAF) reveals an adjacent but more integrative approach to define fields. Based on the general assumption that SAF are constituted by strategic action as "the attempt of social actors to create and sustain social worlds by securing the cooperation of others" (ibid. 17), the authors relate the structural outcomes of these agentic efforts to the emergence of *shared understandings* that represent the unique bonds for interactions within a particular field:

> A strategic action field is a constructed mesolevel social order in which actors (who can be individual or collective) are attuned to and interact with one another on the basis of shared (which is not to say consensual) understandings about the purposes of the field, relationships to others in the field (including who has power and why), and the rules governing legitimate action in the field. (Fligstein and McAdam 2012, 9)

The authors' emphasis on shared understandings essentially links Bourdieu's notion of illusio with Hoffman's insights on collective rationalities. Hence, the authors elaborate this linkage by distinguishing four categories, which help to capture the constative facets of shared understandings as follows (ibid. 10pp.):

- Directly linking to Bourdieu and Wacquant (1992), Fligstein and McAdam's first remark on shared understandings refers to the perception of what is going on in the field respectively, "what is at stake".

[11]In one of his more recent papers, Hoffman suggests that researches who address (organizational) fields should embrace questions on how collective rationalities emerge rather than asking what impacts collective rationality has on a given field: "[. . .] how it is developed, which field members contribute to its development, and maintenance, how it is transmitted to other actors, and how it changes over time" (Wooten and Hoffman 2008, 138).

- The second facet of shared understandings draws on SAF as relational spaces, in which actors develop a mutual awareness about their own position in a field's structure as well as how their position relates to those of other members of a particular SAF: "One way of thinking about this is that actors know who their friends, their enemies, and their competitors are because they know who occupies those roles in the field" (Fligstein and McAdam 2012, 11).
- Third, the authors address issues of legitimacy as they detect shared understandings about what practices, tactics, and forms of organization are viewed as legitimate and meaningful within the context of a field.
- Fourth and finally, Fligstein and McAdam assume the presence of interpretative frames, which help actors to make sense of the relations and interactions that are prevalent within SAF. In this respect, the authors explicate that fields consist of different interpretative frames with each reflecting the relative position of the respective actors: "actors will tend to see the moves of others from their own perspective in the field" (ibid.).

To summarize, all of the authors mentioned above consider fields on the one hand as context for repeated interactions among a somehow bounded group of principally diverse actors, who are thus aware of their mutual engagement in the field. On the other hand, each of the field concepts assumes the existence of surrounding structures ("illusio", "collective rationalities", "shared understandings") that affect the mutually-linked actors within the field. In the course of this book, I will seize both facets of field theory. However, I adapt the concepts of collective rationalities and shared understandings in a rather selective way that allows me to align them with the institutional logics perspective and increase their applicability in terms of my empirical operationalization.

First, I conceive of collective rationalities as *aggregated and repetitive patterns for linking ideas, intents, and actions within the context of distinct, analytically constructed meso-level orders*. Collective rationalities thus inform the material practices that reproduce the particular field. Secondly, my notion of shared understandings emphasizes a field's *dominant evaluation criteria for legitimate action*. As such, shared understandings reflect the distinct cultures of a certain meso-level order and guide the evaluative frameworks for the involved actors as prevalent symbolic constructions. Applying Hoffman's notion that issues are the contents that define and trigger a particular field's emergence, Fig. 3.1 represents my stylized model for the general constitution of an issue-based field.

I work from the general assumption that fields usually contain references to various institutional orders. Hence, a field's collective rationalities and shared understandings are usually shaped by more than one single institutional logic. This perspective offers additional value for my analytical investigation in two ways. First, it helps to understand the position of a particular field in the context of the broader interinstitutional system. Second, this fine-graded perspective proposes the analytical scope to delineate the institutional tensions that translate into the immediate struggles over the definition of a field's constitutive issue as well as the legitimate means to approach it.

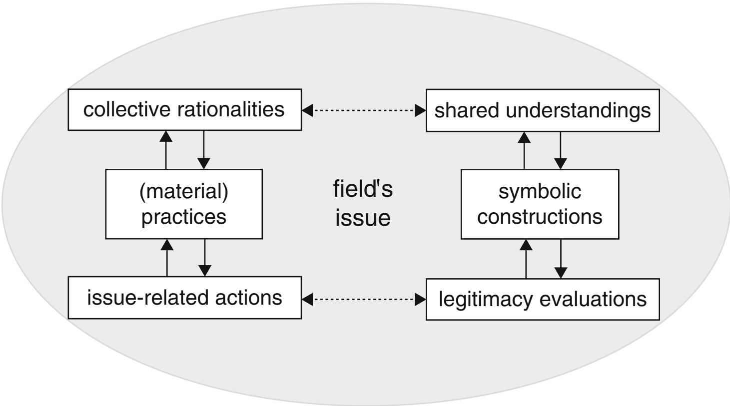


Fig. 3.1 General constitution of an issue-based field

3.2.2 Coherence and Conflict

Although the theoretical framework of fields offers some interesting insights on the institutionalization and differentiation of meso-level structures as more or less stable contexts for individual action and interaction, scholars widely missed the opportunity to increase the analytical strength of the concept. One key aspect that indeed complicates this attempt is the widely acknowledged assumption that fields are principally *nested*.

Since the analysis of meso-level orders addresses the void between the micro-level of individual action and the macro-level of social structure, it necessarily covers a broad scope of socially and culturally constructed in-between-contexts. Indeed, Bourdieu's general account of field theory assumes a vertical differentiation of fields in the sense that "every subfield has its own logic, rules, and regularities" with each stage in this division entailing "a genuine quality leap" (Bourdieu and Wacquant 1992, 104).

Fligstein & McAdam translate this view into their SAF approach as they "conceive of all fields as embedded in complex webs of other fields" (Fligstein and McAdam 2012, 18).[12] Furthermore, they conceive of a two-dimensional relationality, which on the one hand distinguishes the previously mentioned vertical-nestedness of fields within other fields and on the other hand focuses on the power relations that emerges a consequence of horizontal relationships among

[12]While this perspective generally suggests that any layer of meso-level order like e.g. organizations, social movements, or governmental systems are themselves made up of strategic action fields (see ibid. 9), constellations in which the relationship between nested fields resembles hierarchical traits resemble a system that looks like "a traditional Russian doll: with any number of smaller fields nested inside larger ones" (ibid.).

them.[13] In each case, I assume that any of the sub- or adjacent fields develops its own collective rationalities and shared understandings. Hence, the ongoing diversification of the meso-level order into an infinite number of distinct ones turns the analytical separation of coherent fields and the identification of related boundaries into a tough analytical challenge.

In order to reduce the complexity that stems from the general assumptions of a two-dimensional relationality between fields, I will again draw on Hoffman's work. His approach for grasping the institutional dynamics within issue-based fields offers a simplification, as it generally divides only two layers of vertical-nestedness—the overarching field and a discrete number of potentially conflicting subpopulations:

> As the field comprises subpopulations, each employing its own language and cultural frame for understanding the issue being debated within the field, the form of institutional pressure becomes equally diverse in its form and frame. [. . .] They [subpopulations] redefine and transmit corporate norms and beliefs into terms, institutions, and cultural frames that represent their interests and culture. (Hoffman 2001, 136)

Linking to the heritage of NI, Hoffman points out how the actors' cognition of field-level norms and beliefs is affected by the interests and culture of particular subpopulations. In other words, any subpopulation situates distinct collective rationalities and shared understandings that inform its constituting (material) practices and guide the symbolic constructions for the cultural framing of legitimacy. This theoretical finding implies two-folded perspective on field-coordination. On the one hand, coordination is a matter of mutual practical and symbolical alignments between actors within subpopulations; on the other hand, it tackles the potential conflicts, which arise from the discrepancies of actors embedded in different subpopulations. Regarding the latter aspect, Hoffman captures the resulting tensions at the intersection of conflicting subpopulations in terms of arenas, where "multiple field constituents compete over the definition of issues and the form of institutions that will guide organizational behavior" (Hoffman 1999, 352: see also Brint and Karabel 1991).

As the concept of fields generally represents an analytical attempt to understand the coherence of distinct social contexts, the emphasis on conflict and struggle essentially stresses the complementary facet of demarcation and differentiation between them. Consequently, the interplay between coherence and conflict becomes a variable that affects the structuration of every field on any layer of constructed meso-level order. Applied to the concept of issue-based fields, I would argue that coherence on the level of the field is rather loose since participation only

[13] Regarding the dimension of horizontal relationships, Fligstein and McAdam distinguish between two qualities of correlation. While *proximity* refers to the degree to which SAFs maintain recurring ties of mutual affection, the distinction between *dependent and interdependent* fields measures aspect of power as it captures the extent and direction of influence that characterizes the relationship between any two fields (Fligstein and McAdam 2012, 18). The authors believe that "[a]rmed with these distinctions, it is now easier to appreciate just how complicated and potentially consequential are the ties that link any given strategic action field to its broader field environment" (ibid. 19).

requires actors to share a common sense of or interest in the issue of the field as well as a shared scope of legitimate ways to approach this issue. Hence, the conflicts taking place at the arenas between subpopulations primarily shape the reproduction of the field and the institutional life within. While I would not assume that subpopulations are fully free of conflict, I assume that these levels of meso-level order reproduce relatively consistent rationalities and understandings implemented by rather homogeneous members. Hence, I assume that the higher the coherence among members of a particular subpopulation, the more impact and momentum they gain in the broader structure of power relations within their issue-based field.

3.2.3 Communities as Meso-Level Order

Reviewing community concepts in the context of innovation studies, I concluded my discussion with a definition, which describes innovation communities as non-commercial actor constellations that consist of self-selected members, who engage in the collaborative development, improvement, or application of novel entities, like e.g. certain products or software programs. In order to sustain the constitutive modes of open and generalized exchange, members of innovation communities share the outcomes of their efforts back to the collective body of knowledge (see Sect. 2.3).

This take on communities considerably differs from NI-related approaches, which discuss communities primarily in terms of territorial proximity and the potentially isomorphic impacts that co-location has on organizational activities (Marquis et al. 2007; Marquis and Battilana 2009). Thornton et al. (2012) capture communities differently, as they describe them as a general institutional order, which expands the interinstitutional system initially formulated by Friedland and Alford. However, the scope of their "revised interinstitutional system" (ibid. 73) waters down Friedland and Alfords theoretical foundations to a rather eclectic heuristic, which is supposed to inform empirical research but actually lacks institutional substance (Friedland 2013). To explain the idiosyncrasies of communities as institutional traits of distinct meso-level orders, I will therefore leave the track of NI. Instead, I will review discussions that capture communities as an additional governance mode, which expands the dominant forms of structured exchange prevalent in contexts of firms, markets, or networks.

Drawing on such a comparative distinction, Adler (2001) approaches the foundation of communities by contrasting them with hierarchies and markets as primary governance principles. Adler grounds his distinction with regard to the coordinating aspects that enable interaction within these modes: while the ideal type of the market relies on the price mechanism to govern exchange between competing suppliers and anonymous buyers, hierarchies use authority to create and coordinate a horizontal and vertical division of labor (ibid. 216). Communities, instead, rely on the key coordinating mechanism of trust, which governs collective action in the following way:

> In a collaborative community, values are not individual beliefs, but the object of shared activity; they have to be discussed and understood in similar ways by everyone. The basis of trust is the degree to which members of the community believe that others have contributions to make towards this shared creation. (Heckscher and Adler 2006, 20–21)

Adler and colleagues interpret the increasing relevance of trust and collaborative communities as an outcome of the new knowledge-based economy, which unveils the limits of markets and hierarchies. The egalitarian forms of community-based exchange (e.g. between automobile firms and their suppliers) are likely to enable more effective knowledge generation and dissemination because they deliberately foster interaction among individuals who intend to work together to create shared value. The assumed benefits and advantages of this mode fuel a rather Marxist interpretation: Heckscher and Adler consider the rise of collaborative communities as trigger for overturning the dominant modes of capitalist organization in the direction of more collaborative and trustful ways of doing business.

In a less normative way, recent studies that approach communities in the general context of value creation also try to capture their distinctive properties and organizing principles by contrasting them with more established governance modes. For instance, Seidel and Stewart (2011) draw on the typology of organizational architecture to specify the "C-Form" in contrast to markets, hierarchies, and networks:

> [...] we propose that the C-form [community form] architecture has four characteristics that define it: (1) fluid, informal peripheral boundaries of membership; (2) significant incorporation of voluntary labor; (3) information-based product output; and (4) significantly open sharing of knowledge. (Seidel and Stewart 2011, 49)

While the last two points essentially resemble the insights that I derived from my discussion of community concepts in the context of open and distributed innovation, their remarks on fluid, informal boundaries of membership and voluntary labor indeed offer additional features that set apart the governance type of communities. Other than relying on employment relationships or any market- or alliance contract, community interactions lack formal or legal contracts but are instead based on intrinsic motivation, common goals, and a mutually acknowledged philosophy.

In contrast to sharp distinctions between communities and market- or firm-based modes of coordination, it is much more difficult to distinguish between communities and networks. Essentially, the form of the network itself is an attempt to describe a coordinating mode for action that is neither market nor hierarchy: "In network modes of resource allocation, transactions occur neither through discrete exchange nor by administrative fiat, but through networks of individuals engaged in reciprocal, preferential and mutually supportive actions" (Powell 1990, 303). Indeed, most of the analytical facets that separate communities from markets or firms also apply to this broader notion of networks. Nevertheless, the dominant application of network governance to contexts of value creation clearly emphasizes relationships between organizations that seek to gain either direct monetary profit (see e.g. Hagedoorn's analysis of patent pools in Hagedoorn 2002, 2003) or indirect benefit from their participation (Powell et al. 1996).

Consequently, while knowledge and value creation within networks usually attempts to leverage complementary strength and mutually-beneficial relationships between the participating actors, exchange of knowledge and ideas within community contexts usually lacks such instrumental purposes but embraces rather non-commercial goals, open sharing, and a volunteer philosophy. Additionally, Demil and Lecocq (2006) consider the community-based mode of what they describe as "bazaar governance" as "neither market nor hierarchy nor network". In their view, actors who engage in the bazaar of communities are not led by price mechanisms as in markets, formal hierarchies like in firms, or calculated engagement that sustains mutual benefits in networks. What particularly distinguishes the bazaar governance of e.g. OSS communities from network governance is that it lacks formal regulation, membership is low-threshold, and rights over its outcomes are non-excludable: "Actors in the network are generally selected according to their strengths [. . .]. This is not the case in an open source community, where no one is asked to present a set of characteristics to be accepted. Members may be 'passive' adopters or 'active' contributors" (Demil and Lecocq 2006, 1455).

To sum this up, the features that distinguish different governance modes draw on their structural bonds for mutual exchange, the normative basis for engagement, and the fundamental motivation for the participating actors. Thus, the previously-discussed findings on the distinguishing features between communities and market-, firm-, and network-based types of coordination can be summarized as in Table 3.2.

While the insights derived by the governance discourse mainly address the domain of material practices, the cultural cognitive aspects that sustain their symbolic integrity appear less relevant. Nevertheless, in order to delineate communities as a distinct type of meso-level order, cultural cognitive aspects can hardly be neglected. Indeed, in his seminal work on the "Architecture of Markets", Fligstein (2001a), too, recommends considering any form of structured exchange as a field, in which all interactions reveal "cultural constructions that are understood by participants" (ibid. 68). Although I agree that this perspective on markets is worthwhile for grasping any form of structured exchange, I consider the cultural dimension to be particularly relevant for communities, which otherwise lack settled regulative or normative structures. Since membership relies on informal, low-threshold participation, the interactions between community members as well

Table 3.2 Distinctions between governance modes

	Community	Market	Hierarchy	Networks
Structural bonds	Reciprocity/trust	Price mechanism	Authority	Complementary strengths
Normative/ regulative basis	Common interests/ shared goals	Contracts/ property rights	Employment relationship	Agreements on (future) collaboration
Motivation to participate	Intrinsic identification with community purpose	Doing good/ profitable business	Trading workforce/labor division	Increasing individual performance by mutual support

as their strategies for approaching joint topics for collaboration both require high degrees of social cohesion and the symbolic implementation of constitutive values, which together spur a certain collective identity acknowledged by the actors involved.

Stressing this institutional facet, Heckscher and Adler (2006) emphasize that interaction in collaborative communities is not exclusively about the material production of shared outcomes but similarly about the symbolic definition of related purposes or discussions on the appropriate means to coordinate individual contributions without restricting them. In community settings, though, the search for dominant meanings requires high degrees of sensitivity regarding the symbolic ground for interaction: “This is possibly the most difficult aspect of the difficult move to collaboration: finding ways to debate core orientations while still working together” (Heckscher and Adler 2006, 21).

Gläser (2001) also highlights the importance of a particular sense of belonging as precondition for communal relationships. Although his work originally focuses on the prevalence of communities in contexts of OSS and science, he grounds his argumentation in a broader discussion of the community-based governance type and particularly emphasizes the relevance of collective identities as pivotal means to shape and sustain related forms of interaction: “A community is an actor constellation that consists of individuals who perceive to have something in common with others, and whose actions and interactions are at least partially influenced by this perception” (Gläser 2001, 6). In their attempt to distinguish online communities from rather loosely coupled “online crowds”, Dobusch and Kapeller (2013) conclude that the mutually shared belief in a certain kind of community-based identity not only influences the individual actions and interactions but also the constitution of collective action and the community itself: “Members perceive themselves as being part of the community, thereby performatively making the community a group conscious of itself as a certain community” (ibid; see also Dolata and Schrape 2016).

On the one hand, the theoretical discussion of the structural specifics of community-based governance supports my initial definition of communities as non-commercial actor constellations that consist of self-selected members who collaborate by the means of generalized exchange. On the other hand, especially the insights on the social construction of communities and the corresponding importance of collective identities for their cultural reproduction motivates me to extend this initial formulation. Hence, I assume that *the communal mode of interaction is enabled and recursively stabilized by the constitutive values of openness and accessibility of knowledge, which are symbolically acknowledged and practically implemented by the actors involved.*

3.2.4 CBI in Ambiguous Fields: Insights from OSS

To illustrate the specific properties of innovation communities as meso-level orders, I will again draw on insights from the fields associated with open source software. As pointed out before, the reproduction of material practices and symbolic constructions helps to create collective rationalities and shared understandings that actors draw on to inform and guide their actions. However, since actors usually find themselves in nested and partly overlapping field structures, they face multiple rationalities and understandings and need to reflect on a variety of potentially contradictive references for legitimate action.

The Linux initiative offers an exemplary case of how communities and their members comply with the resulting ambiguities and potential contradictions. Due to Linux' unexpected but extensive proliferation, the principally open and deliberative community that sustained the operating system's further development also sought hierarchical modes of coordination. Hence, the project created an elaborated decision-making structure to guide its prospective evolution as well as to organize procedures to review submissions of code to inform decisions whether a particular submission gets incorporated into the core of Linux or not:

> The organic result looks and functions like a decision hierarchy, in which responsibility and communication paths are structured in something very much like a pyramid. Torvalds sits atop the pyramid as a benevolent dictator with final responsibility for managing disagreements that cannot be resolved at lower levels. (Weber 2004, 91)

Below the top of this pyramid, a core group of well-recognized Linux programmers constitutes an inner circle of decision-makers that support Torvalds in his exalted position. Although this kind of elitist leadership intuitionally contradicts the characteristics of open and inclusive collaboration, it does not conflict with the actors' general mindsets. Since the need to channel the broad and diverse contributions from the community of Linux developers is widely recognized, the practical acceptance for the implemented structure is quite high as well. This is also because the decision-making hierarchy is still very informal in the sense that neither there is an official document, which specifies who participates in the inner circle, nor any measure of explicit project management applied to the project (Weber 2004). In addition, Torvalds' quasi-dictatorship is legitimated by high community credibility based on his incomparable knowledge about as well as commitment to the overall project:

> In fact, one of the most noteworthy characteristics of Torvalds's leadership style is how he goes to great lengths to document, explain, and justify his decisions about controversial matters, as well as to admit when he believes he has made a mistake or has changed his mind. (Weber 2004, 90)

It is certainly true that individual contributors usually favor loosely controlled projects with flat hierarchies and tacit rules more than centralized nodes of power and formal organizing mechanisms, clear commands and explicit rules. Nonetheless, the widely dispersed development, the need for peer review and the quirkiness of hackers in general require at least some guiding mechanisms that sustain an optimal balance between control and anarchy (Holck and Jörgensen 2005; Fitzgerald 2006b). Indeed, the case of Linux proved that it is possible to find a pragmatic balance to relieve tensions between hierarchical and community-based modes.

Thus, while the practical principles of community coordination seem stable enough to deal with such concessions, the social cohesion of OSS communities requires a rather strict implementation of its symbolic values and constitutive ideological bottom-lines—as cultural features, they inform the external distinctions that separate the open source approach from proprietary strategies. What really supports the self-identification of individual programmers as members of a particular OSS community is the symbolic consensus in the perception of a "joint enemy" (Weber 2004, 139). For the case of Linux, Microsoft occupied this vacancy in an exemplary manner.

Indeed, in late October 1998, a Microsoft strategy paper leaked by Eric Raymond revealed the company's offensive attitude against the Linux OSS initiative. In the context of this document, the Microsoft authors concluded that "OSS poses a direct, short-term revenue and platform threat to Microsoft, particularly in server space. Additionally, the intrinsic parallelism and free idea exchange in OSS has benefits that are not replicable with our current licensing model and therefore present a long term developer mindshare threat" (Halloween Document 1 (Version 1.17), see also Seidel and Stewart 2011, 44). Raymond's open response to the "Halloween" documents thus summarizes the values and ideological principles of open source sharply:

> I've been watching Microsoft run its game for nearly twenty years and the Halloween memoranda were the last straw. I'm mad as hell, and I'm not going to take it any more. [. . .] they [the documents] reveal exactly how seriously Microsoft takes the threat from Linux and other open-source projects. And they reveal in detail the dirty tricks Microsoft is willing to use to stop them. [. . .] The real issue is that they won't leave me and my friends any safe place. They want to hijack the Internet we built with brains and sweat and blood; they want top-to-bottom control of computing everywhere; they're determined to have it all, forever and ever, amen. That is the deepest subtext of the Halloween memoranda. And that, ultimately, is why I must be Bill Gates's enemy. (Raymond 2003)

This quote is interesting because it shows the emotional involvement of Raymond and the degree to which he feels personally threatened by Bill Gates. This reception contrasts with his rather analytical description of the "bazaar mode" (Raymond 2001) and clearly points to relevance of personal, nevertheless culturally-maintained perceptions of legitimacy as a normative precondition for collaboration. Against this background, the relationality and nestedness of meso-level orders suggests that although the coordination of action within communities is hard, interaction between actors of differently coordinated fields is even harder. Nevertheless, like most other OSS endeavors, the development of Linux also integrates not exclusively its core communities but other subpopulations including legal entities or commercial firms as well. Since these also become stakeholders within a broader field, actors across these subpopulations compete over the definition of the issue at stake.

As O'Mahony (2003, 1183) points out, communities engaged in OSS contexts usually apply sophisticated legal instruments, which guard the commons-based source code. Means of protection contain software licenses that restrict proprietary appropriation and thus enforce compliance to these licenses through normative or legal sanctions (see also Sect. 2.3). Yet, O'Mahony and Bechky (2008) also propose variables that enable constellations in which heterogeneous actors collaborate across different subpopulations. In this context, the authors emphasize the need for mediation between the concurring interests and cultures and the particular relevance of "boundary organizations" as potential facilitators for the joint endeavors. In their analysis of community-firm-relations, they identified points of divergence within the rather symbolic sphere of informal norms, perceived interdependence, or transparent decision-making. In contrast, convergent interests mainly refer to material aspects like enhanced technical capabilities of the software, its market share and diffusion, or the improvement of individual skill through exposure of commercial performance challenges (ibid. 432). In the discussion of their findings, the authors conclude that all of the observed OSS projects first struggled to launch collaboration with firms but later managed to bridge the divergent interests through the creation of nonprofit boundary organizations: "Creating these entities forced communities and firms to confront their interests and adapt their organizing practices with respect to four domains: governance, membership, ownership, and control over production" (ibid. 437).

Against the background of these insights, two findings become obvious. First, contradictions between open source and proprietary software development modes primarily translate into a value-based clash between corporate and community cultures. Still, related tensions find relief when the participating actors are capable to define and negotiate the scope of practical collaboration. These processes are necessarily reflexive, as actors grasp the multiple facets of the institutional environment they are embedded in. Secondly, what really facilitates collaboration between actors from different subpopulation are the legal instruments that have become institutionalized in the context of OSS.

Relating these insights to the broader accounts of community-based innovation, it turns out that although the sphere of OSS is exemplary for the key conceptual features of this approach, it is also outstanding in its institutional setting. Actually, most of the other empirical contexts that apply CBI lack comparable institutions like legal licenses or nonprofit foundations that guard their commons. Accordingly, the issue-based fields that emerge around these less settled representations of CBI are likely to intensify the institutional tensions between the subpopulations involved. As a consequence of the absence of formal institutional regulations, the cultural and cognitive aspects that sustain a community's cohesion become even more important. When there is no legal enforcement that sanctions threats to generalized exchange of knowledge and ideas, it is essentially a moral decision whether individuals comply with the informal practices that reproduce associated forms of mutual solidarity, self-organization, and culture.

3.3 Agency and Entrepreneurship

As shown before, meso-level constellations like community-based fields or subpopulations differ from market-, firm-, or network-based modes as they embrace high degrees of trust, lack formal or legal contracts, and sustain reciprocity through generalized exchange instead of trading commodities commercially. Building on the fact that individual actions always takes place within multiple meso-level structures, I argue that any purposeful effort that fosters the commercial exploitation of community-based innovation leaves the ideal-typical institutional sphere of communities and intersects instead with business realms. Thus, the individuals that become entrepreneurs for community-based innovations can surely participate in different intuitional contexts at the same time—at least as long as they comply with the understandings and rationalities that are shared within. To manage these challenging and partly paradoxical implications of the field, actors need to prove their capabilities for strategic action.

Referring to Fligstein and McAdam's (2012) notion of strategic action fields, actors that intend to participate within the boundaries of a particular meso-level order indeed require an appropriate degree of *social skill*: "the way in which individuals or collective actors possess a highly developed cognitive capacity for reading people and environments, framing lines of action, and mobilizing people in the service of broader conceptions of the world and of themselves" (ibid. 17; see also Fligstein 2001b). Put this way, Fligstein and McAdam's concept of social skill refers to Giddens' understanding of knowledgeability as a variable for the human capacity for purposive consciousness: "To be a human being is to be a purposive agent, who both has reasons for his or her activities and is able, if asked, to elaborate discursively upon those reasons" (Giddens 1984, 3). Due to their knowledgeability, actors are not only capable of reproducing the conditions that shape their activities practically, but also of monitoring them reflexively and becoming agents in the following sense:

> Agency concerns events of which an individual is the perpetrator, in the sense that the individual could, at any phase in a given sequence of conduct, have acted differently. (Giddens 1984, 9)

Reproduced across time and space, such reflexive interventions initially alter the situated actions of human agents. Still, they also affect the practices that recursively reproduce the structure of social systems, which, at least to my understanding, include any meso-level order like, e.g. issue-based fields and their subpopulations:

> According to the notion of the duality of structure, the structural properties of social systems are both medium and outcome of the practices they recursively organize. [...] Structure is not to be equated with constraint but is always both constraining and enabling (Giddens 1984, 25)

Still, this recursive structuration of social systems always involves certain degrees of contingency as even knowledgeable actors can hardly monitor all the consequences caused by their actions. The continuous flow of conduct and cognition that reproduces social systems such as communities, markets, or firms across space and time therefore always entails both: a flow of intentional, reflexively monitored action as well as unintended consequences which may recursively feed back and become the unacknowledged conditions of further actions in turn (ibid. 8).

Taking into account these general assumptions on the structural embeddedness and reflexivity of social action, the following subchapter elaborates theoretical ideas on how particular practices of entrepreneurship link to broader meso-level structures and their institutional constitution (Sect. 3.3.1). Thereafter, I will relate these insights to particular constellations of community-based innovations and discuss the resulting implications for the dilemma of entrepreneurship in the field of open source hardware (Sect. 3.3.2).

3.3.1 Institutional and Economic Takes on Entrepreneurship

As described in the prior sub-chapters, the agentic capacities of individual actors are affected by a multifaceted set of rules and resources provided by social systems from various levels of social order. These may either refer to the macro-level of a society's institutional foundations as well as to the more immediate meso-level orders of fields. Here, institutional logics from different domains merge into distinct collective rationalities that compete over the definition and allocation of a certain issue at stake. While these institutional entanglements are of course relevant for most types of social action, this book particularly emphasizes entrepreneurial action in the context of issue-based fields that form around innovation communities. However, the particular heritage of NI-related theories generates the need to discuss the term of entrepreneurship in a broader context.

Indeed, DiMaggio's (1988, 14) description of organizational actors that concentrate sufficient resources to create new institutions as "institutional entrepreneurs" has triggered a whole wave of research, which draws on institutional entrepreneurship as its own theoretical concept (see e.g. Garud et al. 2002; Maguire et al. 2004; Greenwood and Suddaby 2006). Often generalized in terms of "institutional work," related approaches describe the "purposive action of individuals and organizations aimed at creating, maintaining and disrupting innovations" (Lawrence and Suddaby 2006, 215) and thus embrace the agentic power of actors who actively shape the institutional environment they are embedded in (see also Lawrence et al. 2009).

This perspective differs noticeably from what is considered as entrepreneurship in the economic realm. Here, not the institutional environment but the market equilibrium is affected by entrepreneurs who identify opportunities to invent novel (or improve already available) goods or services, allocate financial resources to promote these, and finally found commercial companies to appropriate related assets on the market (Casson 1982). Framed this way, entrepreneurship tightly relates to innovation per se, as entrepreneurial actors transform markets by identifying market opportunities and implement technical or organizational innovations to exploit them (Drucker 2014; Schumpeter 2000). Following Schumpeter, the entrepreneurial innovative mode of economic action spurs the renewal of markets and thus triggers "creative destruction", the process he highlights as "the essential fact about capitalism" (Schumpeter 2003 [1942], 38). Consequently, entrepreneurial ventures necessarily have to create exclusive economic value that sustains their viability in the context of competitive markets. Related business models therefore need to exploit innovative ideas or other unique value propositions (Demil and

Lecocq 2010) as well as establish transactional links between the company and its exchange partners (Zott and Amit 2007).

Recently, scholars from the field of institutional theory have linked both aspects of entrepreneurship by addressing the mutual effects of entrepreneurial ambitions in creating business companies on the one hand and the meso-level orders in which these ambitions take place on the other. In their review of institutional aspects of entrepreneurship, Hwang and Powell (2005) generally apply a broader view that refers not just to the creation of new business ventures, but also to the social contexts and mutual effects between entrepreneurial action and its surrounding institutional environments. This approach reveals two interesting findings. First, instead of promoting the rather unidirectional concept of institutional entrepreneurship, the authors argue that entrepreneurial action lies between the poles of individual agency and its institutional conditions: "[...] we mean that while much entrepreneurial activity is purposive, it is not necessarily directly intentional" (Hwang and Powell 2005, 180). As actors are institutionally embedded in e.g. meso-level orders like fields, their entrepreneurial ambitions as well as the business models of the resulting ventures are constantly (re-)shaped and contested by these contexts (ibid.). Second, complementary to the institutional effects on entrepreneurship, the creation of new organizations can also alter the field structure. Drawing on the institutional logics perspective, Hwang and Powell assume that when entrepreneurship imports a particular logic from an existing domain to a new or nascent domain (as it sometimes does), established arrangements are commonly disrupted: "When such profound transpositions do occur, entire fields can be reshaped, and new organizational models and practices are adopted" (ibid. 200).

In a later work, Powell and Sandholtz (2012) refine this perspective by focusing on the organizational and institutional alignments that accompany entrepreneurial processes in the field of biotech. The authors draw on the variable of institutional proximity to discuss entrepreneurship in terms of reconfigurations and transpositions. The former occurs between nascent domains (like e.g. the commercial companies within the fields of pharmaceutics and genetic engineering) that already maintain cross-interactions and result in rather familiar organizational forms. Transpositions refer to entrepreneurial activities across distant domains, as demonstrated in the empirical case of their study, academic science and the commercial field of biotechnology. Here, because actors enter culturally foreign and unfamiliar settings, they mainly rely on practices from their former domain and therefore implement rather novel organizing practices to the domains in which the particular entrepreneurial efforts take place:

> Central to our inquiry is a conceptual distinction between two types of recombination: reconfiguration, a mechanism through which familiar attributes and elements are put together in new but recognizable ways; and transposition, a mechanism through which attributes and elements are introduced into foreign domains, spawning new-to-the-world forms of organizing. (Powell and Sandholtz 2012, 94)

While recombination yields rather smooth entrepreneurial activities, transpositions usually lead to institutional friction that thus generates significantly novel organizational forms. As challengers that potentially disturb settled market structures of incumbent firms, entrepreneurs that transpose novel practices and business models to settled fields predominantly face the resulting tensions in cognitive and moral dimensions: "On the cognitive side, transposed practices are not readily recognized; they seem out of context, off-key, or irrelevant; they do not fit existing category structures. On the moral side, transpositions may be attacked as inappropriate, outrageous, even profane." (ibid. 96)

Emphasizing the cultural-cognitive pillar, too, Aldrich and Yang (2012, 2014) tackle the mutual relation between entrepreneurial action, organizational forms, and their institutional context by emphasizing the cultural aspects of entrepreneurship:

> [...] we can think of new venture creation as a process in which entrepreneurs interpret opportunities while embedded in a system of cultural understandings, drawing upon and conditioned by their (learned) habitual responses to the situations they encounter. (Aldrich and Yang 2012, 6)

The authors consider the biographical background of entrepreneurs, which refers to both their private and familiar origin and professional career, to be highly influential for the habits, routines, and heuristics that shape the startup process of their respective ventures. This influence is supportive rather than restrictive because the entrepreneur's former work experiences and their specific working styles form a base from which they face the entrepreneurial challenges: "[...] once entrepreneurs have more knowledge about the specific firms that they want to create, they can identify, compare, and select effective procedures to develop new routines" (Aldrich and Yang 2014, 61). Aldrich and Yang conceive this evolving process as learning by doing, which may be either deliberate or accidental but always resembles trial and error. In this respect, the authors thus coincide with Hwang and Powell who emphasize the limits of an entrepreneur's intentional agency as "organizational participants often discover their interests 'on the fly,' so to speak, as strategies and goals co-evolve." (Hwang and Powell 2005, 180).

While I am also reluctant to overemphasize the agentic capacity of individuals or organizations to alter the institutional conditions purposefully for their entrepreneurial activities (as promoters of approaches like institutional work suggest), I do believe that actors are cognitively capable of reflecting on them. I also agree that finding the right fit between new organizational forms and the institutionalized field settings in which they launch resembles work in progress that often faces institutional tensions. Entrepreneurial actors may approach these by either adapting the culturally accepted routines and practices of the given field, or trying to expand incumbent understandings and practices through challenging dispositions derived from their originating fields. If a new venture sticks to the second approach and succeeds in leveraging their organizational practices, the entrepreneurial impact will certainly also affect the institutional structure of the overarching field.

The relationships between entrepreneurial action, the emerging business ventures, and mutual meso-level implications essentially link the NI-related takes on entrepreneurship to Giddens' general notions of the duality of structure and action. Indeed, Sarason and colleagues interpret business entrepreneurship as recursive processes that evolve as entrepreneurs interface with the structural conditions that at once enable and constrain the entrepreneurial endeavor (Sarason et al. 2006). In the context of my own work, the link to structuration theory consequently offers an opportunity to integrate the effects of entrepreneurial actions (micro) with the mutual impacts of (and on, respectively) the meso-level order of communities. While the NI-related perspective makes visible institutional tensions that are likely to arise within issue-based fields that include subpopulations governed by different dominant modes of coordination, Giddens' accounts of knowledgeability and agency focus on the particular ways in which actors deal with these tensions practically. Since agency always implies the risk of unintended consequences, the recursive structuration of social systems entails certain degrees of contingency that may affect the reproduction of any distinct meso-level order, be it a single startup company, the broader innovation community, or the whole field, in unexpected ways.

3.3.2 CBI and Entrepreneurship

While the entanglements between OSS communities and commercial enterprises have already been a topic for many studies (see e.g. Kogut and Metiu 2001; Dahlander and Magnusson 2005; Fitzgerald 2006b; Rolandsson et al. 2011), the analysis of innovation communities as seedbeds for entrepreneurial actors to build new ventures is less appreciated (O'Mahony and Lakhani 2011). Nevertheless, a couple of studies from the fields of user innovation hold interesting insights that directly relate to the topics at stake in this book.

For instance, Shah and Tripsas' (2007) study on the juvenile products industry introduces the concept of user entrepreneurship. They find that within contexts of innovation communities, members often become "accidental" entrepreneurs in the sense that "the development of the idea, experimentation, adaptation, and preliminary adoption often occur before the formal evaluation of the idea as the basis of a commercial venture" (Shah and Tripsas 2007, 126). While decisions on appropriate business models for the exploitation of novel ideas and opportunities are central during the early phases of internationalized entrepreneurship, the authors consider accidental users entrepreneurs to develop, test, share, and refine their ideas before they even think about founding a firm. During this transformational process of becoming entrepreneurial, efforts to commercialize formerly amateurish ideas expand the common set of practices by adding rationalities from the business domain.

In contrast, Hienerth's (2006) findings from communities engaged in rodeo kayaking suggest that lead users, who are assumed to anticipate trends and act ahead of the state-of-the-art, catalyze new industries by intentionally starting their own companies and selling user-innovated products to a growing market. In order to finance further developments, iterate on the product design, and set up distribution, the lead users observed in this study started to offer prototypes of the kayaks and then subsequently switched to sell finished products: “Lead users who wanted to create a competitive, high-quality product had to start commercializing their inventions in some form” (ibid. 286). Hienerth also found evidence that related processes of commercialization affect corresponding user (innovation) communities in terms of openness, interaction, and collaboration. For instance, lead users tend to carry out their business ventures in the context of “sub-communities”, which essentially represent precursors of the startups that are eventually founded (ibid. 287). In the case of rodeo kayaking, these sub-communities restricted the free disclosure of knowledge within the overall community to non-strategic and non-commercial issues only, which significantly changed the reciprocity of knowledge exchange within the broader constellation:

> The flow of communication between the two different levels of communities is still used for innovative activities, but while information from the overall community is transferred freely, there is no information outflow from sub-communities because of commercially sensitive content. (Hienerth 2006, 287)

Drawing on a similar point, Brinks and Ibert’s (2015) study in the context of fingerboarding and geocaching aims to further elaborate “the paradoxical relationship between the lifeblood of interest communities on the one hand and the entrepreneurial calculus on the other” (ibid. 3). Tackling the general assumption that communities usually exchange knowledge on an open and generalized basis whereas entrepreneurial ambitions tend to monopolize knowledge, the authors’ concept of mushrooming entrepreneurship suggests a three-stage, process-based perspective that turns this static contradiction into a rather dynamic notion of entrepreneurial friction (ibid. 5pp.):

- The first and earliest stage represents a phase of pre-community development in which single actors engage in fuzzy tinkering but do not yet share their enthusiasm and excitement about a common topic.
- The second stage is shaped by a growing interconnectedness of actors who then become members of a joint community of interest and elaborate their particular subjects through increased interaction. In the metaphor of mushrooming, spores are now proliferating like mycelia—quite similar, the ideas generated in the first phase are now ready for prospective entrepreneurship.
- In the last phase, the diversification of practices and interests within the growing community becomes apparent. This stage is accompanied by both exogenous attempts to appropriate developments of the community and entrepreneurial activities aiming to establish firms from within the community. These startups essentially represent the mushrooms growing from the fertile communal grounds.

Thus, Brinks and Ibert’s findings also suggest that the increasing sophistication and diversification of an innovation community affects its internal structure, as well as the collective rationalities and understandings that constitute its institutional setting.

Not coincidently, all of the studies that relate to community-based user entrepreneurship address contexts in which intangible, commons-based ideas are transformed into material products. In the information sphere, anybody who has the skills and a PC is potentially able to become an entrepreneur for a certain software application, operating system, or digital service. Entrepreneurial processes that build on tangible goods, however, usually require higher investments in raw materials, manufacturing facilities, and iterative prototyping. Since not everybody who is engaged in the creative and supportive process of tangible community-based innovations is able to transform their ideas and designs into actual products, opportunities for potential entrepreneurs occur quite often. As mentioned by Hienerth (2006), the entrepreneurs who seize these chances catalyze the commercial exploitation of community-based innovations as they spin off ventures that disseminate related products into broader consumer markets. As I will show in my empirical investigation of the 3D printing field, the particular meso-level constellation that usually surrounds such entrepreneurial efforts creates a challenging situation, in which prospective founders of community spin-offs face the practical implications of the dilemma of entrepreneurship.

Chapter 4
Analytical Framework and Methodology

Abstract This chapter merges the conceptual and theoretical insights that inform this book in order to operationalize the analytical framework, which is applied to explain how the institutional idiosyncrasies of innovation communities affect entrepreneurship in the field of desktop 3D printing. Additionally, I outline my methodological approach as well as the data sources my analysis draws on. In the context of my empirical investigation, I apply a triangulation that allows me the describe the evolution and change of the 3D printing field, delineate shared understandings on how this issue should be approached appropriately, and finally synthesize the actors' practical responses to the dilemma of entrepreneurship.

In the following chapter, I develop the analytical framework, which I apply to empirical questions that are at stake in this book. It draws on the theoretical assumptions discussed above and integrates the insights, which I have derived from my review of literature associated with the topics of commons, communities, and innovation.

To reiterate, in Chap. 2, I delineated the practical foundation of innovation communities in terms of collective creation of knowledge in the commons-based domain. This particular mode for the coordination of collective action draws on the appreciation of community-based values, such as open and non-proprietary exchange of knowledge, voluntary but reciprocal assistance, and the collective aversion against IP. Thus, it contradicts established business practices and triggers the dilemma of entrepreneurship for those members of innovation communities, who develop ambitions to exploit collective outcomes commercially.

In Chap. 3, I discussed innovation communities as a matter of meso-level order that contains distinct sets of collective rationalities and shared understandings. While collective rationalities reproduce practical patterns of how actors link their ideas, intents, and actions in connection with the particular subject of community innovation, shared understandings delineate the symbolic constructions, which guide mutually acknowledged evaluations about the legitimacy of these practices. Merged in the context of a field, these meso-level orders serve as referential frameworks for actors that engage in processes of community-based innovation. Since these contexts imply various institutional logics, in principle they contain ambiguous orientations for action, which actors need to consider and adopt in a knowledgeable way. In the argumentation of the present work, the impact of these

J.-P. Ferdinand, *Entrepreneurship in Innovation Communities*, Contributions to Management Science, DOI 10.1007/978-3-319-66842-0_4

ambiguous institutional references collide in contradictions between community- and business-oriented modes of innovation, which are each backed by particular sets of material practices and symbolic constructions. Since the dilemma of entrepreneurship results from tensions between different sets of practices and constructions, I conceive it as an institutional topic.

4.1 Applying the Field Perspective

Since any analytical effort to grasp topics of innovation necessarily deals with many institutional facets as well as a wide range of actors, it principally entails high degrees of complexity. Separating the macro-, meso-, and micro-levels of analysis might help detangle some of these complexities. Indeed, this perspective also represents a reasonable way to make the matter of innovation applicable to existing sociologist theories. Drawing on Friedland and Alfords notion of the interinstitutional system, Sect. 3.1 proved evidence that technological innovation in general, and CBI in particular, takes place between the institutional orders of capitalism and science. Each of them contains "supraorganizational patterns" that shape the ideal-typical modes for scientific and capitalist innovation. Hence, I contrast the institutional implications that influence innovation communities CBI in terms of community- and business logics: the former reflects the institutionalization of the egalitarian and communitarian principles of science; the latter carries the institutional implications of capitalism. While community logic represents the extended sense of common ownership of knowledge as well as the corresponding modes of distributed governance, the business logic emphasizes marked- and firm-based modes of organization that seek economic profit. Between both poles, the institutional landscape for innovation may be represented as in Fig. 4.1.

According to the inherent notions of conflict that influence Friedland and Alford's understanding of the interinstitutional system, the material practices and symbolic constructions informed by the particular logics principally include contradictive

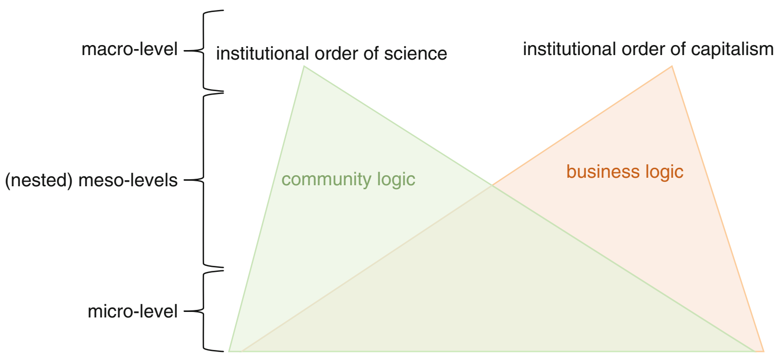


Fig. 4.1 Stylized interinstitutional system for innovation

implications. Sketchily applied to the present field of interest, the business logic e.g. suggests trading potentially innovative knowledge as a commodity enclosed by secrecy and IP protection; instead, the community logic embraces a commons-based approach that entails open access and sharing of novel findings.

The analytical concepts of material practices and symbolic constructions translate the actual effects of institutional logics to the micro-level of social action, where they become available to organizations and individuals to elaborate (Friedland and Alford 1991, p. 240). They then merge into immediate interplays among symbols, beliefs, norms and motives, which actors reproduce when engaging in a particular field (Reay and Jones 2015). According to Friedland and Alford, institutional analysts need to pay close attention to this "content" of institutional logics in order to "explain what kinds of social relations have what kind of effect on the behavior of organizations and individuals" (Friedland and Alford 1991, p. 252)

Indeed, while I do not generally neglect the importance of these macro-institutional foundations, I believe that the institutional life that constitutes (and is constituted by) multifaceted processes of "doing innovation" is primarily located within meso-level orders. Depending on the particular subject of innovation, involved actors will probably develop practices, which they believe are most eligible to push this issue forward. Moreover, they will also develop mutually shared understandings about how these innovative practices should be implemented appropriately.

The concept of issue-based fields thus allows me to distinguish between different intents, motivations, and exchange structures. Indeed, analysis based on issue-based fields groups actors into rather coherent subpopulations, based on actors' shared understandings about the innovative issue at stake and similar rationalities, which inform their activities and strategies to approach it. Consequently, to explain how innovation communities affect entrepreneurship in the field of desktop 3D printing, I merely concentrate on the institutional dynamics within the corresponding issue-based field and among its subpopulations. Nevertheless, I do not consider any of these meso-level orders as isolated entities. Instead, issue-based fields and their subpopulations exist only to the extent that the involved actors reproduce the symbolic constructions and material practices, which constantly iterate the interactions in connection with the field's constitutive issue.

Hence, to ground my ground my research in the context of NI-related theories, my analytical approach emphasizes the subpopulation (SP) that predominantly embraces properties of innovation communities: groups of actors that collectively engage in the development, improvement, or application of novel entities and exchange related knowledge as commons. However, since these communities primarily spur the explorative aspects of innovation and usually lack the means for exploitation and further diffusion, it becomes likely that commercial appropriators like investment firms or corporate companies enter contexts of community-based innovation in order to tackle the void of potential under-exploitation. Together with those consumer-customers, who are inclined to purchase community outcomes without maintaining social ties to the respective group, these actors are supposed to form a business-based SP, which aligns with the logic of capitalism. Hence, the general heuristic structure of an issue-based field in contexts of community-based innovation can be modelled as in Fig. 4.2.

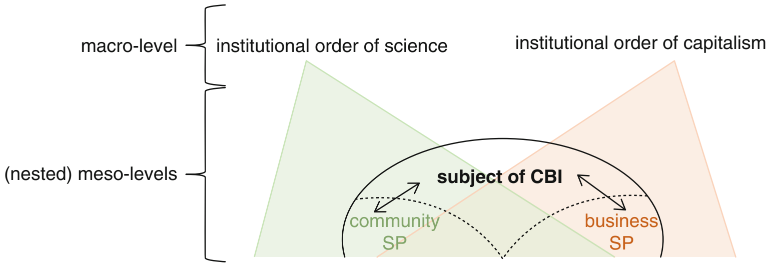


Fig. 4.2 Field level perspective on CBI

Applied to the empirical case at stake, this perspective helps to delineate the collective rationalities and shared understandings, which together reproduce the innovation communities for 3D printing. In reference to Friedland and Alford's assumption that only the notion of institutional contradiction is able "to restore meaning into social analysis in a way which is neither subjectivist, functionalist, nor teleological" (ibid. 240), my own analysis emphasizes the institutional tensions that arise within the meso-level context of the issue-based field. Here, a melting pot of institutional macro-references from capitalism and science corresponds with contrasting attitudes on how innovation in the context of 3D printers should be realized. Thus, any of the related tensions and contradictions are considered as part of the explanation for the dilemma of entrepreneurship.

4.2 Re-framing the Dilemma of Entrepreneurship

Aiming to operationalize the institutional tensions, which arise when community members develop entrepreneurial ambitions to monetize outcomes from collective processes of community-based innovations, I return to Chap. 3's theoretical discussion, suggesting ways to re-frame these contradictions as a clash of cultures at the intersection of community and business logics. The reasons therefore are threefold:

- *First* and in most general terms, this perspective generally applies to the core of a NI-related view on the cultural-cognitive elements of institutions: "[...] the shared conceptions that constitute the nature of social reality and the frames through which meaning is made" (Scott 2001, p. 57).
- *Second* and tightly linked to the prior point, the agentic capacities that enable social skill (Fligstein 2001b) and knowledgeable reflexivity (Giddens 1984) rely primarily on the cultural empathy of actors. At the same time, these scholars see any degree of meso-level order as socially constructed. Between the poles of individual agency and meso-level structures, distinct fields are thus reproduced by actors that apply "cultural understanding[s] of what forms of action and

organization are viewed as legitimate and meaningful within the context of the field" (Fligstein and McAdam 2012, p. 88).
- *Third* and most pragmatically, since CBI-related fields usually lack settled regulative structures that govern the rules for action, frictions that stem from entrepreneurial efforts predominantly play out in the cultural and cognitive dimension.

The implied notions of culture essentially link to Swidler's (1986) article on "Culture in action," which gained some considerable relevance in the newer facets on institutional theory. Assessing culture's independent causal role in informing what she calls "strategies of action," Swidler refers to a more actor-centric position and clearly relates her perspective on Bourdieu's Habitus concept. In line with Bourdieu, Swidler refers to the internalization of cultural (as well as material) dispositions and how these dispositions affect the ways that actors perceive their positions in the social world. While the habitus shapes cognition of actors in a rather coherent way, Swidler considers cultural properties as principally diverse and leading to rather contingent outcomes:

> People do not build lines of action from scratch, choosing actions one at a time as efficient means to given ends. Instead, they construct chains of action beginning with at least some pre-fabricated links. Culture influences action through the shape and organization of those links, not by determining the ends to which they are put. (Swidler 1986, p. 274)

Furthermore, Swidler's notion of culture defines agency and cultural consciousness in ways that expand average NI-related interpretations. She argues that actors are capable of engaging in different cultural frames and implement strategies of action by drawing on *culture as a toolkit*: "[a] repertoire from which actors select differing pieces for constructing lines of action" (Swidler 1986, p. 278). Additionally, strategies of action on the one hand represent cultural products that incorporate distinct habits, moods, sensibilities and worldviews but on the other hand, culture at the same time provides a repertoire of capacities for actors to construct varying strategies of action that fit their personal objectives (ibid. 284).[1]

In the analysis that follows, I pick up the linkage between cultural frameworks and the interpretive processes that inform both action and evaluations of legitimacy to delineate the inherent structure of diverse issue-based fields; therefore, my analytical approach emphasizes cultural implications on collective levels of action. Consequently, the cultural variety within heterogeneous issue-based fields potentially reveals what DiMaggio calls intergroup contrast and polarization:

> The existence of group-level cultures (shared understandings partly independent of individual beliefs) is also suggested by the tendency of groups to adopt public positions more

[1]Recent receptions of Swidler's work exaggerate even these tendencies. Especially the framework of "cultural entrepreneurship" (Lounsbury and Glynn 2001), which describes the purposive efforts of actors to produce rationalizing accounts or stories in order "to shape the attention and perceptions of various audiences, justifying the group's legitimacy and helping to coordinate its expansion to shape the attention" (Wry et al. 2011, p. 450), draws heavily on Swidler's culture-as-a-toolkit-argument but widely misses her foundations in (institutional) theory.

> extreme than the preferences of their members, especially when acting with reference to a contrasting group. What is striking is not polarization per se, but the cultural availability of polarized stances (representations of collective opinion) on which members of each group can converge. (DiMaggio 1997, p. 273)

Breaking this down to elaborate on the dilemma of entrepreneurship, I assume that community-based subpopulations embrace distinct group-level cultures and thus constitute "groups of constituencies that cut across organizations and share common language, perspectives, and assumptions about the nature of business" (Hoffman 2001, p. 136). The resulting practices of "doing innovation" are thus likely to collide with the principles of economic entrepreneurship.

Actors, who intend to become entrepreneurs for CBIs, thus face institutional ambiguities that usually translate into struggles for legitimacy. For instance, while the shared understandings associated with the community logic involve reluctance toward the private appropriation of outcomes from collective innovation, any entrepreneurial effort to launch new ventures in more or less established market settings nonetheless requires a business model based on exclusive unique selling propositions (USP) and economic value. Although distinct subpopulations are in constant struggle over the interpretational sovereignty of the issue at hand and the further institutionalization of their field, it is at the intersection between them that the dilemma of entrepreneurship becomes a valuable analytical lens. Here, the institutional arena for the clash of cultures takes place on a micro-level stage, where potential entrepreneurs for community-based innovations face ambiguous criteria for legitimate action (Fig. 4.3).

Although I consider the institutional life within issue-based fields as institutionally connected with the macro-level logics, for which they provide observable contexts for action, I doubt that individual actors are fully conscious of the institutional macro foundations, which partly guide their actions. However, I believe that actors are very aware of the institutional conditions that organize the rules and resources at the level of the particular fields and subpopulations. For instance, when a member of the Linux community contributes code to the joint development endeavor, he or she is certainly and at least practically aware of the collective rationality that shapes the realm of OSS but may not reflect on the close relationship to the scientific spheres, which constituted Richard Stallman's purpose in creating the building blocks of free software. Translated to the dilemma of

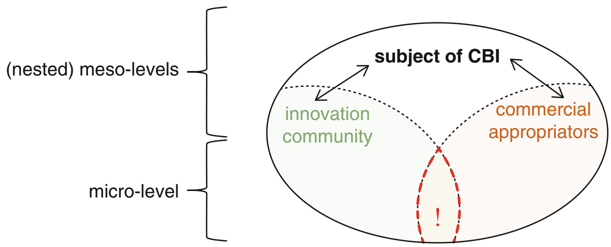


Fig. 4.3 Constitution of the micro-level arena

entrepreneurship, individual capacities to navigate these complex situations indeed depend on the actors' knowledgeability—their ability both to reflect on potential ambiguities and thus construct chains of action that ideally comply with both relevant subpopulations, and to merge the immediate implications of community- and business logics.

4.3 Methodological Foundation and Sources of Empirical Data

In looking for an eligible empirical context through which to elaborate my theoretical understanding of community-based innovation, the broader field of open source hardware first piqued my attention. As a relatively new phenomenon, OSH reveals a rather unexplored context, which adopts all framing conditions to apply general questions on CBI. However, compared to the exemplary and intensively researched case of OSS, the context of OSH appears even more well-suited for exploring the dilemma of entrepreneurship. As sketched out in Sect. 3.3.2 before, this is because the immanent need to turn intangible, commons-based ideas into material products by the means of physical production concretely necessitates entrepreneurial opportunities to scale the production process, reduce manufacturing costs, and thus enhance the economic viability of open source hardware devices.

Indeed, the broader field of open source hardware consists of various actors that include different communities, startups, established companies, legal entities, or non-governmental organizations like the Open Source Hardware Association (OSHWA) that intends to institutionalize the issue of OSH similar to what the Free Software Foundation did for OSS. However, due to the variety of topics and applications that apply an open source approach, the umbrella of OSH comprises different specialty communities as well as associated business companies that either engage in open source drones, open source robotics, open source music equipment, or other applications. For the purpose of this book, I therefore switched my initial ambition to address the integrative issue of OSH in favor of focusing on the field that merges around the concrete issue of 3D printing.

In order to trace the general dynamics on the meso-level of related innovation communities and focus on the particular contexts of the entrepreneurial dilemma, my empirical operationalization draws on a triangulation of data collection and—analyzing methods:

- First, I focus on the historical development of the so-called RepRap community, which clearly forms the source of the field. In order to trace the initial motivations that led to the adoption of 3D printing technologies for personal use as well as dynamics that affected the community's development, I dug through more than 1700 posts published on the RepRap development blog between March 2005 and December 2010. I extended this rich body of process-generated data by selectively including content from associated sources like the "RepRap builders" blog, or the "RepRap-dev" mailing list.

- Besides this rather retrospective view, I secondly analyze more recent blogposts, forum threads, and related internet-based discussions in detail, which deal with the increasing commercialization of open source 3D printing and related frictions that stem from market pressures. In this regard, especially the case of Makerbot Industries, a 3D printing startup that initially emerged from the RepRap community and then changed its business strategy to become more proprietary, caused quite a stir in the community. Analyzing the related controversies discursively allows me to derive the community's shared understandings on legitimate ways of entrepreneurship as well as particular points of contention that accompany the increasing relevance of the business logic.
- Third, I conducted qualitative, semi-structured interviews with the founders of six 3D printing startups between 2013 and 2015—three of them were of US American origin and the other three came from Europe. Although this might not seem like a large number of cases, this sample covers some of the internationally most renowned startups connected to the RepRap community. The interviews address the actors' backgrounds in open source hardware, their entrepreneurial transformation, various facets of their business practice, the immanent tensions they perceive as well as their strategies for mitigating them.

In the following sections, I cover my general methodological considerations, both in terms of actual methods and modes of analysis. I will start with my approach to describing the emergence, institutionalization, and change of the field that forms around the issue of desktop 3D printing. Thereafter, I elaborate on the institutional tensions that shape the arena for the entrepreneurial dilemma in the context of the field. Last, not least, I explicate how I explore the practical implications for individual action that organize the agency of actors within my field of inquiry.

4.3.1 Descriptive Representation of the 3D Printing Field

Although relatively young, the recent history of 3D printing is characterized by considerable change and constant contestation of what issue, exactly, lies at the heart of the field. Indeed, it took only 8 years from the initial formulation of the RepRap project for mere ideas of self-replication to be transformed into a considerable variety of actual technologies—a move that essentially fostered the rise of 3D printing. In the 2013 edition of Gartner's much-noticed hype cycle of emerging technologies, 3D printing even outcompeted topics like "big data" or the "internet of things" on its way to the "peak of inflated expectations" (Gartner 2013).

To set the scene for my attempt to elaborate the institutional idiosyncrasies of innovation communities empirically and ground the dilemma of entrepreneurship in the context of my research, I move through the description of the field's emergence, its development, and change in the first part of my analysis (see Sect. 5.1). As already mentioned before, I tracked the digital traces of RepRap's history by reviewing blogposts and documentations that community members posted online during the formation and evolution of the RepRap community. This descriptive approach leads to a chronological representation of the issue-based field of 3D printing that adapts Garud et al.'s (2002) exploration of Sun Microsystems's sponsorship of the Java open source technology.

My observational focus is thus sensitive toward the institutional dynamics and reconfigurations that stem from the entry and the exit of particular actors or even populations—as well as/or the alteration of the interaction patterns and power balances among them (Hoffman 1999, p. 351). According to Hoffman, particular emphasis should also be concentrated on "disruptive events" that "can sharply end what has become locked in by institutional inertia" (ibid. 353). However, since I assume that the field at stake in this study is rather less settled and inert than Hoffman's, I focus not only on events' disruptive effects but also more broadly on their impacts on the general and progressive (re-)configuration of the field.[2] Translated to my research case, this analytical perspective offers foundational insights on the rise of the RepRap community as well as the increasing struggles that emerged when commercial ambitions became more relevant.

4.3.2 Tracing Shared Understandings on Legitimacy

Attempting to grasp the actors' attitudes towards what is going on in the context of the 3D printing field, my methodological approach emphasizes the symbolic constructions by which members of a subpopulation generate meaning and evaluate legitimacy. Tracing the debates and discussions, in which legitimate ways of dealing with a field's constituting issue are contested and negotiated, thus forms an appropriate starting point to analyze the resulting shared understandings that are prevalent within distinct subpopulations.

Although the cultural-cognitive elements of institutions form a central focus of NI related research practices, the existing body of related literature widely lacks discrete methodologies for grasping them qualitatively. To fill this gap, a reasonable detour takes us to the field of anthropology and especially to Geertz (1973), who asserts that "the concept of culture is essentially a semiotic one" (ibid. 5). While he coincides with the NI-related notion that culture consists of socially-established structures of meaning (ibid. 12), he locates cultural traces as semiotic systems of construable symbols and signs.

[2]While the current research on field-configuring events draws on temporally and spatially bounded moments that enable direct interaction among field members (Hardy and Maguire 2010; Schüssler et al. 2014; Schüßler et al. 2015), I consider also incidents like obtained milestones, external shocks, or legal/administrative happenings as potential triggers for discontinuities and change within the field. Of course, these events may also affect the established practices and understandings in connection with the issue of the field (see Hoffman 1999, p. 353).

Barley adapts this semiotic approach to culture in order to "build a theory of how groups of people construct systems of meaning" (Barley 1983, p. 394) in the context of his sociological study of occupational and organizational cultures. Consequently, he refers to the concept of culture in terms of symbolic assumptions, interpretations, and perspectives that become traceable through the empirical analysis of *cultural codes*—systems of signification that organize "the processes by which events, words, behaviors, and objects carry meaning for the members of a given community, and to the content they convey" (ibid.). Analyzing cultural codes generated by the stories, myths, and symbols specific to a particular field captures the cognitive interpretations of individuals, the perception of their environment as well as aggregated meso-level cultures: "From the semiotic perspective, the members of a social group will act similarly, to the degree that they share the same codes for imputing meaning to the world" (Barley 1983, p. 397).

Together with Barley's (1983) study, Weber et al.'s (2008) investigation on the movement for grass-fed beef (respectively how it created a new market for related farming goods) informs my methodological attempts to trace institutional tensions in the context of community-based innovation. Stressing variables of cultural change in connection with social dynamics that lead to the emergence of novel market structures, Weber and colleagues borrowed techniques from semiotics in order to identify structures that organize the movement's collective meaning system. Thus, what they label as semiotic chain analysis directly refers back to Barley's analysis:

> Put simply, a semiotic chain is a form of disciplined interpretation [...] to map denotative and connotative aspects of meaning in a single system of associations and oppositions. Denotative relationships refer to associations between specific practices and elements of a cultural code. Connotative relationships connect these elements to broader cultural oppositions. (Weber et al.'s 2008, p. 537)

Indeed, each cultural code differentiates into two opposing poles, which organize individual experience through evaluative classifications and signify value dimension of moral good (or in my application: legitimate) and bad (illegitimate).[3] Furthermore, cultural codes imply both connotative and denotative dimensions that complementary refer to the practical and discursive aspects of the particular meaning system, respectively. Connotative codes capture redundant expressions of messages or interpretations that "[run] through numerous activities and events and thus act as the cultural glue for attributing coherence and consistency to myriad separate actions, events, and objects" (Barley 1983, p. 399). The denotative dimension then shows how the cultural oppositions between the contrasted domains link to more immediate practical considerations.

[3]Analytically applied, the semiotic chain analysis therefore always entails a normative bias that reproduces the cultural preferences that are prevalent in the particular context of research. Consequently, what empirically turns out as desirable representations of a certain cultural code in my own research embraces the innovation community's points of view. However, this moral bias is of course leveled in the context of the conceptual and theoretical discussion of my findings.

In their application of this heuristic, Weber and colleagues find that the two poles of each cultural code are usually linked to broader institutional domains. In Weber, Heinze, and DeSoucey's study, applying this analytical approach to the cultural codes that prevail the social movement for grass-fed beef reveals the following results:

> To make sense of their environment and their own actions, the movement's participants commonly enlisted three cultural codes with oppositional structures: authenticity vs. manipulation, sustainability vs. exploitation, and natural vs. artificial. Each pole of the opposition in a cultural code was linked to a different institutional domain: the insurgent domain of grassfed production, marked positively as an affirmation of moral values, and the domain of the incumbent industry system, marked negatively as a violation of moral values. (Weber et al. 2008, p. 538)

It turns out that the evaluative attitudes that distinguish desirable from undesirable poles are always dependent on the domain within which the discursive discussion of the particular issue takes place. In the context of my theorization of innovation communities, what Weber and colleagues label as "domains" I instead might call institutional logics, conceptualizing their mutual effects on distinct subpopulations. Regarding the structuration of meso-level orders and the assumption that they usually consist of subpopulations that reproduce their very own sets of relevant values, norms, rules and resources, dualism within cultural codes also reproduces the institutional tensions between the community- and business-based subpopulations.

Consequently, I believe that the prevalence of cultural codes and the opposing poles that contrast their connotative and denotative aspects represent the struggles of power and interpretational sovereignty that take place at the arena of issue-based fields. By stressing certain articulations and attitudes in connection with a particular cultural code, actors reproduce the cultural cohesion of the subpopulation, in which they are embedded. Additionally, tracing the dominant patterns of how actors make sense of, and express their interpretations of cultural codes thus helps to aggregate the shared understandings, which recursively guide the cultural dispositions of their common subpopulation.

To elaborate on the institutional tensions within the issue-based field of 3D printing, I will focus on the topic of entrepreneurship and the particular codes that constitute the contrasting attitudes either associated with the community- or business logic. Focusing especially on raw data from the field's community-based subpopulation, I then apply what Weber (2005a) labels as "paradigmatic clustering": an in-depth exploration of paradigms (that is "larger cultural structures that evoke distinctive institutional concerns", see ibid. 232), which subsequently sheds light on the communities' shared understandings and broader institutional foundations. By contrasting the community member's desirable attitudes and articulations on entrepreneurship with the actor perspectives from the business subpopulation, I infer the actual contents that are contested at the arena between them. Indeed, I believe that the rather discursive contrasts in attitudes and articulations, which I derive from the analysis of the cultural code of entrepreneurship, directly link to the actual contradiction that constitute the practical implications of the entrepreneurial dilemma.

4.3.3 *Elaborating Collective Rationalities and the Actors' Scope of Agency*

Characterizing the institutional tensions that are prevalent within the field of 3D printing requires the complementary analysis of the symbolic constructions and material practices that guide and inform entrepreneurial actions. While the former can be traced by deriving dominant shared understandings (see above), the latter seeks the identification of patterns of collective rationalities. Recapturing Friedland and Alford's assumption that institutional logics provide distinct sets of material practices that are available to organizations and individuals to elaborate on (Friedland and Alford 1991, p. 240), adding a meso-level order that merges different sets of material practices increases the complexity of such endeavor. However, the questions of how actors implement these practices requires empirical investigation addressing the ideas and intents by which actors attach meaning to their actions. In the setting of my research, I relate these theoretical considerations to the practices, which actors in the 3D printing field use to face the dilemma of entrepreneurship.

Indeed, I assume that actors, who initially participate in innovation communities and then develop commercial ambitions over time, necessarily need to reflect upon the potential tensions that arise at the intersection of their community background and entrepreneurial effort. Consequently, each of their practical responses to the dilemma of entrepreneurship displays a notion of individual agency, which potentially affects their institutional environment.

The empirical emphasis on the reasoning and rationalization of action narrows the opportunities for empirical data collection down to qualitative methods that reveal the nuances of actor's attach meaning to their actions. Since I assume that knowledgeable actors are widely aware of the ideas and intents that inform their actions, interviews are appropriate means to search for related insights. Consequently, I approached founders of 3D printing startups with semi-structured interviews and asked them about their particular background in the RepRap community, the circumstances that let them become entrepreneurs for 3D printers, the struggles they faced in this process, and how they tried to respond to them. I then transcribed the interviews verbatim and coded them with the qualitative data analysis tool ATLAS.ti.

Although my coding strategy for the generated interview data starts with a rather open approach looking for similarities and patterns among the cases observed, I take a second analytical step to structure the emerging codes and contents in two systematic ways. First, I applied the entrepreneurial process as a heuristic to link the interviewees' actions and experiences to the phases of their becoming of founders

(1), their efforts to create (2) and sustain (3) a viable business. This chronological layer helps me to unveil conceivable changes of the founders' attitudes and mindsets that accompany their increasing experiences as entrepreneurs. Secondly, I put particular emphasis on the denotative codes, which I revealed through my discursive analysis of the CBI-related controversies. Assuming that these codes reflect general contradictions and cultural discrepancies immanent to the dilemma of entrepreneurship, tracing the founders' practical ways of approaching them renders relevant insights, which delineate their scope of agency. However, since entrepreneurs of 3D printing startups act at the intersection of both community- and business realms, I assume their practices to entail ambiguous rationalities, which work in two likely ways: to inform the actors' agentic capacities and to alter the structuration of the field's meso-level recursively.

Chapter 5
Innovation Communities and the Dilemma of Entrepreneurship in the 3D Printing Field

Abstract This chapter starts with a description of emergence and change within the 3D printing field. I analytically distinguish three different phases of transformation and trace their particular impacts on the field's structure and its constituting issue. Indeed, especially the case of Makerbot and its decision to abandon the open source approach from the core of their business model caused a stir in within the field. I thus derive a taxonomy of opposing codes that delineates community and business stances within the dilemma of entrepreneurship. In order to explore the practical responses of actors that face this dilemma, I analyze interviews that I conducted with founders of 2nd generation community spin-offs, which already took the consequences of the Makerbot controversy into account to inform their own business strategies. It turns out that these actors are highly aware of the challenging contexts for their entrepreneurial efforts and thus try to incorporate aspects from both community and business realms within the business models of their RepRap-related startups.

Before I proceed with my empirical investigation, it has to be mentioned that the original technology behind 3D printing was already invented the 1980s. More precisely, Scott Crump filed the patent for a fused deposition modelling technique, which still resembles the dominant operating system for most 3D printers, in 1989 as "Apparatus and method for creating three-dimensional objects" (Crump 1989, patent published 1992). Based on his patent, Crump subsequently co-founded Stratasys, which developed into a massive and market-leading company for 3D printing and rapid prototyping (see Fig. 5.1). In 1991, Stratasys also trademarked "fused deposition modelling" (FDM) as the term, which describes a "computer driven machine" for "making a physical embodiment of a graphic design by a material deposition process" (Stratasys Inc 1991).

While this forms the technological foundation of 3D printing, other factors such as the associated attempts of IP protection and its industrial applications for professional prototyping and manufacturing purposes clearly root 3D printing in the proprietary business domain. In contrast, the present study addresses specifically the adoption of 3D printing technologies by an open source community called RepRap. To separate this focus from the industry scale application, I label the issue of the emerging field as "desktop 3D printing", since this terminology sharply delineates RepRap's unique approach, which is to create rather small, easy to use

J.-P. Ferdinand, *Entrepreneurship in Innovation Communities*, Contributions to Management Science, DOI 10.1007/978-3-319-66842-0_5

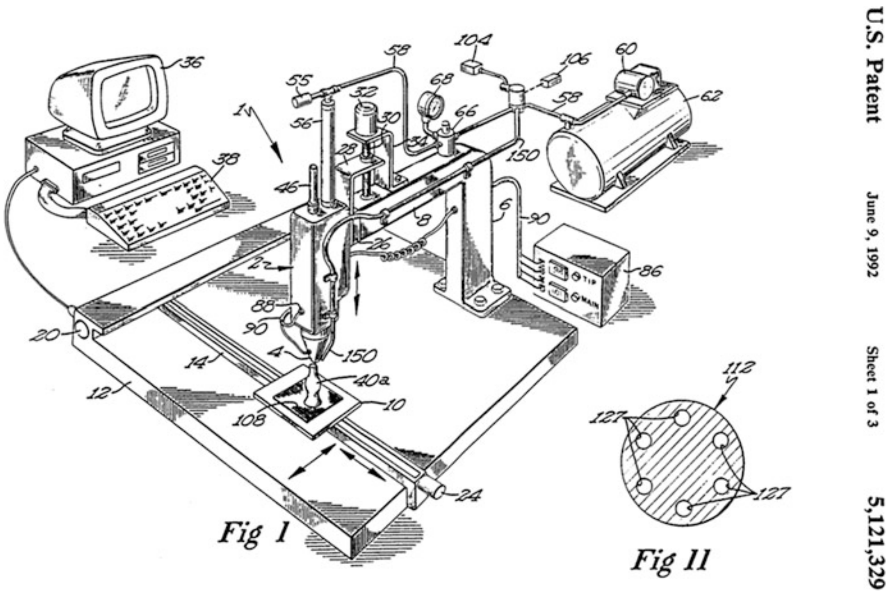


Fig. 5.1 FDM process as sketched in Crump's patent (40a is the 3D printed object)

devices. Additionally, "desktop 3D printing" is a label commonly used by practitioners as well.

Although the general issue of desktop 3D printing is relatively new, it has already created a considerable momentum, which resulted in the emergence and further differentiation of the field, which represents the empirical context for my research. As I will show in the course of this chapter, the structuration of the field is indeed characterized by unsettled times. Focusing on the emergence and change of the RepRap innovation community in particular, as well as the increasing entrepreneurial efforts carried out by community members, my empirical investigation applies the proposed analytical frame as follows:

First, to capture the origins, the rise, and the corresponding change of the field, I will conduct a descriptive representation of the field based on the events and incidents that affected its evolution (Sect. 5.1). Second, I delineate the innovation community's shared understandings about the legitimate ways to approach desktop 3D printing by analyzing online discussions and related controversies about the commercial appropriation of community-based knowledge. In this context, I derive a taxonomy of contrasting attitudes, beliefs, and orientations towards desktop 3D printing between the field's community- and business-based subpopulations (Sect. 5.2). In Sect. 5.3, I draw on my interview data to analyze how the founders of 3D printing startups perceive their entrepreneurial transition as well as related challenges that result from the ambiguities and contradiction that shape their institutional environment. The focus on the field's micro-level thus allows me to gather insights on the actor's scope of agency as well as the degrees of reflexivity that inform their practices—as well as their strategies for coping with the struggles of finding a viable business model to comply with their diverse peer groups.

5.1 Emergence and Change of the 3D Printing Field

My description of the emergence and change of the field that forms around the issue of 3D printing mainly grounds on raw data from the internet. More precisely, this data stems from the RepRap forum, the RepRap mailings lists, websites that associate with the 3D printing community like e.g. makezine.com or hackaday.com, as well as corporate and personal websites of actors that engage in the development of desktop 3D printers. Inspried by Garud et al. (2002) chronology of events in the context of Java, Table 5.1 provides a general chronology that sketches out the events which notably influenced the emergence and dynamic change of the issue of desktop 3D printing.

Dividing the chronology of events broadly into the three different phases of inception, proliferation and diversification, I partly refer to the three-fold heuristic of "tinkering," "structuration," and "diversification" provided by Brinks and Ibert's (2015) interpretation of mushrooming entrepreneurship (see Sect. 3.3.2). However, while their analysis encompasses rather practical patterns of how actors engage with certain innovations, I adapt this framework in a way that better captures the particular meso-level transformation of the desktop 3D printing field.

5.1.1 Inception

The original idea to apply the industry scale approach of FDM-based manufacturing to a personal usage context needs to be attributed to Adrian Bowyer. Indeed, Boyer's initial idea of the RepRap project intended to adopt the industry-scale technology in order to develop an affordable and easy to use self-replicating machine: "It was designed to make its own parts to be assembled by people into another RepRap" (Jones et al. 2011). When Bowyer launched an Internet Blog on this issue in April 2005, it subsequently triggered the interest of a rather small group of people that converged into RepRap's core development team, which started contributing ideas and designs for printing nozzles, filament extruders, and other components almost on a daily basis. Related sketches, drawings, and CAD models were all document and exchanged without any restrictions on use and IP protection. [1]

[1]To avoid legal constrains, the RepRap developers introduced the term of "Fused Filament Fabrication" as an equivalent to the Stratasys' FDM trademark (see: http://reprap.org/wiki/Fused_filament_fabrication).

Table 5.1 Chronology of the issue-based field around desktop 3D printing

	Date	Place	Event
Inception	March 23, 2005	University of Bath, UK	The RepRap blog is started
	Summer 2005	University of Bath, UK	Funding for initial development is obtained from the UK's Engineering and Physical Sciences Research Council
	November 6, 2005	University of Bath, UK	Launch of the RepRap Wiki
	August 15, 2006	Cornell University, Ithaca, NY, US	Public launch of the Fab@Home and first release of open source files for the Fab@Home model 1 at the Solid Freeform Fabrication conference in Austin, TX
	September 13, 2006	University of Bath, UK	The RepRap 0.2 prototype successfully prints the first part of itself
	February 22, 2007	WWW	Launch of reprap.org as inclusive homepage for the project covering general forums, blogs, mailing lists, wikis, and design repositories
	May 10, 2007	University of Bath, UK	First working prototype of the RepRap "Darwin" 3D printer revealed.
Proliferation	April 14, 2008	Bath, UK	Adrian Bowyer prints an iPod mount for his wife's Ford Fiesta as probably the first example of an object being produced by a RepRap for reasons other than a demonstration or making another RepRap
	May 23, 2007	Brooklyn, USA	Announcement of the RepRap Research Foundation (RRRF) as an official non-profit corporation (according to the United States of America) dedicated to helping researchers involved in the RepRap project by offering research parts for sale at low prices.
	May 29, 2008	University of Bath, UK	Realization of the first completed reproduction: "parent" RepRap machine prints out plastic parts for a working "child" RepRap machine
	October 18, 2008	Brooklyn, USA	Zach Smith launches thingiverse.com, a website dedicated to the sharing of user-created digital design files
	December 12, 2008	Hempstead, UK	First official European RepRap spin off: Incorporation of Bits from Bytes by Ian Adkins and Iain Major
	January 2009	Brooklyn, US	Incorporation of Makerbot Industries by Zach Smith, Bre Pettis and Adam Mayer
	October 18, 2009	University of Bath, UK	Release of the "Mendel" as the 2nd official RepRap 3D printer

(continued)

Table 5.1 (continued)

	Date	Place	Event
Diversification	October 5, 2010	Rock Hill, SC, US	3D Systems acquires Bits From Bytes
	August 23, 2011	Boulder, CO, US	VC firm "The Foundry Group" leads a $10 million financing in Makerbot Industries
	April 2012	worldwide	The "RepRap Family Tree" estimates over 400 derivates of the initial RepRap Darwin
	February 10, 2012	Brooklyn, NY, US	Thingiverse updates terms of use and license options; MakerBot Industries is allowed to use any design uploaded to their service on a royalty-free basis for about anything they chose to use it for
	September 19, 2012	Brooklyn, NY, US	Makerbot launches the Replicator 2, partly closes open source
	April 1, 2013	Hempstead, UK	Bits from Bytes discontinues open source 3D printer lines
	August 15, 2013	Eden Prairie, US	Stratasys acquires Makerbot for $403 million

In the summer of 2005, Bowyer, who worked at this time as an academic in the fields of mathematics and engineering at the University of Bath, UK, acquired grants from the British Engineering and Physical Sciences Research Council, which supported his ambition and essentially turned RepRap formally into an university-based research project. Nevertheless, RepRap's ideological and practical proximity to OSS-related contexts constantly increased, as the RepRap developers not only used open source design software to draw parts or open source firmware to connect the components, but also presented the RepRap idea at OSS summits like the LinuxConf Australasia in January 2006, where a related talk by a RepRap core developer was even voted "Best Of LinuxConf" (Olliver 2006).

Indeed, although the project started mainly as an individual effort by Bowyer, from the beginning it maintained an inclusive and open nature. For instance, when Bowyer first launched the RepRap project among his academic peer group during his keynote speech at the 2006 National Conference on Rapid Design, Prototyping & Manufacturing he also emphasized the political theme of "Wealth without Money" behind his RepRap idea as well as its proximity to the open source ideas as follows:

> Consequently I have decided to give the entire machine and all its design files away free under the GNU General Public Licence, like Linux. This ensures that no one (especially not me) has control over, and restrictions on, the technology. It is a happy coincidence that this—the morally correct thing to do—is also the only stable strategy. [. . .] So the self-copying and evolving RepRap machine may allow the revolutionary ownership, by the proletariat, of the means of production. [. . .] I have decided to call this economics Darwinian Marxism. (Bowyer 2006b)

It becomes obvious that the principles of OSS represented an important point of reference for the RepRap project. Indeed, since the beginning, the emerging issue of desktop 3D printing is accompanied by strong ideological imperatives to open access to any sources of knowledge (like e.g. building manuals, design blueprints, bills of material etc.) that are required to rebuild and further develop the machine.

At this time, a group of seven people regularly contributed to the project and constituted the core team of the project. Besides Bowyer's colleague also based in Bath, three members of this group came from the US and the other two from New Zealand. This early constitution of the growing innovation community reveals that RepRap-related development efforts indeed were dispersed, both personally in terms decision-making and locally in terms of the participants' origin. Nevertheless, the collective contributions spurred various design iterations of hardware components, advanced coding of both 3D graphics software as well as controlling firmware, and increased insights on suitable raw materials for the printing process. Thus, they maintained steady progress in the project's overall development. Figure 5.2 illustrates this progress as it documents the increased quality of objects actually printed by early RepRap devices.

Parallel to the technical progress, also the community that grouped around Bowyer thrived. Besides the seven designated core developers that engaged with the RepRap project shortly after Bowyer set up his blog, an increasing number of people joined the online discussions on new parts, design iterations, or related software applications. In response to growing interest on that issue, Bowyer launched the RepRap "Builders Blog" end of July 2006 parallel to the original

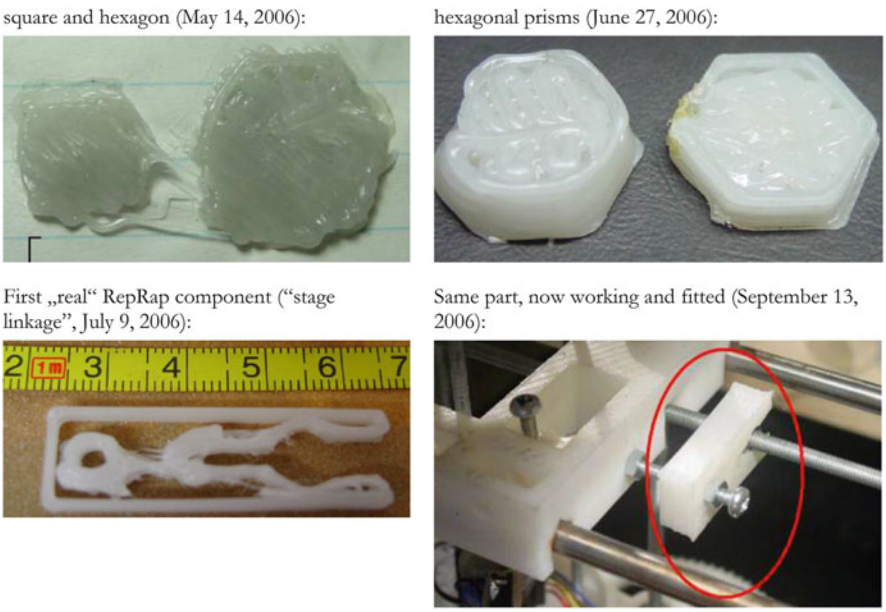


Fig. 5.2 Work in progress in printed parts (source: Hodgson 2012)

one in order to enable broader exchange "for any of them who want to record their discoveries, hints, calls for help, pictures of triumphs," in building their own RepRaps (Bowyer 2006a).

Besides this internal proliferation, also the external boundaries of the RepRap project first became apparent when community members noticed the "Fab@Home" project. Initiated by two students at Cornell University's department of Mechanical & Aerospace Engineering, Fab@Home represented an attempt to invent "a simple, low-cost, user modifiable freeform fabrication system," which essentially resembled the technological properties of the RepRap project (Malone and Lipson 2007, 245). When Malone and Lipson presented the designs for the Fab@Home model 1 device at the Solid Freeform Fabrication conference in Austin, 2006, they clearly mentioned their inspiration from the RepRap project as well as their application of an open source approach. Nevertheless, their general intention to create a machine that "has the potential to revolutionize manufacturing, even to allow individuals to invent, customize, and manufacture goods cost-effectively in their own homes" significantly differed from RepRap's guiding vision of self-replication. When one of the contributors to RepRap developers' blog raised the question, whether it would be worthwhile to merge some aspects of both projects, the commentators reacted reluctantly and emphasized the contrasts rather than the similarities between both projects (Bailard 2006).

In May 2007, when Bowyer and his colleagues revealed the working prototype of the first official RepRap "Darwin", the RepRap project and its community reached one definite milestone (Fig. 5.3). Beside the fact that various members of

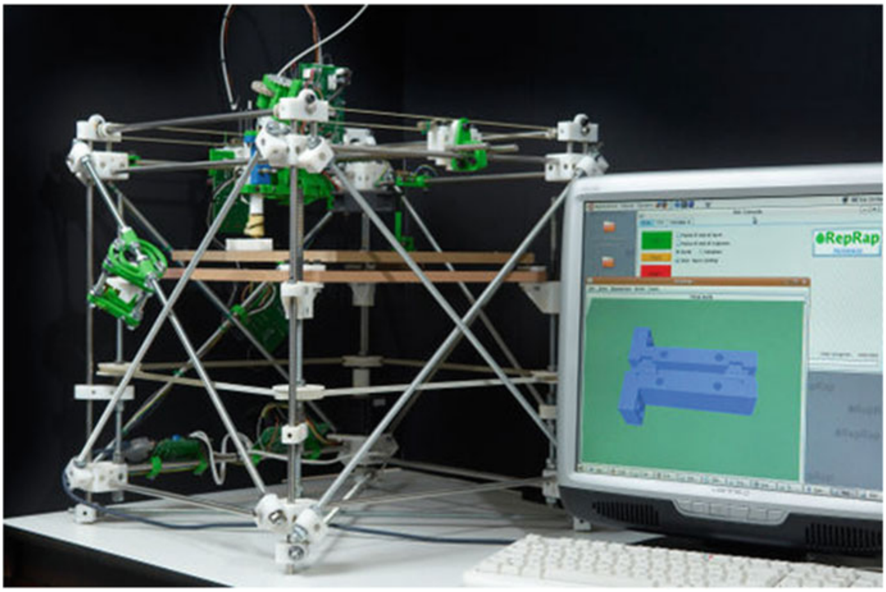


Fig. 5.3 The RepRap "Darwin" 3D printer (http://reprap.org/wiki/RepRap_Darwin)

the RepRap community had already created personal prototypes of RepRap-related 3D printers, and the fact that the Darwin also was not "replicated" but assembled with the help of professional tooling by Bowyer and his research student Ed Sells, the Darwin included many contributions from the community and proved its collective capability to build a working 3D printer almost from scratch.

With the proof that it was indeed possible to build working 3D printers with the help of self-fabricated and off-the-shelf components, the Rep Rap project entered a new stage. A community member that I met for an interview summarized the momentum of this phase as follows:

> As time went by, RepRap really became the thing. Although Fab@Home was merely the printer that worked, it lacked the context. It provided no software, and no community. RepRap, on the contrary, had a rather chaotic approach. Every few weeks, Adrian Bowyer showed up with his novel experiments. All these half-baked ideas inspired others to try things out on their own. Quite often, it was obvious how to tweak and improve these things. Since everything related to the construction was available online, people downloaded it and pushed them forward. This is how the community got bigger and bigger. (I-CM, translated by author, see Sect. 5.3 for interview index)

To summarize the first phase of inception, it is obvious that the innovation community that emerged around the RepRap project defined the issue of desktop 3D printing both in practical and symbolic ways. Although it was Bowyer who initially set the rules and resources for interaction and knowledge exchange, his application of open source principles created rather egalitarian structures for open knowledge sharing, mutual assistance, and decentralized participation that together fostered the technological progress of the project. Additionally, Bowyer's guiding vision of self-replication and "Darwinian Marxism" influenced the issue of the emerging field ideologically. While at least the group of core developers agreed on these notions, the growing number of associated community members that contributed to RepRap's "builder blog" broadened the scope of possible applications of 3D printing as a general-purpose production technology. Indeed, related points of view gained importance in the proceeding proliferation of desktop 3D printing.

5.1.2 *Proliferation*

Due to the open and barely-regulated nature of the RepRap project, the ongoing structuration of the field that formed around the issue of desktop 3D printing was an interplay of diverse and interdependent aspects. However, the launch of the reprap.org website as the digital home of RepRap in February 2007 had an important impact on the coordination of related information exchange as it consolidated the various instances of prior community building. The inclusive homepage gathered all RepRap related forums, blogs, mailings lists, wikis, and design/object repositories and subsequently implemented a sub-forum architecture, which allowed people from all over the world to open new (resp. join already existing) user groups as local, face-to-face representations of the RepRap online community.

As another response to the project's increasing momentum, Zach Smith, who was among the first contributors and implemented the new homepage, too, initiated the "Rep Rap Research Foundation" (RRRF) in May, 2007 consensually with the mandate of the core community. Other than the Free Software Foundation, which in its beginning essentially raised funds to pay people that write OSS code, Smith founded the RRRF in order to play a support role by providing an online store that offered research parts for sale at low prices. In the Blog post announcing the RRRF, Smith explained his intents as follows:

> In essence, the RRRF will harness the economies of scale in order to make it easy (and cheap!) to get involved with the project. Also, since it is non-profit and run by volunteers (you/me!) the prices will be super low. (Smith 2007)

Essentially, the RRRF reflected a concession to the peculiarities of open hardware, namely that although anybody can access the blueprints of related devices, building them requires the purchase of material components and the skills to assemble them properly. While the RRRF primarily represented an approach to surmounting the first of these hurdles, the potential benefits of the economies of scales also introduced a new and rather business-oriented kind of thinking to the RepRap community. To align this with RepRap's overall framing as a research project and to keep the foundation and its board out of any patent litigation, Smith founded the RRRF as a non-profit corporation and initially added member rules containing that "Members agree to use all hardware supplied to them by the RRRF for research purposes only and not to use it for commercial gain" (Collins 2008). However, although this approach satisfied the demands articulated by the community and therefore gained clear support, initial discussions about the non-commercial clause also raised questions on its discriminatory implications.[2]

Shortly thereafter and directly referring to the RRRF model, Ian Adkins, who joined the RepRap community only few months before, also started to sell complete hardware and electronic kits based on RepRap designs under the label "Bits from Bytes". Although Bits from Bytes offered quite the same choice of products as the RFFF, the RepRap community widely appreciated Adkin's effort, who was also "trying to set up a UK and Europe distribution for RepRap parts to get over the shipping problems" (see Adkins' comment below the blogpost of "nop head" 2007).

On the technical side, the printing devices incrementally advanced and the quality and resolution of printed goods improved steadily. Due to this progress, the first completed reproduction (at least of all the parts made of plastics) performed by the RepRap Darwin 3D printer was realized end of May 2008 at Bath University in the UK. The picture in Fig. 5.4 shows Bowyer and Vik Olliver, who was one of

[2]As a reaction to the related forum discussion Smith and the RRRF board slightly altered the wording of the membership rules as follows: "Members agree to use all hardware supplied to them by the RRRF for research purposes only and not to use it for commercial gain. *This restriction is limited just to the supplied hardware; anything made or derived from it is not subject to any restriction by the RRRF*." (Collins 2008, my italics). Generally, this early forum thread already pointed towards the contradictions that reached the project in its diversification phase.

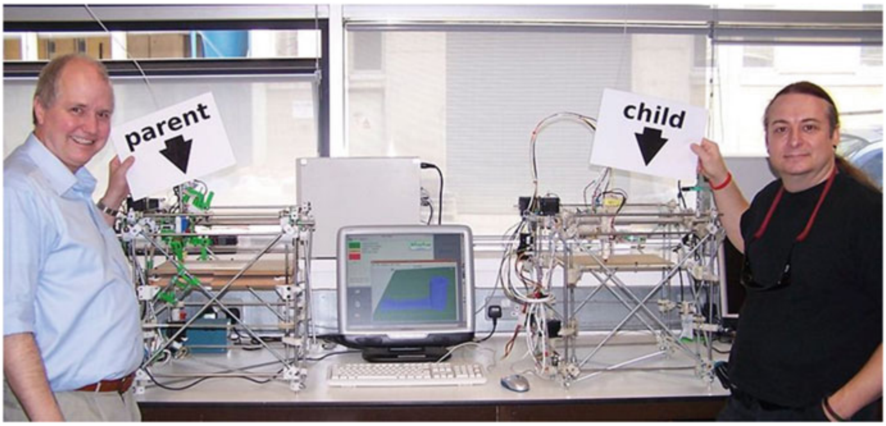


Fig. 5.4 First implemented replication by Adrian Bowyer (*right*) and Vik Olliver (*left*) (source: http://reprap.org/wiki/About)

the early and certainly most proactive members of RepRap's core development team.

Given that RepRap was indeed capable of replicating its skeleton but lacked the ability to create any of the electronics that make it work, this first instance of replication on the one hand represented a considerable success for the RepRap project but on the other hand could not hide the principal limitations of polymer-based 3D printing. However, since all the design files for the printable polymer parts were open source and all electronic components were either available at the RRRF or common suppliers, the RepRap community and its various activities scaled up fast.

In the course of RepRap's dynamic proliferation, two general paths of development emerged. The one was mainly engaged in further improvements on the original printing devices. Related efforts mainly point towards the developments of so-called "derivatives," which represent novel and altered incarnations of the initial RepRap "Darwin" 3D printer. In this context, Ed Sells, who was a member of the RepRap core developer team, released the "Mendel" as the second official and well-recognized RepRap 3D printer in October 2009. The other path used the RepRap devices as general tools that enabled people to make (that means: print) objects and goods for purposes not directly linked to the means and ends of self-replication.

It was again Zach Smith, who provided the internet-based support architecture, which facilitated related community efforts by launching the "thingiverse.com" website as a lean, digital repository for printable 3D designs:

> The dream behind Thingiverse is that someday in the not so distant future, when everyone has a RepRap machine, they will be able to go to Thingiverse.com, find a useful/interesting/cool thing, download it, print it, and 15 minutes later be able to hold the actual thing in their hands. This is the coming revolution of digital fabrication and we want to help you make it happen. (Smith 2008)

While the vision of the "coming revolution of digital fabrication" at first glance resembles Bowyer's early prospects of "revolutionary ownership," at this time it had the immediate effect of attracting a whole scope of people less interested in topics of self-replication than tinkering and making things. Indeed, the motif of "making things" or "stuff" was (and still is) central for the so-called "Maker Movement"—a thriving subculture that consists of technologically savvy people, who merely use electronic or computer-controlled devices to tinker and create things for fun. Although there have always been connections between the US American members of the RepRap community and the local Maker communities, the growing coherence in aims and interests even led to a partial amalgamation of related groups.[3]

With the advancements of technological capabilities and the growing interest in related applications, the market demand for 3D printers increased as well. Although the RRRF offered a supply for single components and kits, it hardly could satisfy the growing requests from the RepRap and Maker communities. These circumstances, together with the expiration of Stratasys' original patent for FDM, which RepRap-related applications essentially draw on, led to the inception of the first corporate community spin-offs for 3D printing in 2009. Not coincidently, the first two of such ventures were (co-) founded by Ian Adkins of Bits from Bytes and Zach Smith from the RFFF.

Indeed, Ian Adkins together with his co-founder Iain Major incorporated the already- existing Bits from Bytes supply platform as a venture in December 2008 and subsequently released the Rapman 3D printer as their own version of the RepRap Darwin as a complete, partly assembled kit in January 2009. A little later but in a quite similar way, Zach Smith founded Makerbot Industries together with Bre Pettis and Adam Mayer in Brooklyn, NY in March 2009. Nevertheless, while Adkins communicated his entrepreneurial ambition to the RepRap community implicitly by just advertising the company's product offer, Smith declared the launch of Makerbot and its first 3D printer called "Cupcake CNC" rather boldly. In a related announcement on the RepRap Blog, he for instance stated the following:

> The idea behind CupCake CNC and MakerBot in general is that we love 3D printing, and digital fabrication in general. Our dream is for everyone in the world to have cheap, easy

[3]Although there have of course been hobbyist approaches to metal- or woodworking and even tinkering in electronics before, the "Maker Movement" represents a renaissance of such "do-it-yourself" (DIY) modes of personal production/invention. Related dynamics started around 2005, have its roots in the US and are interdependently linked to the efforts of O'Reilly Media (resp. its later spin-off Maker Media), which is the publisher of the "Make Magazine" as well as the organizer of associated events called "Maker Faires". Today, there are more than 100 hundred Maker Faires per year, which are dispersed all around the world. In 2013, the original Maker Faire event was held in San Mateo, CA with 900 exhibiting makers and 120,000 people in attendance (http://makerfairedc.com/about/). In 2014, Barack Obama hosted a Maker Faire at the White House in Washington D.C., where he also raised a call to action to create a "Nation of Makers" (https://www.whitehouse.gov/nation-of-makers).

access to these cool technologies. For us, that means that we should provide them as cheaply as possible, and make them as easy to use as possible. (Smith 2009)

Within the RepRap community, the commercial ambitions of their members were discussed from a certain variety of angles. On the one hand, people were worried that the development speed and general momentum of the original RepRap project could decline when core contributors start to concentrate their effort on their own endeavors. On the other hand, people also saw positive effects for the project as the products offered by Makerbot and Bits from Bytes were assumed to lower the entry barriers for those less familiar with the core technology and could therefore expand the reach and diffusion of the RepRap idea.

Indeed, Makerbot took off especially fast and from the beginning triggered a lot of public interest. However, it was not Smith but Pettis who became the "face" and main spokesperson of the company, as e.g. he covered the 21st volume of the Make Magazine (released 01/2010) that featured a report on 3D Manufacturing at home. What followed was an entrepreneurial success story that, in its first phase, was marked by several new incarnations of the initial Cupcake CNC and a newly developed 3D printer called "Thing-O-Matic." Additionally, both the Thingiverse.com library for 3D designs and the RRRF essentially became part of Makerbot. At first glance, this switch appears legitimate, as Smith was the initiator of both projects, but it also represented a loss of decentralized control for the community since the person in charge was no longer exclusively a distinguished RepRap developer but also the co-founder of promising commercial startup company.

Even though these commercial tendencies considerably broke with the community spirit of the early phases of RepRap, its members confronted neither Makerbot nor Bits from Bytes with any direct offense.[4] This can certainly be traced back to the high credibility of Smith and Adkins and the fact that both companies kept revealing the blueprints of their devices as well as the code of their soft- and firmware applications under open source licenses and therefore still contributed to the further development of the RepRap project. Indeed, while the strong accounts to open source and the GPL were initially simply the result of Bowyer's personal affinity towards these approaches, the general buzz of open source hardware as well as the sparking entrepreneurial efforts within the RepRap community raised rather tangible discussions on IP-related topics.

Indeed, since applications of the open source hardware approach not only proliferated in the context of 3D printing, but also in connection with the decentralized and collective development of microcontrollers, musical devices, or open design in general, questions on how to deal with open source licenses for physical goods became more aware. For this reason, a couple of interest groups

[4]To mention as a side fact, when Zach Smith announced Makerbot on the RepRap Blog, Adrian Bowyer declares, as he said "in the interests of openness and letting everyone know what's going on" that he is one of the investors in Makerbot. Thus, he also had a personal interest in whishing them good luck (see Bowyer's comment below Smith 2009).

started to attend to this matter. Since the original GPL as well as modified Creative Commons licenses only apply to the file-based blueprints of related open hardware devices, entrepreneurs in this field usually struggle to find a proper match between their intents to keep the hardware designs open and the wish to secure the company against product cloning. So, a group of legal experts, open source enthusiast, and founders of open hardware startups (with Zach Smith among them) met in NY in early 2010 to tackle these issues. In the course of the discussion, people decided to determine practical norms instead of opting for a probably "long and painful" legal recourse (see Gibb 2014, 7–8). As a further outcome of this workshop, the group came up with a conjoint definition for open source hardware that essentially addresses a good practice for OSH-related businesses as well:

> Open source hardware is hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design. The hardware's source, the design from which it is made, is available in the preferred format for making modifications to it. Ideally, open source hardware uses readily-available components and materials, standard processes, open infrastructure, unrestricted content, and open-source design tools to maximize the ability of individuals to make and use hardware. Open source hardware gives people the freedom to control their technology while sharing knowledge and encouraging commerce through the open exchange of designs. (http://freedomdefined.org/OSHW)

Rather than being an official and binding license, this definition and its implications reflect a set of standards for the main properties that hardware has to embrace to be "open source" and thus serves as a "social contract that the open hardware community has agreed to uphold" (Gibb 2014, 14). However, as the next section will show, these moral obligations did not prevent people from expanding or even abandoning this social contract.

Regarding the phase of proliferation more generally, it becomes obvious that a couple of considerable changes affected the nature and conditions of the issue-based field. First, the successful replication of potentially printable parts marked a further milestone for the RepRap project but also showed principal limitations concerning the realization of complete reproduction. Second, various aspects built on RepRap's momentum, like the establishment of its general website, the launch of Thingiverse repository for 3D designs, or the facilitation of the components supply by the RRRF and Bits from Bytes, which significantly lowered the threshold for participation and especially appealed people from the growing maker movement. Third, the interests, intentions, and purposes for people to contribute to RepRap or at least engage in the issue of desktop 3D printing became ambiguous. Whereas the spirit of the first phase was characterized by people's desire to seed the idea and make it thrive, this second phase revealed first attempts to bring the harvest of these efforts, represented through the foundation of community spin-offs designed to sell RepRap-related devices. However, since the criteria for being open source became reflexive and more transparent, entrepreneurial actors became aware how to comply with them. Since the first 3D printing startups embraced these criteria, the original community reacted with support rather than with concern. As a general tendency, all of these developments called the initial issue of self-reproduction into question and linked the means of 3D printing to the ends of making "stuff" that did not relate directly to the replication of the 3D printers themselves.

5.1.3 Diversification

The emergence of multiple interests and purposes that expanded the initial scope of the RepRap project, which already began to take place during the prior phase, continued to shape the field and triggered a diversification in both technological as well as actor-related facets of the field's further development. Regarding, for instance, the original RepRap community, inspiration and novel technological developments were constantly fueled by new entrants, like e.g. Josef Prusa from the Czech Republic or Erik de Bruijn from the Netherlands, who made major contributions to the project and subsequently joined the team of RepRap core developers. This dynamic is best captured by the so-called "RepRap family tree", which represents a community-based initiative to document the emerging variety of RepRap derivatives and delineate the overall evolution of the project.[5] Indeed, the explorative strength of RepRap's community appears particularly obvious, when the derivative 3D printers that descended of Sell's Mendel 3D printer are taken into account (see Fig. 5.5).

The technological developments of 3D printing devices and the further evolution of RepRap derivatives, which significantly scaled up from 2010 onwards, also led to the constant involvement of new people in the field. In their empirical survey on "3D printing communities and emerging practices of peer production," Moilanen and Vadén (conducted in 2012, released in 2013) found evidence that the community itself became increasingly diverse. According to the authors, the scope of people engaged in 3D printing consists of three different groups of which the first intends to develop 3D printing devices ("developers"), the second wants to build and tinker with related technologies ("early adopters"), and the third just prints objects with 3D printers without being involved in associated developments ("end users"). By offering multiple forms of participation and corresponding, low-threshold channels for support (like the RepRap forums, mailings lists, and chats), or the design repositories provided by thingiverse.com (and later: youmagine.com), at this time the still community-based field indeed maintained the means to serve all of these ends.

While all of these community outcomes resemble the evolutionary dynamics that Bowyer intended to trigger with the RepRap project, the path of the emerging

[5] The term "derivative" is very common within the RepRap community. It is used to describe iterations and further developments of former, already existing RepRap devices, which usually incorporate gradual technological deviations from previous models.

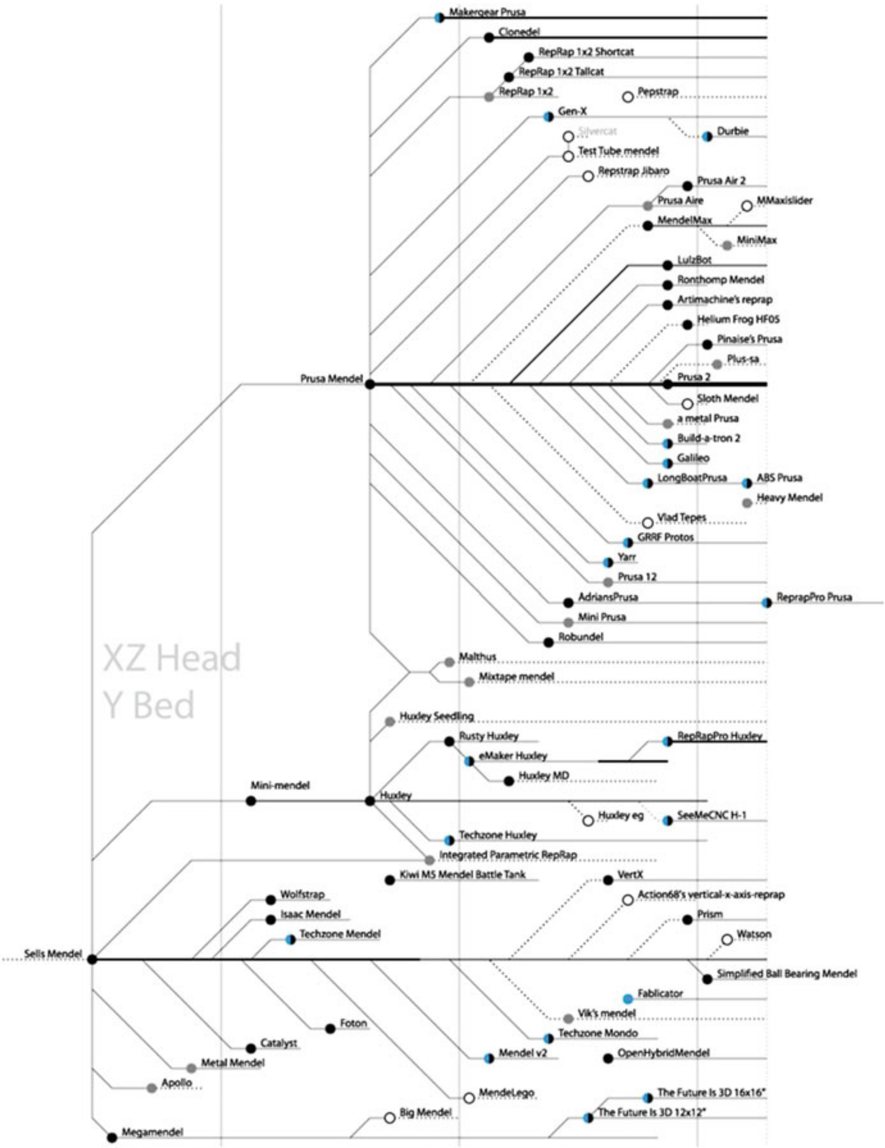


Fig. 5.5 RepRap Family tree—RepRap Mendel and derivatives

startups increasingly developed in a different direction. Here, for instance, the branches of the RepRap family tree that depict the rather linear evolution of Bits from Bytes' and Makerbot's 3D printers, illustrate quite sharply that the companies' 3D printer designs found only minor reception within the broader scope of the RepRap community (Figs. 5.6 and 5.7).

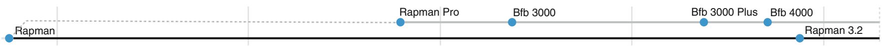


Fig. 5.6 RepRap family tree—Bits from Bytes' RapMan and derivatives

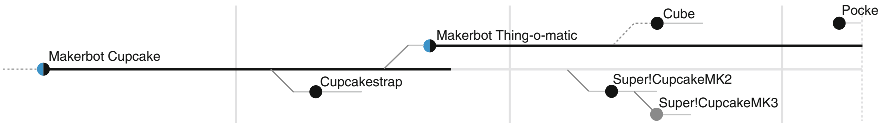


Fig. 5.7 RepRap family tree—Makerbot' Cupcake CNC and derivatives

In contrast, the organizational evolution of both startups was more dynamic. The first, Bits from Bytes, was acquired by 3D systems in October 2010, a world-leading company originally engaged in the market for industrial scale 3D printers. With this move and the stealthy integration of Bits from Bytes' "RapMan" printers into 3D systems commercial product portfolio, the startup and its founders subsequently left the RepRap community without much noise. In comparison, the story of Makerbot attracted more attention. With the acquirement of $10 million in venture capital from a hardware investment group in August 2011, Makerbot scaled up its corporate development in terms of organizational growth and increasing sales numbers. Supported by the monetary investment, the company launched the 3rd generation printer "Replicator" with a huge media response, which catapulted the company to the forefront of the emerging market for desktop 3D printers. However, since Makerbot still at this time revealed all its design blueprints, as well as the source code for its soft- and firmware, the venture's corporate success seemed to provide the proof that viable business models for hardware companies could be built on an open source approach.

The launch of "Replicator 2" seemed to be the next step on Makerbot's mission, as it was intended to make 3D printing even more accessible for users who do not have in-depth technological expertise and just want to print out their favorite objects. Yet, what distinguished this episode from the company's antecedent evolution is the fact that the Replicator 2 was the first 3D printer that was released after Zach Smith left Makerbot. Furthermore and even more importantly, the launch of the new product was accompanied by the company's decision to stop revealing the entire design files for the printer according to open source principles. Although these instances essentially reflected the strategic switch within a single company, they considerably disturbed the cohesion of the entire field.

Almost ironically, Makerbot was acquired by Stratasys, the company that initially filed the patent for the fabrication process of almost all desktop 3D printing technologies, for more than $400 million in June 2013. In October, Makerbot started to file patents on content, like e.g. a quick release extruder (published in 2014, see Makerbot Industries 2014), which the community claimed to resemble designs that were around in the open source domain before and were even shared on Makerbot's thingiverse.com platform. Shortly thereafter, the company actively entered the patent wars, when Stratasys Inc. initiated a lawsuit against another vendor for desktop 3D printers, accusing them of infringing on the company's intellectual property rights on another patent (Sharma 2013).

With the entry of economic actors like 3D systems, Stratasys, or a couple of other commercial vendors of closed source 3D printers, the field of desktop 3D printing, its inherent structure, the nature of actors involved—as well as their foundational attitudes towards the field's issue—became significantly diverse. While one group of actors still improved upon RepRap devices in order to accomplish the mission of self-reproduction, other former community members competed with commercial vendors for a share of the desktop 3D printing market. Although the first two examples of RepRap related startups eventually left the track of open source hardware, there were also plenty of other community spin-offs trying to merge market viability with being open source. I will return to them later more extensively.

Summing up this phase of diversification, a couple of insights become obvious. First and foremost, the expanded purposes of 3D printers, which initially focused on self-replication and increasingly changed into the making of random things, attracted not only a more diverse group of hobbyists to become users of RepRap-related devices, but also grouped economic actors, which started to engage in the field. However, the increasing orientations towards economic exploitation of desktop 3D printing became a topic for both corporate ventures that intrude into RepRap's open source domain and a growing share of its own community members, who started to become entrepreneurs for 3D printing startups in increasing numbers. While the first of those startups left the open source communities that they emerged from, at least partially, others still acknowledged the open source agenda and even emphasized this as a corporate USP. Although it is uncontested that the whole field originated from the RepRap project, the innovation community, which gathered around the project, suffered a loss of momentum and defining impact on the constitutive issue of 3D desktop printing mainly due to the thriving entrepreneurial efforts of its individual members.

5.2 Institutional Friction: Community Gain Versus Community Drain

As described in the prior chapter, the development of the 3D printing field was affected by various incidences of entrepreneurial effort. These took the form of consecutive waves: the first consisted of early attempts to sell RepRap-related products to facilitate the projects advancement, the second brought the first community spin-offs to the surface, and the third revealed an increasing commercialization and the proliferation of economic thinking.

These emergent entrepreneurial dynamics are tightly linked to the critical case of Makerbot Industries, a company that was initially based on open source desktop 3D printing and then switched its corporate strategy to a more closed source approach.

As already pointed out, with the Replicator 2, Makerbot presented a 3D printer that deviated considerably from its origins in the RepRap and Open Source communities in two different ways. First, the device itself changed from a plywood model that could be assembled and even entirely built by people who don't have access to industry-like machine tools, to a powder coated steel frame that needs a more sophisticated knowledge of manufacturing to be built. Secondly, the constitutional claim of open hardware was not consistent with the Replicator 2, since the company neither released the design files of the printer's frame nor the source code for the graphical user interface of Makerbot's desktop software (see Pettis 2012c).

During the product launch, the company's former peer group discussed Makerbot's credibility as a legitimate member of the OSH community intensively. The Makerbot CEO and co-founder Bre Pettis entered this discussion offensively by posting two articles concerning these topics on the Makerbot News Blog. At this time, Pettis was the last of Makerbot's co-founders still engaged with the company since both Adam Mayer and Zach Smith left the company (resp., as Smith 2012 puts it in his blog, were "forced out") due to struggles over who was running the company (Hive76 2012). However, as a reaction to Pettis' statements, Makerbot users and stakeholders of open hardware in general (as well as RepRap in particular) commented upon both of his blog-posts heavily. It turned out that Makerbot's move represented a true shock to the 3D printing community. While a few comments acknowledged the need for Makerbot's shift in business model, the majority of them explicitly criticized this decision and reflected a broad skepticism often accompanied by largely personal criticisms of Bre Pettis for engaging in illegitimate behavior.

I believe that analyzing related discussions in depth allows me expose the shared understandings that sustain the community's internal cultural cohesion as well as the core dimensions for institutional tension that become apparent in the field. In order to do so, I collected data from online discussions triggered by blog posts and forum entries from the RepRap community, the Makerbot homepage and field-associated websites such as makezine.com, hackaday.com, or wired.com. Contrasting two perspectives, one that emphasizes the community stances and one that justifies Makerbot's strategy for greater economic success, reveals a sharp juxtaposition of conflicting attitudes towards appropriate ways to engage with the issue of desktop 3D printing and thus delineates the communities shared understandings of what constitutes a legitimate entrepreneurial practice.

In the next sections, I apply the methodological approach of semiotic chain analysis (see Sect. 4.3.2) to analyze the debates and discussions that arose in the context of the Makerbot controversy. This type of structured interpretation helps me to elaborate the connotative codes that represent the community's aggregated criteria for legitimate entrepreneurial action, as well as the denotative implications, which represent the community's perception of best practices for spinning out RepRap related startup companies. Figure 5.8 sketches the semiotic chain from the community's point of view. Hence, any of the codes grouped on the left-hand side are associated with positive attitudes associated with the community logic. The

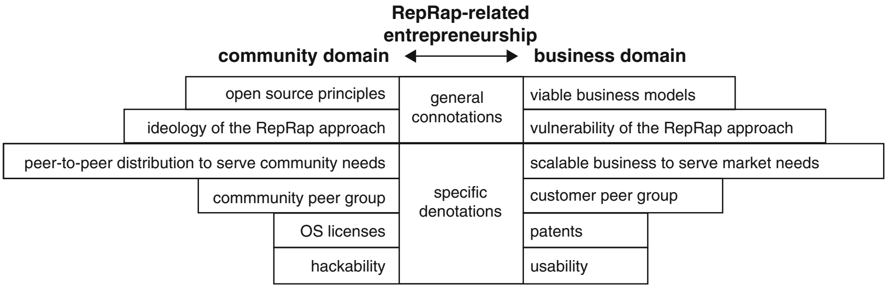


Fig. 5.8 Semiotic chain of contrasting cultural codes on RepRap-related entrepreneurship

right-hand side, instead, represents evaluations of appropriate entrepreneurial practices that rather resonate with the business domain.

5.2.1 Connotative Conflicts and Divergent Understandings on Entrepreneurship

To grasp the general criticisms against Makerbot's strategic shift towards a more proprietary business model, one must remember that the rise of Makerbot indeed went hand in hand with the thriving community for 3D printing (see Sect. 5.1). When Zach Hoeken announced the foundation of Makerbot on the RepRap Blog, he clearly revealed that they "borrowed some of the best ideas from a few of the other open source 3D printer designs [. . .] and combined them into something that is uniquely ours" (Smith 2009). Besides this technological heritage in the RepRap project, Bre Pettis initially also emphasized the ideological bonds between Makerbot and open hardware communities by promoting that they "take open source seriously" and that "it's a way of life for us [them]": thus distinguishing them from other companies, which do not take the "open source ethics" as seriously (Pettis 2010).

In the following 2 years, the rise of both RepRap as a community and Makerbot as a company were tightly linked. Indeed, the reputation of Makerbot as a brand and the "poster child" of 3D printing (Smith 2012) was mainly backed by its high appreciation by the open source community. Besides, Makerbot's various media appearances also emphasized the company's background in open source as a key facet of their stories (see e.g. Anderson 2010; Ryzik 2011; The Economist 2011). Consequently, the publicity of Makerbot also reflected back on the RepRap community, which unleashed mutual gain and sustained the cohesion between both. With Makerbot partly closing the open source for their printers, it cut-off the symbiotic relationship to RepRap sharply. The following paragraphs depict the discourse that accompanied the divorce along two contrasting codes, which I extracted empirically from the Makerbot controversy on associated online discussions.

5.2.1.1 Open Source Principles Versus Viable Business Models

The arguments that relate to Makerbot's shift towards a closed-source business mainly hinge on the company's breach with the principal foundations of open source. Most of the critical comments blame Pettis for violating the reciprocal ties with the open source community. The community members' stances in this discourse mostly resemble the messages of the following comment:

> You built your machine based on RepRap technology and created a company around it and its community. MBI [Makerbot Industries] promised to be an open source hardware company. People have supported you and been loyal customers to you because of that and a lot of that trust has gone into your brand. [. . .] Now you just told your supporters and customers that they are not important anyway since you are going to make millions selling to all the people who do not care. Well, good luck with that. (Comment by "Mårten" below Pettis 2012b)

In contrast to this and similar comments that reveal a rather emotional reception of Makerbot's shift, Adrian Bowyer, who at this time was still acknowledged as an influential spokesperson of the RepRap community, also entered the discussion by soberly emphasizing the projects' initial attempt of self-replication and thus demarcating the emerging split with Makerbot as beyond the scope of RepRap:

> RepRap is Open Source because Darwinian game-theoretic analysis says that Open Source is an evolutionarily-stable strategy for a useful replicating machine that is intended to maximise its numbers in the world. This is a completely amoral fact, and it is the reason that I made RepRap Open Source. [. . .] I don't care about them [people who appropriate RepRap technology and close it off] because I know that by closing off the path that they have chosen, they have turned it into a reproductive cul de sac; they have made their machine sterile." (Comment by Adrian Bowyer below Pettis 2012a)

Although this is certainly true from a technical point of view, the fact that Bowyer himself was one of Makerbot's first investors could be taken as a reason why he missed the Marxist influence of his initial RepRap approach here (see Bowyer 2006b and Sect. 5.1.1). However, community members that not own company shares of Makerbot still tend to draw on moral arguments to penalize Makerbot's violation of the community's constitutive principles in connection with openness and sharing. Related comments on this topic revealed the common attitude that Makerbot could no longer be considered part of the RepRap-related, open source-orientated population of the 3D printing field:

> MakerBot needs to choose. Either you are going to be an open source hardware company and continue having the support of the community that you helped build . . . .or you are going to close down and become a normal company—sell some printers in the short term and the community will move elsewhere. (Comment by "Joshua" below Pettis 2012a)

Pettis' own statements, with which he tried to justify Makerbot's switch in business strategy and a related push to meet the requirements of the consumer market in order to expand the company's reach, indeed revealed that he had already made his decision:

> At MakerBot, we've transitioned from a company that made Cupcake CNC and Thing-O-Matic kits that were hard to put together for a lot of people and they were an education in assembly techniques. We've transitioned into a company that makes a tool, the MakerBot Replicator 2, that has set a new standard in desktop 3D printing because it just works. (Pettis 2012b)

In line with this argument, Pettis also left no doubts that his company was on the path towards a more commercial way of doing business. To achieve this end, the Replicator 2 itself shifted away from its DIY appeal in favor of applying "traditional manufacturing to meet scale" (ibid.). Makerbot's corporate strategy also deviated from the principles of open source in order to "compete in this new market" (ibid.). According to this quote, Pettis was not able to consider an alternative strategy that actually merged both open source idealism and market-driven commercialism within a viable and profitable business model for his company. Regarding Makerbot's relationship to its former peer groups, Pettis was already quite aware of the consequential friction: "MakerBot is coming of age and we need to evolve our relationship with RepRap. We hope and expect it will continue to be a strong one." (Pettis 2012b)

While the company in its early history contributed all its software and hardware developments back to the RepRap project, supported community events, backed local user groups with 3D printers, and enabled exchange of 3D designs with their thingiverse platform, their break-up with this community now re-shaped their relationship to RepRap. On the one hand, Pettis' quote indicates that Makerbot considered itself no longer a part of the RepRap community. On the other hand, it seems obvious that Makerbot was not willing to break completely with this community, although the desired relationship remained fuzzy.

5.2.1.2 Ideology of the RepRap Approach Versus Vulnerability of the RepRap Approach

Regarding the general constellations within the issue-based field of desktop 3D printing, Makerbot's decision to take this step towards closed source not only shocked the community-based subpopulation but also raised discussions on structuration of the field itself. With Pettis framing the strategic change of Makerbot in terms of "growing up" and "become more of a professional business" (Pettis 2012b), the community-based efforts of RepRap and open hardware in general were downgraded by this language to either academic or just playful projects that lacked professional ambitions. Thus, this wording suggests a foundational separation between community- and business based realms and an associated need to decide upon which path leads the company's further direction. Reactions from the community were skeptical of Pettis' description of sharp, functional barriers; they assumed instead a change in Pettis' personal disposition and an associated corporate strategy increasingly focused on making higher profits: "When money comes through the door, principles go out the window. I know that. You know that. We all know that. Why not just admit it?" (Comment by "Bob Cousins" below Pettis 2012b).

Of course, this controversy also addresses conflicting attitudes regarding reciprocity, trust, and related moral arguments on whether entrepreneurial ambitions grounded on collaborative work and collective efforts are capable of sustaining the community or generally impose threats to the collective endeavor. Technically, while there is no doubt that Makerbot's co-founders gained early inspiration and practical support by engaging in the RepRap community, it is also very clear that the company developed the vast majority of the technological improvements involved in the Replicator 2 in-house. However, since these substantial linkages essentially enabled Makerbot's rise, people from community widely share the feeling that the company owes them more than it is willing to give.

Accordingly, related comments generally reveal that reciprocity between taking advantage of the community and contributing back to the community is a key condition for cohesion among its members. That Makerbot stopped revealing the entire blueprints for their printers was thus tantamount to their removal from the solidary contract of generalized knowledge exchange. As the following comment shows, maintaining the reciprocity within the community not only refers to the practical implications of knowledge sharing, e.g. that members get the actual resources to re-build the Makerbot printers from scratch, but also has implications for the moral of the group and the symbolic appreciation of collective effort:

> [. . .] products like Makerbot's incorporate the benefits of uncountable hobbyist development and testing hours, both indirectly as you benefit from prior and parallel efforts such as RepRap, and directly as you get feedback from people working with your own designs. Those hobbyists don't get any portion of your profits or celebrity. What they do get—or have gotten—is access to the latest designs, both hardware and software. Many of them won't make any use of that, sure. Many of them can't, as you say. But some do, and for many others, it's a matter of principle. That principle—that feeling of respect, inclusion, and potential—is both central and fundamental to the OSHW [open source hardware] community. (Comment by "Issac" below Pettis 2012a)

Indeed, the uproar triggered by Pettis' announcements of the shift towards a more closed source approach showed evidence for the community's sensitivity on the principle of sharing. However, while many commenters emphasized what the community had done for Makerbot, almost none of them mentioned the actual improvements, which the company had so far contributed back to the community. It was therefore Bre Pettis himself who called into mind the various community contributions that Makerbot made over the years: "MakerBot has done a LOT for the community. There are thousands of non-MakerBot 3D printers, projects, and businesses that have benefited from our sharing" (Pettis 2012b). It is without doubt that Pettis is true on that point. In the talk he held at the Open Source Hardware Summit shortly after the launch of the Replicator 2, he especially emphasized Makerbot's software contributions, like e.g. the Replicator firmware and drivers, which he stated "alone represent over a million dollars in people working, being paid, during the day, to do this work on the software" (Pettis 2012c).

However, since Makerbot increasingly retrenched practical involvement and subsequently focused on its own devices as well as their group of customers, the ties to its former peer communities became rather affective—in the sense that feelings of a common identity primarily drew on diffuse associations than shared practices, like e.g. the mutual exchange of knowledge. Hence, comments on Makerbot's decision to stop sharing the entire blueprints for their printers revealed the emotional bonds of communities, as people emphasized that, for instance, "It may be legal, or even morally acceptable to take certain actions, but when you're heavily involved with the OSHW community you need to pay close attention to how things FEEL" (capitalization by commenter "macegr" below Pettis 2012a).

One of the main insights drawn from the Makerbot controversy indicates that openness, which represents the most substantive principle and value of innovation communities, became a threat for the company and its economic goals. Bre Pettis was very clear on this point when stating that: "I don't plan on letting the vulnerabilities of being open hardware destroy what we've created." (Pettis 2012a). Indeed, when Pettis made this statement, they already created a flourishing startup with around 150 employees in the middle of Brooklyn and acquired a $10 million venture capital fund to scale their business, too. At this point of time, Makerbot reached a crossroads. On the one hand, the company's background in open source communities and marketing efforts in connection with open hardware and the maker movement in general form a crucial pillar that enabled the company's corporate success. On the other hand, Pettis considered sticking to the open source approach an inappropriate way to face the challenges of his company's current situation: "From a business perspective, we've been absurdly open, more open than any other business I know. There are no models or companies that I know of that have more than 150 employees that are more open" (ibid.).

5.2.2 Denotative Contrasts in Appropriate Entrepreneurial Practices

In the following paragraphs, I will again draw on comments from forum and blog discussions in connection with the Makerbot controversy to delineate the denotative codes that I assume to depict shared, community-based considerations on practical criteria for legitimate community-based entrepreneurship. Similar to the prior chapter, I will contrast the common community perspective with Bre Pettis' statements in connection with the business vulnerability of open source.

5.2.2.1 Business Model: Peer-to-Peer Distribution to Serve Community Needs Versus Scalable Business to Serve Market Needs

From the community's point of view, legitimate ways of organizing value creation in the context of desktop 3D printing embrace notions of rather small, peer-to-peer business models, which serve community needs. In contrast, the business domain favors a startup-based approach of a scalable business, growing market shares and serving consumer needs. Regarding the practical implications of openness and how they respond to these approaches, the first clearly supports open sourcing everything while the latter prefers to open source as much as possible but keep the core business values under IP or secrecy. By way of example, while Bre Pettis stated that, “we are experimenting so that we can be as open as possible and still have a business at the end of the day” (Pettis 2012a), one of the commenters replied that, “[. . .] the community is based on openness, and that means you can’t decide which bits are unimportant enough to share” (comment by “Isaac” below ibid.).

Pettis’ attitude towards keeping the core business values as corporate knowledge also associates Makerbot’s corporate development with the usual strategies of startup ventures that draw on their unique selling proposition to become competitive in their target market and thus fundable for potential investors that help them grow quickly. His following quote reveals his awareness on that strategic loop sharply:

> Because we chose to develop fast and have big competitors, we decided to take investment to bring this technology to people who will use it to do amazing things. Taking investment adds another layer to the business, but has allowed us to grow and make the awesome machine we launched this week [the Replicator 2]. (Pettis 2012a)

In contrast to this general emphasis on growth, the small business approach widely preferred within the community domain lacks this orientation. Instead, the early approaches toward offering parts and components for 3D printers within RepRap’s peer group explicitly avoided corporate forms of organization. Community members preferred to establish cooperative platforms that link demand and supply in rather personal ways. Indeed, the RepRap Forum offered a category that essentially worked as a marketplace where people tendered their offerings directly to others with an interest in purchasing them. According to the very sense of self-replication, the corresponding supply mode for RepRap’s printable parts was back in the day summarized as follows:

> Anyone with a RepRap could sell services and earn back some of his expenses if he wants so. It’s usually way too much trouble to start a webshop yourself, but there could be a central (middleware) platform on which demand and supply can meet. (Comment by “ErikDeBruijn” on the “World-Wide RepRap Printing Webstore” forum thread on reprap.org, 2008)

Although the RRRF, which I introduced in the context of Sect. 5.1, already deviated from the general reluctance toward corporate organization, the fact that it was non-profit, run by volunteers, and provided parts at low prices obviously resembled the means of peer-to-peer distribution. However, this early idealism and rather altruistic support for the RepRap project subsequently vanished in favor of the widely shared opinion that people who invest their time and skills in the provision of parts and products also deserve some financial rewards for their efforts. Acknowledging the fact that people who offer value to the community also need incentives and eventually have to earn a living, too, introduced no serious friction within the RepRap community. Like in the context of open source software, the freedom implied in open source hardware refers to the accessibility of knowledge rather than its price tag. However, the normative attitudes that accompany the supply of open source hardware to the peer group clearly promote low economic margins and entrepreneurial approaches targeting rather modest profits. As an example for this point of view, one of the comments below Bre Pettis' blog post stated the following:

> If being completely open does not work as a business model how did you get this far? The fact is you made a successful business being open so all your excuses are just fluff at this point. Sure maybe you could not get rich being open but that has never been a goal of open source. (Comment by "Concerned individual" below Pettis 2012b)

For Makerbot, this ideal is hardly applicable since the company already employed a significant number of people at the time of the controversy and already faced considerable business responsibilities with their financial investments. Regarding the pricing of the Replicator 3D printers, while some members of the community criticized Makerbot for continually upping the prices and therefore pulling the devices out of the hands of people who "have been putting their time and effort into research and putting new ideas in the community" (comment by "dan" below Benchoff 2012), Bre Pettis justified the rather high price tags by stressing the company's ambitions and liabilities: "We priced the MakerBot Replicator so that we could afford to pay employees, offer health insurance, grow and innovate."

The fact that the company took money from venture capitalists certainly amplified these tendencies as Pettis himself stated that Makerbot had a duty to create value for its shareholders, of course, because "that's part of the startup life" (Pettis 2012a). For the community, Makerbot's affiliation with VC money was perceived as one of the main reasons why the company deserved mistrust. As VCs embody the business ideal of making profit neither by personal nor even by collective effort, but instead by monetary investment, the entry of these stakeholders disrupted the balance, which shook the fragile relationship between the RepRap community and Makerbot company considerably. While some blame the company that they "sold out for $10M" (comment by "Scott" below Pettis 2012a), others simply suggest, "never trust investors" because they "simply not care about ideals" (comment by "Traumflug" below Smith 2012) but instead "about making bets on companies to make money" (comment by "Christian Restifo" below Giseburt 2012).

Essentially, the tensions between the community- and business realms converge on the fine line between low margins and high margins. While the community domain widely reproduces the attitude that it is inappropriate to provide collaboratively developed and open source licensed parts and components in order to gain high profits, the commercial approach of startup ventures like Makerbot does essentially that. Comparing these perspectives, the contradictions between them become obvious: What appears good and legitimate for the former directly contradicts with the appropriate means and ends of the latter.

5.2.2.2 Relevant Peer Group: Community Versus Customer

Similar to this juxtaposition in the matter of business models, the decision whether a 3D printing startup addresses primarily community- or consumer orientated peer groups with its products and supplies also resembles the sharp contrast between the community and business domains. In this connection, Makerbot's decision to gradually closing the sources for their developments also revealed the decoupling between the company's retro- and prospective peer groups.

When Zach Smith announced Makerbot Industries on the RepRap Blog, he emphasized that he and his co-founders "firmly believe and trust in the open source hardware movement and look forward to building an awesome future together" with the community (Smith 2009). Accordingly, the company initially acted in coherence with the associated open source norms and values:

> We share our design files when we release a project because we know that it's important for our users to know that a MakerBot is not a black box. With MakerBot, you get not only a machine that makes things for you, but you also get an education into how the machine works and you can truly own it and have access to all the designs that went into it! (Pettis 2010)

This appreciation of open source spurred the mutually-shared attitudes that Makerbot was a part of the open hardware movement in general and the RepRap-based 3D printing community in particular. Consequently, the community members also initially felt like supporters and contributors for the venture rather than simply like customers for the company's products. In some exemplary cases, the bond between customers and Makerbot products was even emotionally charged as people really intended to support Makerbot because of its origin in the open hardware realm. While one person e.g. stated that he bought early Makerbot 3D printers "inspired by your [in this case: Pettis as a person] early idealist vision" and "wanted Makerbot to succeed" (comment by "Rick Kimball" below Pettis 2012a) another person who intended to purchase a Makerbot Replicator printer in theory later changed his plan, doubting that the company "considers me (a hobbyist/maker type) your target market anymore" (comment by "Eric" below ibid.).

On the one hand, Bre Pettis agreed with his almost customer, which is less surprising considering Makerbot's corporate strategy of entering broader markets for consumer goods. On the other hand, his statement suggests that he evaluates this instance in terms of a shift in rather than a loss of community. Claiming that notions of community had changed over years "from mostly developers to mostly people who just want to use the thing as a product instead of a project" (Pettis 2012a), Pettis implies that not the peer group of RepRap/OSH but the broader community of "folks who want to make amazing things rather than make a 3D printer" forms the relevant core of Makerbot's community. This statement particularly triggered the resignation and anger of Makerbot's former peer group, who felt "downgraded to 'customers'" (comment by "Issac" below ibid.). Another commenter of Bre Pettis' Blog post put the break-up between Makerbot and its early supporters in a similar way:

> I believe we the people who own your products feel like we are a part of your company. We have always cheered for you because you spoke our language, you knew what we wanted, and it felt like we had a shared vision of a high-tech future. (comment by "Matrhint" below ibid.)

Alike comments thus reveal reactions that are more defiant too, as they emphasize that not only did Makerbot switch communities but also that the community may now switch the companies they support. While some ironically suggested that Makerbot "should consider renaming the company to 'Consumerbot' just to be a little clearer" (comment by "H. Snow" below Pettis 2012b), others rather neutrally concluded that the company's turn burned its base (see e.g. comments by "osfa/commons factory" or "Carl" below Pettis 2012a).

It finally becomes obvious that Makerbot ceased to consider those engaged in RepRap and open hardware as their core community. Complementary, the related community for desktop 3D printing widely shared the attitude that Makerbot was no longer one amongst them. Hence, while Bre Pettis' argumentation on that point revealed a means-end orientation to expand Makerbot's peer group to customers that only purchased their products, the reactions from the company's former community implied rather affective feelings of anger and defiance, as they felt downgraded and forsaken by Makerbot's consumer-based marketing strategy.

5.2.2.3 Design Principles: Hackability Versus Usability

The third code that contrasts the potentially contradictory poles of denotative meaning points towards opposing attitudes and categorical distinctions in connection with the 3D printers' material properties and design principles. Related differences, which I discuss in terms of hackability vs. usability, manifest in the immediate physical appearance of 3D printing devices as well as in their particular construction approaches. Hackability embraces a DIY inspired product design that allows people to either tinker with the corresponding devices or even re-build them from scratch. When sold, 3D printers with high degrees of hackability usually take the form of kits that need to be assembled by customers. Usability thus represents a "plug and play" approach that promotes a rather low-threshold usage of readily assembled devices and a reliable out-of-box experience.

Regarding the Makerbot controversy, the matter of the materiality of devices correlates closely with the previous codes. As they were made by an open source hardware company that related mainly to community-based peer groups, early Makerbot printers were plywood devices that contained off-the-shelf components; they were optionally offered as kits (see Sect. 5.1.2). Starting with the Replicator 2, Makerbot printers changed their appearance and quality quite a lot as the company switched to a powder coated metal frame that included almost no adjustable details and therefore restricted hacking on the machine to a considerable degree.

At first glance, this change in designs and construction affects the utilization of the corresponding 3D printers as it shifted from improving the devices itself (not only but mainly by the means of self-replication) to modelling and printing out random objects. The more sophisticated approach to manufacturing also reifies Makerbot's new attitudes in connection with the broader topic of IP and open source. Bre Pettis summarizes this mutual adaptation as follows:

> [...] with our wooden machines, we empowered the making community to innovate. With our current machine, the folks who can really innovate on it are people with factories who can take the design to a place with a much lower cost of living than Brooklyn and folks there won't have health insurance [...]. (Pettis 2012a)

This argumentation thus adds another layer to the controversy on openness as Pettis states that one reason for not sharing the design files is that average community members do not own the tooling and machinery devices required to utilize them anyway. Instead, revealing the blueprints for the Replicator 2 would primarily enable professional vendors with manufacturing facilities to create cheap clones and thus harm Makerbot's business. While some community members share this perception, others doubt the implied causality between the reasons and effects of going closed source: "With the Replicator 2 looking a bit more like a polished consumer project and less like a hobbyist's dream, it's clear that there is a desire to push more mainstream." (Comment by "Barry" below ibid.)

It turns out that the distinct orientations toward usability and hackability and related approaches to product design resemble binary contradictions, too, as hackability resonates well with the community-based foundations of open source and usability reflects more of product criteria prevalent in consumer markets. In connection with these opposing poles, one rather affirmative comment below Bre Pettis' blog post stressed an interesting comparison to another quite popular example of the IT realm stating "RepRap is like linux" while "Makerbot is like the Apple of 3D printing" (comment by "Kendall" below Pettis 2012a). However, since the actual technological advancements of the Replicator 2 reflect only incremental improvements compared to the rather state-of-the-art RepRap project at this time, the actual distinctions between the Makerbot's Replicator printers and other RepRap-related developments are primarily a matter of sophistication in marketing and outer product design than in technological expertise.

5.2.2.4 IP: OS Licenses Versus Patents

At first glance, the question of the licensing of hardware-related content adds a more technical layer to the general matter of reciprocity: while the open source communities generally apply licenses associated with copyleft or creative commons, patents represent the usual choice of business corporations to secure their IP within the contexts of market competition. However, as already mentioned earlier, the GPL and creative commons licenses generally lack legal opportunities for enforcing them in connection with hardware, since both relate to copyright law that predominantly applies to the blueprints but not the physical products and their working principles. Instead, IP regulations that protect functional devices against cloning or unauthorized utilization stress the patent law, which entails a very distinct legal framework including corresponding practices for filing, protection, and infringement. Thus, any attempt to regulate the IP of OSH devices like 3D printers under open licenses is essentially misleading and therefore reflects a rather symbolic act that shows an appreciation for open source ideas and an affiliation with community values:

> When most people think of open source, there is an assumption that those involved with the community will stay in the spirit with continual open source licenses. But the license itself doesn't really enforce this. Anybody can just take open source stuff, build proprietary stuff around it and package it up and ship it for money; then make millions when they popularize it. (Comment by "urquanmaster" below Prusa 2012)

Besides the fact that open source licenses and patents address different legal scopes, I contrast them as opposing poles in my discursive analysis of the community's stances towards the IP-related topics. Here, while open source licenses are assumed to maintain high degrees of openness, the potentially destructive effects of patents as well as other forms of restrictive IP protection are closely associated with the notion of "dead-end derivatives" and their negative implication for the community's reproduction.

According to the initial approach of RepRap and the corresponding terminology, derivatives represent iterations of former RepRap devices that incorporate technological deviations and thus contribute to the ongoing evolutionary process. Against this background, the application of open licensing strategies resembles a rather fuzzy approach to sustaining the open and integrative niche that actually enables the collective effort and incremental progress of RepRap-related developments. Since patents essentially restrict the application of filed components in deviant contexts, they inherently create dead-end derivatives, which harm the reciprocal exchange of knowledge: "When people take designs that are open and they close them, they are creating a dead end where people will not be able to understand their machines and they will not be able to develop on them." (Pettis 2010).

Compared to this early statement of Pettis, his later take on secrecy and IP protection aligns instead to his perception of increased market competition and Makerbot's re-framed business strategy. Stating that the company "had to spend a lot of money with patent attorneys making sure we don't infringe on the vast array of patents in the 3D printing space" (Pettis 2012a) he conceives of filing own patents as necessary part of struggling for competitiveness and market shares. However, Pettis clearly addresses the potential enforcement of these patents to the "billion dollar companies with arsenals of weapons" and emphasized his ambition "to come up with a way of licensing them in a way that doesn't suck" (ibid.), i.e. that the company will not accuse individual hobbyists for patent infringement.

Summing this up, the appreciation of open source licenses and related criticism of dead-end derivatives and patents reflects a whole array of normative presumptions about the ethical foundations that sustain the OS community, its constituting practices as well as general problems associated with broader claims of community drain. In the business realm, the lack of legal liability that accompanies this open type of IP regulation is thus considered a threat for competitiveness, which facilitates cloning and weakens a company's bargaining hand when it comes to patent lawsuits.

5.2.2.5 Mixed Feelings About Cloning

Besides the obvious contrasts that link the previously discussed codes to either the community- or the business-based foundation of desktop 3D printing, the Makerbot controversy revealed rather ambiguous attitudes concerning the matter of cloning. Clones are derivate 3D printers that identically resemble the technological properties of an already-existing design. Although cloning does not confront the open source licenses und definitions in principle, it though harms the "unspoken rules of open source hardware" stating that "cloning ain't cool" (Torrone 2012).

Roughly one month before Makerbot launched the Replicator 2, the company was confronted with a crowdfunding campaign of the so called "TangiBot", introduced on kickstarter.com as "the affordable Open Source 3D Printer" (Strong 2012). More precisely, the value proposition offered by Matt Strong, who launched the campaign, referred to the fact that he offered a clone of Makerbot's Replicator 1 3D printer including the same performance and features at around 2/3 of Makerbot's Replicator 1 retail price. Indeed, while Strong did not claim to offer any further developments on the device itself, he emphasized instead the related manufacturing improvements, his hopes to set up more efficient production facilities overseas (according to his statements, most likely in China or the Philippines), and the corresponding reduction of the price for 3D printing devices. Although Strong's kickstarter campaign failed clearly as it only reached about ten percent of the ambitious funding goal of $500,000, it spurred a lively discussion on the legitimacy of promoting a direct clone of a rather-established open source hardware device so explicitly.

The immediate reactions to TangiBot were generally ambiguous as some appreciated the clone as a necessary part of OSH and others embraced the "unspoken rules," critical of cloning. In related discussions on the internet, some commenters' arguments, for instance, simply highlight the fact that Strong's approach widely complies with open source principles and even reflects "what open source is all about", namely "no monopolies" (comment by "stunmonkey" below Benchoff 2012) while others emphasize the moral dimension of open source e.g. as follows:

> The goal for open source is typically to make your own, not to sell your own replica. The business model is supposed to involve some actual value added by the entity doing the selling. To do otherwise is simply leaching the work off of the previous contributors and leads to a withering of the project. (Comment by "mystixa" below Flaherty 2012)

Regarding these contrasting stances in the narrow context of Strong's crowdfunding campaign, it becomes obvious that these do not fit direct associations with either community or business domains. Instead, the community itself appears rather divergent in their assessment of the TangiBot case. Hence, even the arguments that emphasize the possible advantages of cut-off prices predominantly place related benefits on the community level, as cloned devices like the TangiBot push down the cost of entry and therefore "is helping the proliferation of 3D printers by making it cheaper than the 'big guys'" (comment by "dext3r" below Benchoff 2012).

However, the whole controversy surrounding the TangiBot fueled Makerbot's struggle in connection with the Replicator 2. Although the crowdfunding had already failed, Pettis also referred to this Kickstarter campaign to justify his own company's move to a more closed source approach: "Tangibot was a real eye opener for us and even though that project wasn't successful, it gave us a lot of insight into the manufacturers that are coming down the road who will copy MakerBot because we may make it easy for them" (Pettis 2012a). He added that such incidences expand the scope of market competition, as the company not only faces "big competitors who are entirely closed" but also competition from below represented by "kickstarted projects making inexpensive hobbyist 3D printers" (ibid.).[6] Moreover, Pettis assumed that neither the users nor the big competitors are likely to benefit from shared design files but only the cloners that undermine Makerbot's competiveness by ripping off their products.

Summing up the topic of cloning and its particular implications for reciprocity, cloning open hardware devices is merely perceived critically, but with no strict taboo, within the community domain. As long as the clone itself sticks to open source principles, it is thus considered to help to proliferate desktop 3D printing. The particular case of TangiBot's crowdfunding campaign also revealed the implicit rules of OSH, which clearly prefer value-addition to devices instead of just copying them for commercial purposes. However, whether reductions in price serve as proper contribution and add value remained contested. Although the attitudes within the community are rather ambiguous on this topic, Pettis' discussion of the TangiBot case clearly adds another justification for the company's step toward a more closed source approach. Consequently, the business domain perceives cloning as a general threat to market competiveness, as cloned devices cut off retail prices for already established products and eventually reduce market shares.

[6]In this context, the terminology of "kickstarted" refers to entrepreneurial activities that engage in crowdfunding campaigns in platforms like kickstarter.com in order to raise funds for the realization of a certain product or project. The "TangeBot" campaign mentioned above represents one example for this practice.

5.3 Facing the Tensions: Insights from Second Generation 3D Printing Startups

As described in Sect. 5.1.3, the diversification of the issue-based field of desktop 3D printing put more pressure onto the community-based subpopulation that struggled to sustain their symbolical and practical foundations as these were increasingly imposed on by the business logic. Related frictions culminated in the case of Makerbot, which thus revealed the implicit contradictions at the heart of entrepreneurial efforts to found a startup based on community-based innovations.

However, related attempts by community-members to create ventures did not end because of Makerbot's critical reception. Instead, the related controversy set the scene for a second generation of startups attempting to align the community-background and open source character of 3D printing with the creation of viable business models. Founders of those startups are increasingly aware of the challenges that accompany their entrepreneurial endeavors as well as the potential threats, which economic exploitation could impose on their community. Since community support is crucial for any startup that intends to launch OSH applications such as 3D printers, the damage that Makerbot did to the community's cohesion is therefore likely to decrease the future chances for people intending to launch new ventures. Against this background, the following sections analyze how entrepreneurs in the field handle this challenging situation and bridge the institutional gap between community- and business criteria for legitimate action.

To gain insight on this topic, I conducted interviews with six founders of 3D printing startups between 2013 and 2015, three from the US and the other three from Europe. As a common denominator for this sample, all of the founders made their first contacts with 3D printing in the open source context of the RepRap project. While these six interviews represent the core of the sample, I will also draw directly and indirectly on interviews, which I did with actors offering complementary and/or adjacent perspectives in order to ground my findings more broadly. These additional perspectives include investor's attitudes towards open hardware, experiences from founders of adjacent OSH-related fields, general community stakeholders that are not engaged in entrepreneurial activities, or representatives of the Open Source Hardware Association. Table 5.2 gives a brief overview over the conducted interviews, their respective quoting indication (if directly quoted), some basic organizational information, as well as the particular source of data collection.

In the upcoming paragraphs, I will emphasize the founders' experiences in order to trace patterns of how their particular personal as well as community background affected the founding process and the corresponding transition of becoming an entrepreneur of 3D printers (Sect. 5.3.1). Afterwards, I focus on the perceived tensions and threats stemming from this background as well as the founders' strategies and practices to face and relieve them (Sect. 5.3.2). In Sect. 5.3.3, I will finally draw on more general patterns of how the entrepreneurs manage

Table 5.2 Sample overview

Quoting ID	Origin	Year est.	# of employees[a]	Data source
Core sample: 3D printing startups				
I-S1	US	2012	18	Face-to-face interview
I-S2	US	2011	90	Telephone interview
I-S3	US	2011	25	Face-to-face interview
I-S4	EU	2011	65	Telephone interview
I-S5	EU	2011	3	Face-to-face interview
I-S6	EU	2012	3	Face-to-face interview
Additional sample (directly cited)				
VC firm (I-VC)	US	2010	Not specified (n/s)	Telephone interview
Core community member (I-CM)	EU	–	–	Email interview
Additional sample (for validation of insights only, not directly cited)				
Hardware startup incubator (2 interviews)	US	2013	n/s	Face-to-face interview
Open source hardware assn. representative	US	2011	n/s	Face-to-face interview
Founder OSH drone startup	US	2012	n/s	Face-to-face interview
Founder OSH microcontroller company	US	2004	n/s	Face-to-face interview
Founder OSH thermocycler startup	US	2011	n/s	Face-to-face interview

[a]Numbers reflect the state at the time of my inquiry—since startup companies tend to vary a lot in terms of their employees, this information has to be interpreted with caution and just serves as a rough orientation for the particular company's size

inbound and outbound contributions in order to sustain interaction with both of their community and consumer peer groups.

5.3.1 Community Backgrounds and Entrepreneurial Transitions

Analyzing the initial points of contact that drove the designated founder's interest in 3D printing reveals that while European actors drew on RepRap's core ideas as well as the corresponding devices (almost all originated from the second official RepRap printer "Mendel", see Sect. 5.1), actors from the US were mainly affected by

Makerbot's momentum in connection with the emerging "Maker Movement." Indeed, all of the US-based interviewees developed their deeper interest in 3D printing technologies due to their dissatisfaction with early Makerbot products. While one prospective entrepreneur rather pragmatically mentioned that he bought Makerbot's first 3D printer, "[. . .] built it and it kind of sucked" because "it didn't work that well" (I-S3) another interviewee told that he was ideologically disappointed:

> Around February of 2010 or so, I actually ordered a Makerbot cupcake and then they send out a spam saying, oh it's little delayed, in the meantime you can learn CAD programs and they recommended SketchUp [a program provided by Google]. And I was so offended that an open source hardware company recommend a proprietary application. (I-S2, please note that all of the following interview quotes are verbatim and unedited)

While the first prospective founder acted on his discontent by initiating a meetup group of 16 people that aspired to build RepRaps, the latter cancelled his Makerbot order and ordered a 3D printer that "was a truly free software and open source project" (I-S2) instead. Therefore, although Makerbot's approach was different from RepRap's from the beginning, further engagements with 3D printing and related discussions about the implied technologies and possible options for improving Makerbot's deficient devices took place largely within the realms of RepRap's digital community and its respective means of interaction.

Complementary to these digital means of exchange, local interaction also proved crucial for the entrepreneurs' early adoption of 3D printing technologies. In this regard, community-based workshops, which operate under names and concepts like hackerspaces, FabLabs, or Techshops, offer the shared usage of machine-tools, facilitate face-to-face collaboration and thus generally embrace the norms and values of openness and accessibility (Dickel et al. 2014). In the context of open hardware, such shared machine shops represent a crucial support for innovation communities as they provide the infrastructure to produce the tangible 3D printing machines that incorporate the open source designs. For five of the six founders covered in my sample, on-site formats like construction meetups provided a setting in which they not only had their first hands-on experiences with RepRap devices, but also started to realize the market potentials of 3D printing.

While all of the interviewees first became familiar with community- and open source-based applications of 3D printing, their effort to identify and carry out entrepreneurial opportunities reveals obvious differences. One group slipped into becoming startup founders almost by chance; they hardly intended to gain economically from their hobbies:

> The whole idea of starting a business came up fairly late. We already saw that what we're doing was sort of a blend between doing things together like in a community and doing something sort of commercial. Because we were giving workshops for people who wanted to build their own 3d printers and of course everybody who wants to build one needs to have parts [. . .] so we also organized the buying of the components. [. . .] From those workshops, we already found out that there is a lot of interest in building 3D printers. And at the end of 2010 it was already clear that a lot of people online also wanted to order it. So we decided we should also create a web shop and also create a company. (I-S4)

Indeed, around the year 2010, the topic of 3D became vastly more popular. In connection with the proliferation of interest, the related community diversified in a way that less technology-savvy people also joined in (see also Sect. 5.1.2). Since these people were more interested in using than building an actual 3D printer, the demand for working devices sold for reasonable prices exceeded the actual supply. Thus, people who had the capabilities and skills to create 3D printers were almost pushed towards selling them to these new community entrants und thus becoming commercial in a certain way. The following quote captures the spirit at that time quite sharply:

> Once I had like a functional 3D printer, people started offering money for it, we just automatically started working together as a company. And it wasn't until quite a long way down the line that we thought that we probably need to formally agree something. (I-S1)

In contrast to the group of accidental entrepreneurs, others were very clear on their commercial ambition from the beginning of their engagement in 3D printing and thus tackled the emerging entrepreneurial opportunities more actively. In terms of community interaction, these actors mostly remained on the periphery instead of engaging in in-depth discussions on RepRap's core technological issues. As I will point out later, this does not necessarily mean that they take the open source approach less seriously. However, as one of the interviewees mentioned, the rather passive stance towards interaction with the RepRap community also resulted from the reluctance of incumbent community members to entertain the commercial ambitions of new entrants:

> The weird thing with the IRC [the RepRap channel on freenode's *internet relay chat* was and still is a popular community channel for discussion] was that these guys were mean. I mean honestly, they were mean. I was like 'Hey everybody, I wanted to start a company doing 3D printing' and they were like 'Go out of here, go built something an then come back. We're not here to help you start a business.' They were really like they were the elite of the world that are making 3D printers in their garages. And I was not welcome. [. . .] So I just read and read and read. (I-S3)

Indeed, an interviewed community member reported that the people who really believed in RepRap's philosophy of "wealth without money" (see Sect. 5.1.1 or Bowyer 2004) at this time always emphasized the non-commercial character of the project. Consequently, they generally regarded spin-offs like Makerbot and follow-up startups "somewhat skeptically" (I-CM).

Quite ironically, this skepticism against commercial exploitation actually leverages the community's need for business entrepreneurs. On the one hand, community interaction is predominantly about technological details and the improvement of particular components; in this regard, the RepRap community is very agile in creating ideas, exploring new possibilities and thus enabling the technological diversification of the project. On the other hand, all of the startups represented in my sample saw their main contribution and value proposition in consolidating the loose ends into neat, reliable, and properly documented devices:

> In the RepRap community, there are a lot of good ideas but sometimes the ideas are not always packaged very well or promoted in a good way or finalized for example up to the

> point that you have a good manual which will help people other than yourself [. . .]. And so, I guess there is always a lot of room for a company to have an added benefit above all of the good things that are also be there in the RepRap community. (I-S4)

Put in the words of another founder, while community members often had "spots of genius" in certain aspects like firmware, simplified design, or improving a particular component, "nobody was putting the whole package together" (I-S3). Hence, while the community consisted of intrinsically-motivated members mainly interested in tweaking and sharing new approaches to RepRap related technologies and applications, entrepreneurial efforts complementarily focused on improving reliability and uniformity in order to scale the overall production process. This detailed work of compiling and manufacturing an actual product is hardly manageable by the means of community interaction as it entails a complex endeavor, which requires on-site tinkering and immediate individual or team effort:

> Open source hardware is really nice for sharing the first ideas because ideas are a very compact amount of information. But to really refine a technology it doesn't make so much sense. Our work with the 3D printers is very much refining on details. [. . .] then it's getting on a very individual and experienced-based level that is very difficult to share at the first place. (I-S5)

To sum up, all of the entrepreneurs in my sample share the community background to a certain degree when it comes to their background and early careers as founders. While some of them really engaged in the core of RepRap development, others participated in the community rather peripherally in order to learn more about the technologies and their applications. However, all of them gained their competencies in developing 3D printers in close relationship with the knowledge shared in the RepRap community. Since their engagement in this topic started at a time in which the RepRap approach proliferated into broader peer groups of early 3D printing adopters, their skills at building met the equally voracious demand of those who wanted to own a 3D printer but were not so inclined to build one from scratch. While some founders from the sample actively leveraged this entrepreneurial opportunity, other took advantage of these opportunities almost accidently. However, composing, manufacturing, and finally selling reliable 3D printers was a common reaction, one that subsequently led into the commercial exploitation of community knowledge. The next sub-chapter explores how the founders perceive the tensions that accompany their transition.

5.3.2 Starting the Venture, Approaching the Tensions

In Sect. 5.2, I drew on the critical case of Makerbot to derive conflicting understandings of legitimate entrepreneurial practices, which link to either community- or business-based logics of engaging with desktop 3D printing. Since the case of Makerbot represented a popular and controversial instance of an open source hardware company becoming a proprietary business, it created waves of anger within its former community-based peer group. The startup cases that constitute the sample for this empirical investigation are from a second generation of RepRap spin-offs. As all of them were founded between 2011 and 2012, they took Makerbot's entrepreneurial rise, which at this time provided the proof for the viability of OSH-related business models, as a guiding example for creating their new ventures. However, as the following quote exemplifies, Makerbot's switch in business strategy also changed the ways in which the following startups perceived the company:

> In the first years of Makerbot it really was an inspiration for us. It helped serve us as an example to really starting a sustainable business [. . .] We saw that it was possible. And then at some point, when Makerbot got investments and started to change towards more closed, towards more trying to get exclusivity of things, that is really when it stopped being an inspiration for us. (I-S4)

Indeed, none of the interviewed founders adapted Makerbot's approach of making a clear cut between its open source origins and its future in commercial business. However, they surely faced similar downsides when trying to harmonize community and business realms. Regarding the institutional tensions that I analyzed from the community's reception of the Makerbot controversy, there are several sensitive points from the founders' perspectives, chief among them the denotative codes of contradictive design principles, barely enforceable licenses, associated impacts on fundability, and divergent means of approaching community and customer peer groups. In the following sections, I will take on each point to describe the founders' individual perspectives on such tensions and thus delineate the range of reactions with which they tried to relieve them.

5.3.2.1 Approaching the Design Dilemma

Although the community members favor hackability as a design principle that allows them tinkering with the 3D printer itself, hackability is not the principle preferred by the founders for two reasons. First, they recognized that the broader clientele of potential customers, which is more interested in printing things than building devices, indeed prefers usability to hackability. Since the market for 3D printers steadily grew, the demand for 3D printers clearly exceeds community needs. Consequently, the requested product criteria also changed, exemplified here as follows:

> We have a number of customers for whom open source is very important but also all of our customers care more about functionality than that. They are like within my price range, functionality is critical and then probably open sourceness is second or third or even fourth priority. (I-S1)

Secondly, although it is relatively easy to build small batches of hackable 3D printers out of printed parts, plywood frames, or similar off-the-shelf components, it is all the more difficult to scale this approach to production in order to increase batch sizes and simplify manufacturing. Hence, 3D printers made from cast or folded metal not only provide better print quality due to their stable and stiff frames, but also facilitate and enhance the general production process. For instance, one of the founders describes his decision to create his latest printer in metal instead of plywood as follows:

> The reason because [or latest design] is in metal is because it was a better printer and it was simpler and scaled better and cost less to make a high quality product. It wasn't really about the open source here. (I-S3)

From an open source hardware perspective, even if the startups reveal the blueprints for their 3D printers made from metal, the required sophistication in tooling and manufacturing essentially turns them into kind-of dead-end derivatives that hardly serve as starting points for community-based improvements and further tinkering.

The entrepreneurs from my sample applied two distinct approaches in order to harmonize the contradictions resulting from the opposing demands for hackable 3D printers made from DIY-friendly components and for shiny and functional devices made from metal. The first group took a middle course of incremental sophistication. This path was tightly linked to the state-of-the-art developments within the RepRap community and therefore fully applied its ideals and design principles. Since even the latest RepRap printers diverged considerably from the initial aims of self-reproduction, the gap between the community and founder's preferred design principles was not actually that big. While these models still do not look like shiny boxes, they nevertheless incorporate the potential to attract a broader range of users looking for neat print quality and reliability. Due to their common approach to product design, the physical representations of these startups' signature printers show obvious similarities (Fig. 5.9).

The second group of startups just expanded their product portfolio by offering two options for their 3D printers: one hacker-friendly device, which is sold as a kit, and another more consumer-friendly, assembled model, which works out of the box. Like in the case of Makerbot, the companies started out with product launches containing a clear DIY appeal, while later printers were of a rather sophisticated design. Against the background that the startups cases of this second group resemble each other not only in terms of their product diversification strategies but also in terms of their implemented design principles, the 3D printers provided by the particular companies reveal obvious similarities, too (Fig. 5.10).

Other than Makerbot, who over time tapered off their support for their early DIY printers, the founders that stick to the two-fold product portfolio within my sample kept selling and supporting DIY printers. Even though their new devices capture higher profit margins and attract a wider audience, they do so in order to serve and maintain the community base within their clientele. Exemplarily, one founder states that "we still sell [the DIY friendly printer] and we really care about this ideal that we can provide kits instead of just completely finished products. [...] The customers [for these] are also more inclined to make hacks and make modifications" (I-S4).

Fig. 5.9 3D printers that apply RepRap's design paradigms

5.3.2.2 Approaching the IP and Funding Dilemma

The previously discussed matter of product design indirectly affects the broader issue of intellectual property and related open source principles of openness and accessibility of blueprints, too. Even if entrepreneurs reveal the entire blueprints for their printers, their technological properties are so advanced that it has become highly unlikely for individual members from the RepRap community or other DIY enthusiasts to modify or even rebuild them. The fact that the state-of-art-printers contain hardly any off-the-shelf components or 3D printed parts further enforces this tendency. Therefore, the essential open source principles that enabled the exploration and rise of desktop 3D printing diverge noticeably from a true practical approach to development, moving instead into a symbolic adoption of community values. However, since these are still constitutive for the community's shared identity and internal cohesion, the topic of IP remains tricky.

For the entrepreneurs and startups covered in this sample, handling their IP in a way that complies with community ideals but does not harm their business becomes

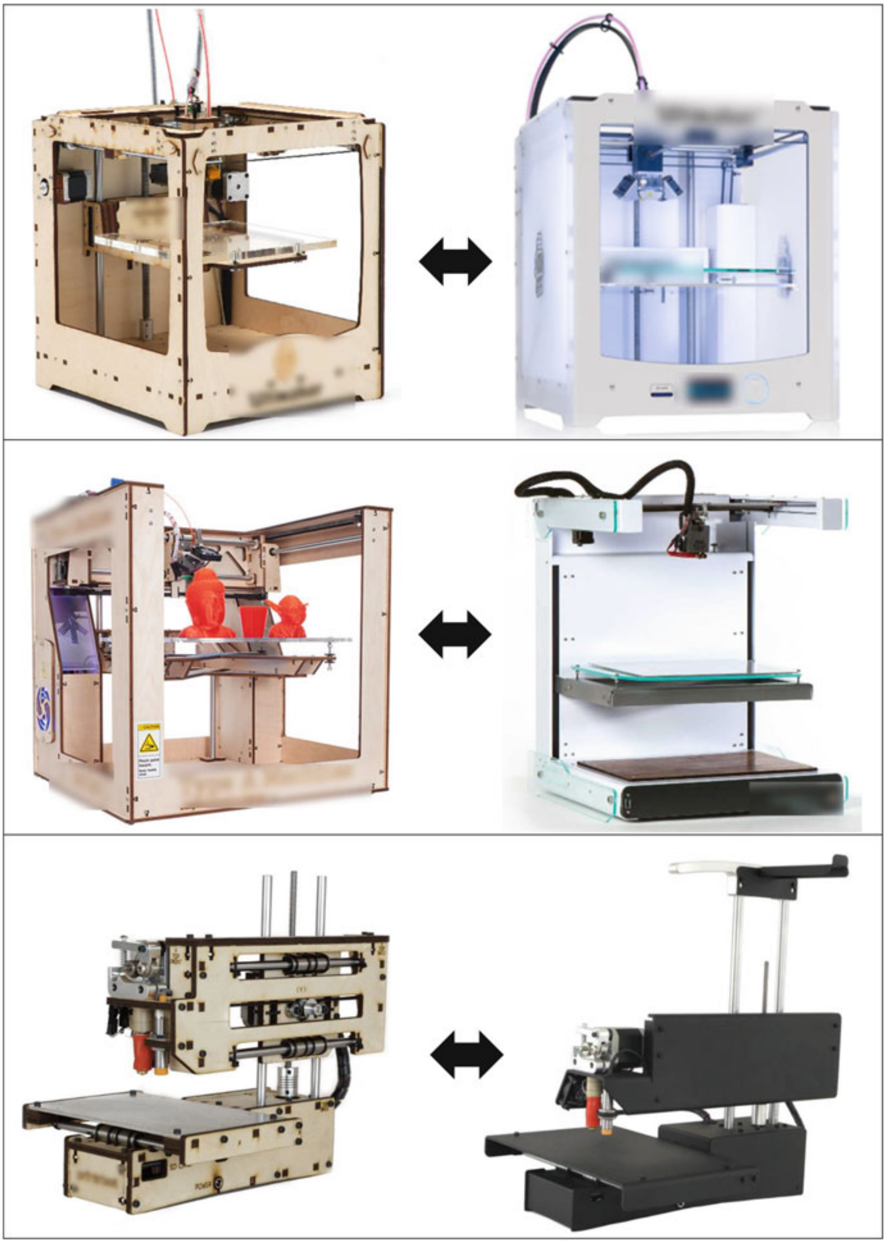


Fig. 5.10 Examples of split product portfolios

a critical challenge. While none of the interviewees mind if individuals rebuild their printers, most founders moan that their openness predominantly helps professional vendors to copy their products for commercial reasons:

> In most cases I really don't mind and I encourage people to make their own [version of our printer], but if it's really a company that is just out there to create a product that undercuts our prices and there is nothing else, to some extent it's harming our company. (I-S4)

The most obvious threat to competiveness remains that an open source company that freely reveals its blueprints enables potential competitors to catch up with their technology without investing in research and development on their owns. In this regard, the founders from my sample accord with the finding that the legal impacts of open source licenses widely fail to cure this general vulnerability of the open source business model. Applying these licenses to hardware therefore resembles more like a "social contract, a gentleman's agreement" (I-S3) and thus make it easy for cloners to ignore them altogether. Further potential threats arise when cheap and low-quality clones enter the market e.g. via e-commerce platforms like EBay and then hurt the brand and reputation of the company that built the original version of the higher-quality printer. According to the interviewees, this happens a lot and really annoys them. Consequently, some of them are reluctant to give away the IP on the printers they developed in its entirety:

> The process of designing a complete printer from front to back is like—I mean, I'm just grasping—but it would not surprise me if I've got a quarter of million dollars in one of my printers. Overall time investment, materials, failures, like bad parts you ordered. [. . .] So, I was reluctant to give that away. Why should I give that away? I did that work. So there is this inside me, like I don't know if I want to open source this, like truly open source. (IS-3)

Since each of the currently available licenses applies exclusively to intangible files, like e.g. the digitally published blueprints of a particular printer, the only legal possibility for entrepreneurs to protect startups against cloning lies in patents. However, as shown before patents are to an open source community like a red rag to a bull. Still, even if entrepreneurs decide to avoid filing patents, they need to consider that the patent right follows a first-to-file approach, meaning that a person who applies to file a patent does not necessarily have to be the inventor of the particular device. So, even if developers of a novel 3D printer publish related files to make it public or common domain, there is in principle the possibility that another person could file a patent on the physical device or one of its unique components. Moreover, since the market for consumer 3D printers is becoming increasingly competitive, open hardware startups also face the latent risk of being sued for infringing other company's patents:

> The reality is that patents will be used against you. It doesn't matter whether you are open source or not. Patents will be used against you. If we want to be a long term successful company, at some point we are going to be sued in a patent lawsuit. It's going to happen. Therefore, you have to play the game. It's like an arms race—no it is an arms race. And just because you don't believe in it, doesn't mean you won't be the receiving end of it. (I-S1)

Stressing another, closely related facet of the IP dilemma sheds light on the matter of startup funding. Generally compared to internet startups that rest in digital markets, hardware startups require relatively high investments for inventory, prototyping, and manufacturing costs. Founders of open hardware startups that seek to acquire venture capital to cover their expenses and scale the business are thus likely to face issues with the VCs if they fully waive their IP. As one venture capitalist told me during an interview, "patents and IP are certainly the most important factor" (I-VC) when it comes to investments. Accordingly, one of the interviewed founders described his experiences with negotiations over venture capital as follows:

> In the conversation with the VC, if you start with like 'we think open source is great because...' they are not gonna continue the meeting and say 'get out, you're not gonna make money' [. . .] VCs have this really narrow view because the critical thing for them is that they want to minimize risk. [. . .] They are not like you have to be closed source, they are like open source doesn't make money, you have to have patents. (I-S1)

It turns out that a startups decision to stay open source potentially enables competitors to harm their businesses, possibly hurts the brand due to low quality clones, makes the startup vulnerable to patent lawsuits, and thus decreases their fundability for venture capitalists. Although these are all serious issues, the interviews reveal some approaches, which entrepreneurs take to solve them.

Within the scope of my sample, one startup had already filed patents. However, this company tried to approach patenting in a way, which still enables individuals to utilize protected contents but restricts commercial vendors from using them without permission. Indeed, these intended practices are supported by patent right, which leaves it up to the patent holder if he or she enforces his or her right to sue people for infringement. Thus, while the patent holder may allow people from the open source community to utilize the protected contents for private use, he or she can ask others, who intend to use this knowledge for commercial reasons, for licensing fees or even prohibit them to use the particular components or technologies: "So, if closed source companies want to take the work done by an open source company and use it, then they should pay for it." (IS-1).

Because holding patents clearly contradicts the open source approach of denying any restrictions on the utilization of commons-based knowledge, this particular company switched to wording of what they do from "open" to "accessible source":

> We talk on our website about "accessible source" and its simultaneously about trying to separate ourselves from the ideological conversation of what is open source and why should it be open source and how is open source gonna safe the world, where it really rapidly breaks into. And it gets it back to the things that we think matter about it, the fact that it is accessible. Doesn't have to be published under a specific license. Doesn't have to be done with non-commercial restrictions. We think the thing that matters is to give users who buy our machine the information they want. (IS-1)

From the entrepreneur's point of view, this conceptual tweak renders a reasonable compromise that merges general opportunities that enable customers to hack their printers with the legal opportunity to restrict any misuse on the company's IP. However, from the broader community perspective, this same company clearly works against the foundations of open source principles, as it transforms knowledge from the commons-based into the proprietary domain.

A second way to limit the business threats that accompany the open source approach is an alternative application of certain file formats that restrict the technical possibilities for their usage. In one particular case, the founder reveals only the so-called "STEP files" (STandard for the Exchange of Product model data) for his designs under the GPL. Since these files contain a true and accurate 3D model of the printer, people can use these data to iterate on the design, print it out, and, as long as they admit the GPL, do whatever they want with the resulting artifacts. However, STEP files do not contain the required information to manufacture the related devices with the help of professional tooling in order to rebuild the printers in a competitive quality:

> I reveal the design in a format that don't allow you to go and manufacture it. You can't get the files to machine shop and say, fold and powder coat this metal. So anyway, it discourages China from knocking me off. (IS-3)

Although this approach copes with the IP dilemma without filing patents, it also restricts the depth and extent of open source knowledge to a considerable degree. While the founder of this startup admits that he is just "too lazy" to patent, a third option for mitigating the vulnerabilities of being open source starts with a more reflective motivation to bypass patenting. In the context of this particular strategy, which is followed by another startup from the sample, blueprints are revealed under the creative commons non-commercial license. This license is supposed to restrict people from using the covered contents for commercial purposes, but otherwise is subject to the already described shortcomings of licensing strategies in the hardware realm. Moreover, this company postpones the publication of blueprints until after the product launch. Being aware that this strategy may cause some irritation within the open source community, the startup communicated their plan in a transparent way and thus proactively prepared for possible criticisms. Given that a company sticks to its promise to reveal designs files after a short period of exclusive exploitation, this approach is likely to work out for the community as well:

> When we launched the [new printer] we said we would be releasing the files within half a year. We did it after 6 months. We give our self a target and we met the target. [. . .] So, we released all of that finding that we were a little bit surprised that people were okay with it. That we were holding our design files for a limited duration. (IS-4)

The other three founders interviewed in this sample just apply the GPL to their blueprints and therefore stay true to the principles of open source hardware. However, to shed specific light on these examples, one of them applied this practice due to a lack of viable alternatives: "there is no real good license for hardware" (IS-5). In the second case, the general business model of this particular startup is not about selling entire printers but some special components that the founder is able to "do really nice for a good price" (IS-6). In this case, the founder of the startup is a much-appreciated member of the original RepRap community who also developed some of the most renowned designs for RepRaps. Spreading the blueprints for his printers in unlimited ways ultimately increases the demand for components that his startup supplies. The founder of the third startup reveals its blueprints without any restrictions, too. Hence, it has to be mentioned that this company often faces product clones sold on websites like EBay. Although they do not have effective opportunities to prevent this, they at least try to needle the respective vendors into respecting the GPL and encourage them to provide the source code for the offered printers themselves.

To follow up with the related topic of funding, it turns out that the one startup, which holds patents to control its IP and increase its fundability, indeed acquired capital from an angel investor and at the time of the interview intended to go for further venture funding. None of the other entrepreneurs took external funds but applied so-called "bootstrapping strategies" instead. To bootstrap a startup generally means to found and build the venture through only personal funding and the operating revenues of the new company (investopedia 2003). The latter point, operating revenues, makes bootstrapping particularly applicable to hardware startups, as they are able to sell their actual products from almost the beginning of their venturing process. Exemplarily, one founder described this path as follows:

> We basically took some of our own money to buy parts with and we were selling parts or we were selling kits and we did charge I guess a bit of a premium so we would be able to buy more parts after that. So, we could buy bigger batches every time without loaning any money. (I-S4)

Recent trends of crowdfunding amplify the effects of bootstrapping as they enable entrepreneurs to collect private funds from individual backers, who pay money for the future purchase of the product pitched in the particular campaign. By collecting these funds, startup founders can move more securely through the production process and thus get an idea of the market demand for their planned products. Within the sample, one founder took this option and succeeded with his campaign, which exceeded the initial funding goal multiple times. Backed by the crowdfunding, the entrepreneur was not only able to produce a first batch of printers but also launch his startup venture: "I didn't do the Kickstarter to get rich. I was early enough and I really wanted to Kickstart the company, and that's what I did. So I took every dime and put it to business." (IS-3)

Compared to the potential of scaling a business by taking high-venture funds, both bootstrapping and crowdfunding approaches obviously perform poorly. However, poor performance usually poses less of a problem for founders of open source hardware. For them, modest growth, long-term viability, and independence from external decision makers seem to outweigh the eventual benefits of a steep growth curve: "One of the reasons that helped with not making any compromises is that I haven't had some 'angel' try to push me into patenting things or whatever. So we had a lot of autonomy from that" (I-S2).

5.3.2.3 Approaching the Community/Customer Dilemma

From a startup's point of view, at least two types of communities constitute relevant peer groups. The one refers to the innovation community that gathers around RepRap, the other resembles the group of customers, who share the common denominator of owning a 3D printer from the particular company. While I have already elaborated on the former, members of the latter primarily engage with each other in order to share their product experiences.

Besides that interaction with these communities requires corporate resources anyways, each of the communities needs to be reached through distinct means (e.g. channels offered by RepRap vs. the company's own "community area") to serve different ends (discuss technology vs. sustain customer satisfaction and brand loyalty). Hence, the startups usually need to find the right balance between their efforts to reach each community. Although the ideological ties to the original RepRap community are strong for most interviewees, their entrepreneurial mind necessarily has to evaluate the pros and cons of interaction with the respective communities.

In terms of interacting with the RepRap community, the potential gain for the startups lies in the technological expertise of its members. Although the increased entrepreneurial dynamics had a rather disruptive effect on the community, it still gathers 3D printing enthusiasts that are pushing technological developments:

> The kind of people who are in the "RepRap" community they are really important. Those are really the innovators. [. . .] They are all doing this from their own passion, which create really great different dynamics if you do it out of passion. (I-S4)

Thus, to become able to leverage these innovative potentials requires startups to possess a credible position within the community. Consequently, the previously quoted founder subsequently added that it "becomes a lot easier if you really know deep inside what it is like to be a member of the RepRap community, it makes you understand those who are" (I-S4). Indeed, the general support of open source principles aside, startups that intend to capture the innovative capacities of the RepRap community really need to engage profoundly in community-approved means of interaction. While this is a minor problem for well-renowned startups, fostering productive exchange with the community may become a struggle for those that are either less popular or simply on the periphery of the community. According to another founder, this is mainly because "there is so much talking going on and also in the open source sphere you have to do your marketing to get noticed" (I-S5).

Regarding this concern, founders often begin to evaluate whether it is worthwhile to invest the efforts it takes to increase the startups' involvement with the community. In the context of the present sample, two entrepreneurs clearly state that they care more about the community of their own customers. Indeed, direct customer support offers similar benefits as intense interactions with the broader RepRap community. Since people who buy 3D printers are often lead users that have a deep sense for technology, they are also "pretty vocal about what they want. And usually these are pretty reasonable and pretty intelligent requests" (I-S1). For entrepreneurs, this type of direct product feedback may help them to identify immediate ways to improve both their devices and their feeling for customer demands. In contrast, the rather diffuse exchange of knowledge, which prevails in the context of RepRap, promises less valuable feedback:

> We've not made a big push trying to support RepRap just because other than saying that we think RepRap is great and we just don't have the time. And we wanna be pretty clear in the fact that we are not focused on the goals of RepRap. [. . .] We're interest in building 3D printers that we can sell a lot of. (IS-1)

Still, there is a twist that makes it increasingly difficult to separate the types of communities I have laid out clearly from each other: most of the early adopters that consider purchasing a certain 3D printer are in fact associated with RepRap or Maker communities as well. While they are not necessarily inclined toward hacking or modifying their printers practically, they still value the related principles of open source approaches and thus have become increasingly aware of a particular company's stance towards these topics:

> The vast majority of people who buy 3D printers right now are people who care a lot more about a product. So they are doing a research and a lot of them are buying American or at least not Chinese and they are people who see a lot of value in the open source world because they see it as being more customer focused. They are like open source stuff, it's nicer people running these businesses. (I-S1)

Consequently, since there may be considerable overlaps between relevant peer groups, entrepreneurial engagement in order to increase a startup's credibility within the original RepRap community can become worthwhile for both reasons of potential technological advancements and strengthened marketing assets. Thus, the challenge remains how to harmonize both community realms in a reasonable manner. The next section tackles the particular ways in which entrepreneurs face this challenge, elaborating more fully on their practices that manage reciprocity in terms of inbound gains and outbound contributions.

5.3.3 Balancing Community and Business Needs

Thus far, it has become clear that the startup founders not only have different backgrounds in the RepRap community, but also approach it in distinct ways to leverage and sustain their business: while some of them focus on community members in both terms of sales and external innovators, others rather invest more heavily in customer-centric peer groups. However, since all of them first got in touch with 3D printing in the context of the RepRap project resp. its Makerbot derivate, their entrepreneurial transitions were all affected by the principles of open source hardware to a certain degree.

Depending on their former engagement in the community, the founders' attitudes towards open source still emphasize either ethical or economic reasons for applying related principles to their business model. In one case of the sample, the ideological heritage and political implications of open source shaped the entire enterprise, as it not only revealed the blueprints of their printers but also almost every aspect of the company's structure and operations: "Which software are we using? How do we set up workstations? What are people's job descriptions? How do you do job reviews, marketing strategies? We are kind of doing all those other things that people don't think of when you think of open source hardware and all that. But we're basically an open source enterprise" (I-S2).

Indeed, as this entrepreneur runs a very strict policy of open source that for instance only allows for the use of free software products, he necessarily also accepts frictions in everyday business practice that may stem from software incompatibilities with their suppliers. However, this almost dogmatic application of open source principles reflects an exception within the sample. At the other pole of the spectrum, founders who focus less on these ideological aspects emphasize the potential economic advantages of being open source:

> I'm not thinking that the political version is not still true but I think it's because the practical is correct. I think that's more important than people just stating that you should be open because openness is great. And my answer is no, it should be open because openness is more profitable. [. . .] I'm interested in open source because I genuinely believe it's a better way of doing business. (I-S1)

The other startups from the sample range between those poles. For them, their background in open source merged with their increasing entrepreneurial ambitions and thus resulted in hybrid models that are as open as possible without hurting the business. Compared to the startup culture in the digital realm, which usually focuses on fast scaling, these open source hardware startups are more interest in slow but steady growth and middle courses that allow them to pursue a viable business strategy without incurring community backlashes:

> If you want to increase revenue then it is always good to non-improve your product but to scale marketing efforts and stop investing in open source. [. . .] But what we are really interested in is really a lasting company which will keep growing. So basically, people are seeing those investments [in open source] still happening all the time and even those investments are getting bigger and bigger. (I-S4)

Although working with different motivations, all of the entrepreneurs emphasize the worth of staying in touch with the open source community. In order to do so, they need to establish corporate practices to leverage inbound contributions, which they receive from the community, as well as channels for outbound contributions, which they share back.

As already mentioned, the inbound contributions that startups receive from RepRap's innovation community are mostly in the form of externally-developed ideas and inspiration for the further development of their 3D printers. Especially those companies, which interact extensively with the RepRap enthusiasts, can gain valuable and targeted inputs from community experts:

> So people inside our company for example focus on some specific parts or either the hotbeds the printer has or some other mechanical components. And somebody outside the company has a lot of knowledge about that and sort of sparring partner to somebody inside the company. And so they work together really. It is almost as if they are really colleagues but the other person is doing it because they enjoy doing it. (I-S4)

In this immediate type of collaboration, those community members, who directly contribute their expertise to the company, also receive personal rewards as they for instance get invites to join (trade) shows and subsequent dinners or novel parts and components that support their R&D efforts.

Drawing on less intensive exchange, other entrepreneurs simply adopt the developments from the RepRap community and apply them in their own devices.

This type of adaption of an open innovation approach turned out to be a common practice within the interviews. While one founder e.g. raved that he had not spend any money in developing the electronics as well as the firmware for his 3D printers, others picked particular components like printheads or extruders from RepRap derivatives and used them in their own devices as well.

However, since there are many different repositories, forums, and individual platforms, on which community members post and share recent developments, even the rather passive entrepreneurs need to dig deeply in the community to recognize its most significant innovations. While these practices are completely reasonable within the general context of open source, those entrepreneurs who benefit from open knowledge are also obliged to share eventual improvements or further developments back to the community, too. However, the extent to which these outbound contributions from the startups really enrich the community depends on the particular ways in which the entrepreneurs interact with the community and share their information. Indeed, although every entrepreneur from the sample intends to give back something, the exchange channels they draw on as well as the impacts of their contributions differ noticeably.

Sharing some kind of design files and blueprints is of course a contribution that they all have in common. However, while one half of the sample developed printers that indeed triggered further derivatives, the other half contributed blueprints that were not well received by the community. Consequently, finding the right channels to make a true impact turns out to be challenging for at least some of the entrepreneurs. Although the first site for exchange would be the original RepRap wiki, the founders largely considered it outdated and suboptimal in terms of efficiency and broader visibility. For instance, even one of the founders that maintained very strong ties to the RepRap core community criticized it in the following way:

> What I try to do is to fork the documentation to my site where I have it under control. Because, what RepRap really lacks is the marketing. Because we are the guys who like to develop stuff, not to write about it. [. . .] So I will try to fork it and see if I can do it better. If I do, I can show to the community that it should be done this way. I mean, unfortunately everything in this world is about marketing and getting out to people. And not many of the guys from open hardware community realize that. (I-S6)

Indeed, publishing the open source blueprints for the 3D printers in the context of the particular company's own website (sometimes in addition to the documentation on reprap.org) reflects a common pattern within the sample. While most founders established related "support" or "community" areas on their homepages to host the blueprints, build instructions and related discussion forums, the one particular startup that pursued the strict open source policy also applied a much more progressive approach to information exchange:

> The directory that we store things in is the public directory. So, if you're watching our archives, you will probably see developments happen before I'll even see them. And that's including unreleased products. And all these files are available online and people can see the machine develop. (I-S2)

A third possibility for sharing files refers to general repositories like for instance "github" or "youmagine." Here, anyone can open up folders to store anything related to open source developments. Since these platforms offer a low-threshold approach to up- and download any type of files, even some of the companies that primarily host their files on their own sides maintain open access folders on these repositories and occasionally link to them for sharing purposes. However, for some founders this is the exclusive mode of contribution. Yet, this approach runs the latent risk that the startup's contributions get lost into the wild of the internet without much recognition from their peer group.

Besides sharing the blueprints for the hardware, some companies also took their outbound contributions to communities further by sharing additional contents like soft- and firmware or supporting local hackerspace communities by providing 3D printers for free. Indeed, the development of open source software that improves the usability of 3D printers provides much additional value for large parts of the community. In one case, the startup even employed two coders that solely work on the improvement of 3D printing soft- and firmware. It is probably due to this considerable effort, that this startup's founder also claimed that "the general the attitude towards us is really positive and I feel we are trying to be very careful with making sure that we always invest enough into the community." (I-S4)

In terms of reciprocity between inbound and outbound contributions, those who invest a lot in the innovation community also receive the most valuable inputs back from its members. However, most startup-community-constellations lack such a self-sustaining exchange process that create mutual gains. Although the entrepreneurs also share their designs out of the feeling of owing the community something, they often realize that their efforts to share do not have considerable impacts. This is a) because community members are barely able to adopt the open source information due to the printers' increased technological complexity and b), because there are no immediate feedback loops in the sense that no community members adopt these designs or even contribute direct feedback back in order to improve or fix eventual bugs. However, since some community people may blame the founders if they stop sharing their files, entrepreneurs keep revealing their blueprints on open repositories or their corporate websites without caring much about their utilization.

Aggregated to a broader community level, these practices are obviously critical for the reproduction of collective innovation. Touching the ideal vision of the open source hardware approach, one of the founders described the following scenario:

> Open Hardware allows you to distribute the development costs onto a large number of people. I do a product, an open hardware project and I sell it. Another guy, to compete with me, is going to take the product and improve it somehow to have market advantage. Because he is no douchebag, he publishes the schemes back. I can take it back and also add something. So, I have again market advantage over him. (I-S6)

Although this is actually no truly collaborative process at all, it thus points towards a context, in which the idea of open source may indeed develop economic advantages over proprietary means of market competition. However, the bottleneck remains the personal effort that community members as well as community-based startup founders are willing to invest in documentation and exchange of ideas and information: at a certain point, it breaks really down to the perils of open source hardware.

While the RepRap community without doubt gathered an immense amount of potentially innovative knowledge on 3D printing and still continues to do so, it also obviously failed to maintain sustainable modes for collaboration among its (corporate as well as individual) members. As companies usually focus on improving their existing technologies, they seek inputs that apply to their particular devices. Since these can hardly be provided by the community, the interviews reveal certain roadblocks that hinder a fruitful conjunction between the open source approach and the founders' entrepreneurial ambitions. These roadblocks usually reflect economic reasoning, as some interviewees doubt that their invested resources in documentation and sharing will trigger rewarding effects on their business. Hence, one interviewee for instance mentioned that, "once I designed my own machine I just stopped contributing because the biggest problem with RepRap is that it becomes a massive time sink" (I-S1). Although other founders' community engagement faded over a longer period, the disruptive tendencies, which the community suffers due to the entrepreneurs gradually withdrawing their involvement, remain essentially the same. However, it is quite interesting that one founder drew on rather moral reasons to justify his of moral disappointment with the community:

> Why people share is because they trust in that other people who share too will somehow be decent to you. It's not sharing in the one to one offline situation where people at least have the opportunity to say thank you. It's just in the big anonymous internet and people just take it from you and you don't even know it. And so you have to trust that the people who take from you don't exploit you. I mean in a way they will exploit you anyways, which is okay, but not in a way that it hurts you. (I-S5)

Regarding the matter of reciprocity between inbound and outbound contributions against the broader context of community reproduction, it turns out that what sustains the community not necessarily promotes the viability of business models. Merging these realms is a challenge, which founders need to adapt in a proactive way, meaning that they really need to invest resources to leverage mutual value. If they succeed, the cross-fertilization between their business activities and overarching community is likely. However, if the entrepreneurs are either reluctant or indifferent in truly engaging with the community, neither inbound nor outbound contributions make a significant impact on either side.

Thus, it turns out that on the one hand self-reinforcing effects gather the smartest people from the community around the most prominent startups. In these cases, the overlap between the more general RepRap community and the customer community of a particular company are obvious and converge in fruitful discussions on potential innovations in connection with the particular company's printer. On the other hand, those startups that take less exceptional positions often have difficulties engaging in intense exchange with the RepRap community effectively. While these startups prefer to focus their efforts on building and sustaining their own brand communities, they still have the opportunity to access the RepRap community passively, e.g. by just keeping up to the latest technological trends and discussion. However, assuming that most startups take this road, related implications may recursively become conductive to an ongoing community drain.

Chapter 6
Field-Level Dynamics and the Gradual Disruption of the 3D Printing Community

Abstract This chapter discusses the insights of my empirical research in conceptual and theoretical terms. With regard to the institutional entanglements that shape the 3D printing field and the corresponding conditions for entrepreneurial action, I emphasize the interfaces between different layers of social order. Additionally, I reconsider the essential differences between the exemplary case of open source software and the empirically observed context of open source hardware. In this regard, the matter of materiality turns out to be a crucial variable in determining the means and ends for community-based innovation. Moreover, the physical transformation of commons-based knowledge into tangible open source hardware devices like 3D printers generates multiple opportunities for entrepreneurship and thus heats up the disruptive tendencies associated with the dilemma of entrepreneurship.

Analyzing the issue-based field of 3D printing reveals a broad range of institutional dynamics and change processes within and among its subpopulations. Historically, the field indeed started out as an almost ideal-typical example of an innovation community. A rather small group of enthusiasts from different parts of the world found each other through the internet and subsequently began to tinker with the new and exciting technology of 3D printing. Backed by the bold vision of creating a self-replicating machine, the corresponding ideological superstructure of "wealth without money" and the first tangible successes in the technological application, the small group developed considerable momentum that attracted a broader scope of likeminded people who joined the emerging community. What followed was a thriving exchange among its members, which was truly based on idea and knowledge sharing and indeed quickly created technological leaps and increasingly innovative outcomes.

In general terms of innovation, the successful community hub for exploration only reflects one side of the coin. On the other side, broader technological diffusion usually requires rather focused and proactive marketing activities, which address larger group of potential users. While such focused and purposeful efforts are hardly applicable by a community as a whole, single members can surely promote this first and foremost entrepreneurial mission. In the context of RepRap, Makerbot was not the very first but the most renowned startup that emerged from the community and became the face for desktop 3D printing, met by increased media coverage. Moreover, the instant success of Makerbot also reflected the first time

J.-P. Ferdinand, *Entrepreneurship in Innovation Communities*, Contributions to Management Science, DOI 10.1007/978-3-319-66842-0_6

that a private company appropriated the outcomes from collective innovation in OSH-related contexts. In other words, it was the first time that the business logic entered the emerging and still-community-based field. In this chapter, I reconsider my empirical findings on the institutional dynamics that affected the field up from this point and discuss them against the broader theoretical and conceptual background of CBI and the associated dilemma of entrepreneurship.

6.1 Field Transitions

The RepRap community started at a special time. When Adrian Bowyer launched the idea in 2004/2005, 3D printing was, besides its professional applications in the context of rapid prototyping, unheard of. As mentioned earlier, 8 years later, consumer 3D printing was at top of the "peak of inflated expectations" on Gartner's renowned hype cycle for emerging technologies (Gartner 2013). Indeed, there is no doubt that this hype about 3D printing has its original roots within the early exchange between RepRap enthusiasts who were really the first to adopt the technology other than for industrial purposes. Regarding the institutional dynamics that affected the field during this 8-year period, my analysis revealed that an increasing imperative for economic gain gradually entered the field by emerging entrepreneurial activities of (former) RepRap community members, who developed an increasing interest to exploit the technology commercially.

Applying the institutional logics perspective in the way proposed in Chap. 4 helps to sort the tangled clusters of actors according to their institutional backgrounds, as it leads to an analytical focus on dominant rationalities and shared understandings that inform the material practices and perceived criteria for legitimate action in the field. Since the people that initially gathered around the RepRap project had an institutional background in either science or open source software (which essentially also incorporated the scientific logic of common ownership, see Sect. 2.2.1), they did not call into question practices of open knowledge exchange and distributed decision-making. Hence, their increased interactions established community-based modes of coordination based on sustained generalized exchange and strong affective bonds backed by mutual trust.

Parallel to the growth of the community, the consumer market for 3D printers also thrived such that the demand for 3D printers was barely satisfied. Moreover, the financial market of venture capital firms also developed a rising interest in the field. As a result, startups like Makerbot Industries, which at this time explicitly promoted open source values and corresponding practices of IP refusal, became able to raise significant investments. By any of these measures, outcomes from the community were more than welcome within the emerging business realms for 3D printing and, as the findings from the interviews show, community members who had the skills to build 3D printers felt almost compelled to become founders of their own startups.

Hence, the increased impact of the market also implicated a couple of formal business criteria that needed to be taken into account by the founders—selling printers also required the startup founders to manage a broad range of obligations in contexts of legal accountability, customer-related warranties, fiscal dues and so on. While this had never been a concern for RepRap tinkerers, once they committed to the business logic, they also needed to serve the corresponding responsibilities. Besides, the entrepreneurial opportunities for earning money by creating a business out of a passion project also became a reasonable detour that first expanded and finally disrupted RepRap's primarily technical aim of creating self-replicating machines. In the following subchapters, I will discuss how the institutional differentiation affected the structure of the issue-based field (Sect. 6.1.1) as well as the personal dispositions of community members that became entrepreneurs for desktop 3D printers (Sect. 6.1.2).

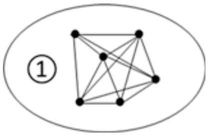
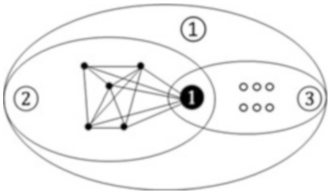
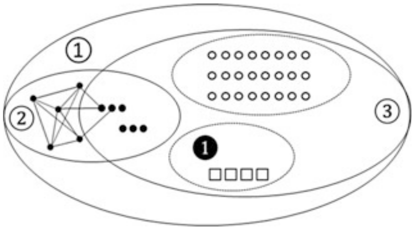
6.1.1 Macro <> Meso Nexus

In my theoretical discussion of meso-level order, I emphasized the matter of two-dimensional relationality, which on the one hand asserts the vertical nestedness of fields within other fields and on the other hand focuses on the horizontal relationships among them (Bourdieu and Wacquant 1992; Fligstein and McAdam 2012). The boundaries that delineate certain fields as analytical subjects thus refer to the extent to which they become observable entities in terms of internal cohesion and external differentiation. Both processes directly affect the constitution of meso-level orders. The field as well as its subpopulations become layers of diffraction for institutional logics, which thus merge into distinct collective rationalities (patterns of linking ideas, intends, and actions) and shared understandings of legitimate action (aggregated symbolic references and general evaluations of legitimacy) that guide and inform practices of actors involved in the particular configuration of meso-level order.

The transformation of the issue-based field that initially formed around desktop 3D printing offers a good example to elaborate the dynamics of ongoing conflict and change within the institutional assemblages at the meso-level of social orders. Against this background, Table 6.1 depicts the three phases of tinkering, proliferation, and diversification as derived from the analysis in Sect. 5.1.

In the first phase of *inception*, the group of people that subsequently became the RepRap community essentially invented the issue of desktop 3D printing by gathering around the idea of the self-replicating machine. As the documentation of this phase reveals, none of them had intents other than pushing the technological application of RepRap forward. Consequently, interaction among this group focused on the exchange of new technical tweaks and general discussions of prospective development options. At this time, RepRap was clearly framed as a research project that, although initially hosted by Bath University, subsequently expanded to a broader clientele of enthusiasts, who unquestioningly adopted the

Table 6.1 Field level transformation

Phase	Stylized model	Aggregating legend
1: “inception”		①: Issue-based field : RepRap community members
2: “proliferation”		②: Community subpopulation ③: Business subpopulation ❶: Makerbot Ind. ∘∘∘ ∘∘∘: Customer
3: “diversification”		••• •••: Sampled startups □□: Corporate vendors

practices of open and accessible knowledge transfer and Adrian Bowyer’s explicit references to the open source ideologies.

Due to the increasing momentum of 3D printing and the corresponding growth of the RepRap community, its members established structures that enabled and sustained their joint endeavor. In this regard, the inception of the community-managed RepRap Research Foundation (RRRF) as well as the launch of the joint homepage at reprap.org created a self-organized infrastructure that helped to coordinate the project’s further rise. Still, since the RFFF supplied community members with parts and components as a non-profit organization and the homepage provided the platform for documentation and knowledge exchange, these first attempts of professionalization promoted the principles of community-based innovation rather than infiltrating it with contradictive tendencies.

In the course of the ongoing *proliferation* of 3D printing, besides the general path towards growth, two main tendencies marked the second phase of the field’s transformation. First, with the growing number of community members, the scope of associated intents and ideas also expanded. For instance, new entrants to the community often prioritized improvements upon the print quality over the original concern of self-replication. Thus, instead of using the 3D printer in order to achieve “revolutionary ownership, by the proletariat, of the means of production” (Bowyer 2006b), the second generation of tech-savvy RepRappers were more excited to broaden the potential applications in order to spur a “manufacturing revolution” (Vance 2010). Second, a growing number of actors without backgrounds in the

RepRap community also developed an interest in engaging with the issue of desktop 3D printing. Since these were either potential customers seeking to purchase a 3D printer instead of building one on their own, or venture capitalists looking for potential investments, both groups of actors were guided by rationalities and understandings associated instead with capitalist reasoning and the corresponding business logic.

With respect to the field's internal structure, the entering of institutional logics that carried implications of the capitalist macro-order led to the emergence of commercial practices and evaluation schemes that obviously differed from the ones, which shaped the community. Consequently, the issue-based field began to differentiate internally into two distinct subpopulations, with each reproducing its own attitudes towards the issue of 3D printing and thus constituting rather coherent and like-minded actor groups. The one sticks to the original background of open source and the other includes actors who intend to appropriate the related developments in commercial ways or just want to make a good 3D printer purchase.

At the very intersection of both subpopulations, one of RepRap's core developers decided to spin-off Makerbot Industries as a startup that clearly based on RepRap and adapted some of the project's core technologies. Despite this common starting point, Makerbot's aim to offer cheap and easy-to-use 3D printers to "everyone in the world" as well as their corporate strategies for diffusion diverged significantly from the RepRap project—instead of providing a peer-to-peer community network that offers the means for technological evolution and self-replication of the machine, Makerbot intends to sell as many 3D printers as possible. Thus, while the company still appreciated open source practices and values, it also adopted business logics that created an increasing relationship of tension to the community's dominant rationalities and understandings.

While I depicted Makerbot in my model of the second phase of proliferation (see Table 6.1) as the only actor residing at the intersection of both subpopulations, this overlap grows considerably during the ongoing *diversification* phase of the field's transformation. As the field as a whole grew further, the subpopulations that already split off stressed their internal cohesion as they increasingly differentiated themselves from each other. Indeed, such contrasts culminated when Makerbot finally decided to switch sides. This key constituting event shook the field's whole structure and revealed the institutional arena that emerged around the issue of desktop 3D printing. Thus, the Makerbot controversy made clear the division in each subpopulation's dominant shared understandings about how to approach the field's issue appropriately (see Sect. 5.2). Additionally, actors within the particular populations reproduced quite divergent rationalities, as the community population still emphasized the ideas and intents of RepRap, and the business population focused on exploiting and leveraging the economic value of 3D printing. Consequently, while the one proceeded with rather value-rational actions of explorative tinkering and open knowledge exchange, the other traded its outcomes as commercial commodities.

In respect to the structure of the overarching issue-based field of desktop 3D printing, the subpopulations decoupled as each was shaped by quite different dynamics. While the market-based population grew in both terms of customers and competitors, the community's impact on the field gradually decreased. For instance, the initial framing of desktop 3D printing in terms of self-replication almost completely vanished. Even its constitutive principles of open source became increasingly blurred as actors from the business subpopulation cared neither about the associated ideologies nor the heritage of open source practices within the field. Despite these struggles over the field's dominant understandings of 3D printing, the number of actors that populated the intersection of the conflicting subpopulations increased, too. Indeed, due to growing market demands, many of the original community members started to carry out the resulting entrepreneurial opportunities and tried to spin-out 3D printing startups by themselves. This new constellation not only spurred competition between instead of collaboration among them, but supported the proliferation of the competitive business logic as well. Consequently, the impact of the business logic as well as the institutional imprints of capitalism decreased the community's relevance within the very field it created.

6.1.2 Meso <> Micro Nexus

As this book emphasizes the impacts of innovation communities on entrepreneurship, the following paragraphs revisit findings on the mutual effects between the subpopulations and the actors involved in my empirical field of investigation. Considering theoretical insights on reflexive agency, while in the beginning, RepRap members applied open source principles cohesively as taken-for-granted facts, the increasing relevance of the opposing business logic caused some friction in the loops that reproduced the community's constitutive rationalities and understandings. Consequently, its members developed higher degrees of awareness of the particular community values and the mutual bonds pf solidarity and reciprocity among them. The discussion on the non-profit status of the RRRF provides a good example for the increased consciousness on the community's building blocks. While some actors further supported the claim that components provided from the RRRF should not be used for commercial gain, others clearly argued against this restriction. Since the open source community was generally skeptical of formal regulations, it finally skipped the non-commercial claim of the RRRF and actually opened to the door for the private appropriation of RepRap-related technologies.

Because innovation communities only exist as long as its members reproduce practices of generalized, open exchange and evaluate legitimacy in terms of perceived reciprocity and trust, any entrepreneurial ambition is dangerous to the community's cohesive boundaries. While Makerbot's decision to drop the open source approach from their business model caused a true shock in this regard, the increasing number of commercial RepRap spin-offs asserts disruptive tendencies on the community in sneakier, more subtle ways, too, even if their founders at least try to contribute to the community's reproduction by being as open as possible.

However, my empirical analysis suggests that some startups do in fact manage to mediate the apparent contradictions within their institutional environment. Essentially, these startups succeeded because their founders were core developers in the RepRap project, early in the market, and thus took exposed positions at the intersection of the community and business realms that allowed them to both generate economic rewards and stay true to RepRap. Nonetheless, most of them faced struggles to relieve the tensions, between e.g. open source licenses and protected IP, or the opposing design principles of hackability and usability. Although these entrepreneurs still appreciate the value of open source and feel obliged to keep sharing their knowledge as well, they subsequently begin to consider the potential downsides of this approach from a business point of view.

Consequently, prospective founders of 3D printing startups need to find a business practice, which to some extent complies with market needs. For instance, the purchasing routines of non-community customers actually reflect dominant means-end-rationalities that let them seek the best value for their money when they buy a 3D printer. Once founded, startup companies can hardly ignore these criteria as the potential clientele that stems from their original community can barely generate enough commercial demand to sustain a viable business. Thus, the startups need to adapt their product offers to business criteria.

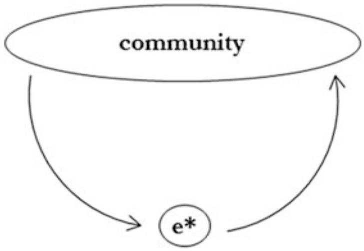
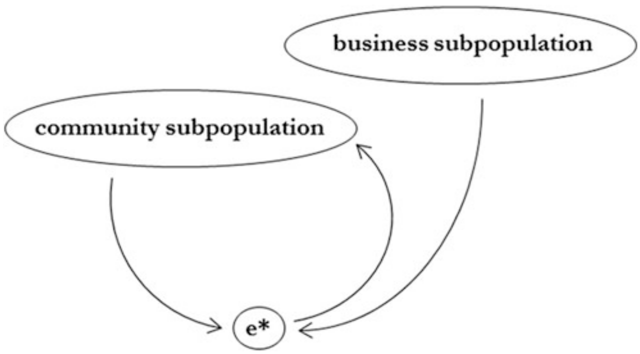
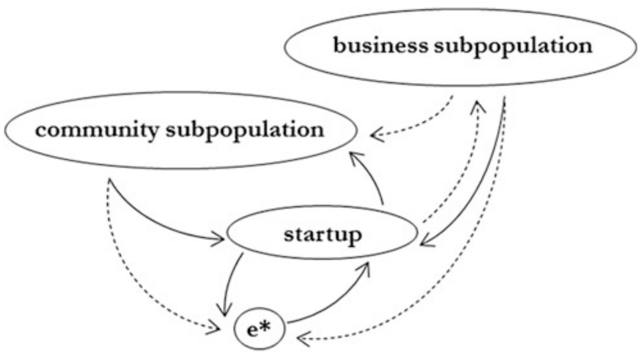
As my analysis suggests, the scope to which the startups comply with the business logic partly depends on their founders' personal position within community contexts. While actors that created startups from the core of the RepRap community (and thus directly noticed the negative effects that the Makerbot split had on the community) were very careful in balancing their business models between community and market demands, entrepreneurs from the periphery invested less in aligning them. Thus, the startups and their business models themselves became a variable for their founder's cultural embeddedness in the original RepRap community.

Although my empirical analysis reveals somewhat general patterns in the context of design principles and exchange practices implemented by some of the covered startups, the effects of cultural embeddedness do not result in isomorphic tendencies. Instead, the founders' responses to the dilemma of entrepreneurship rather depend on their individual reflexivity and the ways of how they personally perceive and react upon the tensions that arise in their institutional environment. In this regard, my findings add evidence for Sarason et al. (2006) structuration view of entrepreneurship, as they emphasize the recursive link between the founders' actions and decisions on the one hand, and the structure of the entrepreneurial venture on the other: "Entrepreneurial ventures are the medium and outcome of the entrepreneurs' actions" (ibid. 286). However, with respect to theoretical notion of nested meso-level orders, broader structures like subpopulations or fields need to be considered as well. While I assume that their institutional properties generally constitute relevant mediums and outcomes of entrepreneurial action, too, I believe that the actual extent of mutual structuration differs among certain meso-level orders and their particular degrees and facets of institutionalization.

In this regard, the recursive structuration of the issue-based field was of course affected by its structural change and the diversification of included institutional logics. Thus, the RepRap community apparently changed its constitution most obviously. Drawing again on the three phases of the field's transformation, Table 6.2 sketches the recursive loops of structuration that reproduced the particular constitution of meso-level order in the 3D printing field.

During the initial phase of inception, actors did not care about the market at all but rather devoted their minds to their joint endeavor of developing and improving RepRap printers in order to reach their common goal of technological

Table 6.2 Intra-field structuration dynamics, e*: (prospective) entrepreneur

Phase	Stylized structuration model
1: "inception"	
2: "proliferation"	
3: "diversification"	

self-replication. This true innovation community reproduced the symbolic constructions and material practices of open, generalized exchange and maintained relationships of high mutual trust. Doing so, they valorized the collective rationalities and shared understandings that recursively sustain the RepRap community as a distinct meso-level order.

This closed loop of internal cohesion got irritated during the *proliferation* phase of desktop 3D printing, when a growing number of stakeholders from the business realm engaged in the issue. As these customers subsequently generated a considerable demand for desktop 3D printers, they also affected the RepRap community members, who were in the potential position to satisfy these demands by starting companies to exploit RepRap-related developments commercially. Once founded, the startups constituted a novel layer of meso-level order, which indeed changed the institutional dynamics that began in the *diversification* phase of the field. As a growing number of community members became startup founders, they subsequently developed an immediate interest in creating the most viable business model for their new ventures.

In this regard, the dilemma for entrepreneurship indeed plays out at the very micro-level, where founders are in immediate charge for the actual viability of their startups. If they succeed with their entrepreneurial mission thus depends on their abilities as knowledgeable agents to smooth the tensions that shape their institutional environment. Consequently, entrepreneurs need to reflect upon their position at the intersection of potentially contradictive subpopulations in order to find a strategy that ideally complies with the contradictive criteria for legitimate entrepreneurial practice or at least hurts none of them directly.

As my interviews show, the founders of my sample were roundly capable of managing these challenging situations. However, against the background of their novel obligations and responsibilities as employers or legally-reliable entities, they perceived a certain pressure to comply with established business routines. As a social system mainly constituted by cultural coherence and value-based bonds that appraise reciprocity over profit, the community, however, was scarcely able to cope with the indirect effects of their former members' entrepreneurial activities. Although the founders of RepRap-related startups tried to incorporate open source principles within their business models and hardly intended to harm their community, the cumulative effects of this action apparently disrupted its practical and symbolic bottom-lines.

The impacts of the community-based startups on the market for desktop 3D printers are less obvious. Although customers for 3D printers as well as VCs interested in the corresponding startups appreciate certain aspects of open source principles, their instrumentally rational routines usually prevail tendencies of cultural convergence with the community. Hence, my analysis suggests that innovation communities usually reflect meso-level orders that lack institutional settlement. Furthermore, the value-based rationalities and cultural sources for legitimacy that sustain their constitutive modes of generalized exchange and high degrees of mutual trust even seem more vulnerable to divergent actions as, for instance, more regulated entities like markets or firms. Consequently, the entrepreneurial dilemma not only represents a challenge that potential founders face, but also a serious threat to the reproduction of the very communities, which initially leveraged the opportunities for entrepreneurship.

6.2 The Entrepreneurial Dilemma Revisited

The previous analysis revealed that the dilemma of entrepreneurship at first glance affects the individual opportunities for founders to cope with contradictive understandings of how to carry out 3D printing startups in legitimate ways. However, as knowledgeable founders that are aware of potential tensions in their institutional environment, they are, in principle, able to identify strategies and practices that comply with both of their community- and business-based peer groups. Yet, any entrepreneurial action dilutes the innovation community's constitutive practices and symbolic constructions, which base on strong ideological values of openness, mutual trust, and shared beliefs of collective identity. Therefore, looking more closely, the entrepreneurial dilemma and the founder's options for solving tend to harm the community, which loses some of its members and subsequently fails to reproduce the constitutive value-based rationalities and understandings, which sustain its internal cohesion.

In the general terms of new institutionalism, the bonds that maintain social systems are considered primarily a matter of cultural cognitive structures, which exert their influence on individuals via "a web of values, norms, rules, beliefs, and taken-for-granted assumptions, that are at least partially of their own making" (Barley and Tolbert 1997, 93). Institutionalized in distinct fields (or other representations of constructed meso-level order), these cultural elements reflect shared conceptions that constitute the "frames through which meaning is made" (Scott 2001, 57). Applied to the structure of the issue-based field of desktop 3D printing, the relevant subpopulations that form the poles of my research case reproduce quite opposing cultures: the one associates with the capitalist business logic, which prefers market- and firm-based governance types and the other with a community logic promoting modes of coordination that resemble the communitarian organization of science. While the community-based subpopulation depends on practices that deal with related knowledge and corresponding developments as common goods, the business realm usually trades these as commodities.

In an ideal-typical juxtaposition, community members on the one hand reproduce *substantive* collective rationalities that promote *values* of openness and accessibility of knowledge. Actors like non-community customers of 3D printers or venture capitalists interested in 3D printing startups on the other hand apply *formal* collective rationalities that inform *means-end rational* action and draw instead on price mechanisms and value for money evaluations to guide their decisions. However, while community reproduction heavily depends on external differentiation in order to sustain internal cultural cohesion, the business subpopulation is widely unaffected by any of the community facets. Still, within this hypothetic sketch of the 3D printing field, both subpopulations would still rest in a balanced state of institutional resilience, as the community domain sharpens its cultural boundaries via demarcation from the business domain, which itself is rather resistant to external forces.

Yet, startups like the ones observed in my sample tip the scales between community- and market-based subpopulations because they infuse economic thinking into the innovation community. Indeed, the adoption of business practices by community members represents acts of private appropriation, which oppose practices of collective, generalized exchange that actually constitute innovation communities as distinct social systems. As the transformation of the 3D printing field suggests, its community subpopulation was scarcely able to cope with incidents like the Makerbot controversy or the growing number of emerging startups and thus struggled to reproduce its internal cohesion in a stable way. In respect to the dynamics within the broader field, the RepRap community lost relevance because even its non-entrepreneurial members became less engaged, in addition to their increasing unwillingness to support the commercial ambitions of others by providing their knowledge for free.

Hence, the institutional constitution of innovation communities along its signature practices of sharing and open knowledge exchange imply strong preferences for the *explorative side of innovation*. Because ideation, incremental technological improvements, and the proliferation of relevant skills all benefit from openness and low-threshold accessibility, innovation communities create a fruitful environment for the creation, development, and iterative prototyping of new ideas. The massive and diverse output of 3D printer designs clearly proves this for the case of the RepRap community. However, the community-constitutive practices of generalized exchange widely fail to approach the *exploitation and diffusion side of innovation*, which necessarily requires production scaling, commercial trading, and a certain business accountability. The sets of material practices and symbolic constructions that delineate the community's institutional background for legitimate ways of "doing innovation" are thus incomplete as they lack the rules and resources which might offer mutually-acknowledged means for commercial exploitation and the further diffusion of their collective outcomes.

Knowledgeable community members who want to become entrepreneurs in the field of 3D printing usually react on this shortcoming by developing and merging practices that ideally comply to both community and business realms. As my analysis shows, these hybrid strategies may include diversifications of the ventures' product portfolio, punctual restrictions in open source licenses to avoid cloning, or creative branding strategies that promote "accessible-" instead of "open source" in order to attract potential investors. The meso-level order of the community thus struggles with such overlaps and blending, because these interrupt the community's cohesive reproduction and weaken its external differentiation, even if the founders of those startups do not mean anything bad to their (former) peer group.

Still, the corresponding tendency of community disruption results from an interplay of external institutional pressures, which stem from the business logic that progressively entered the field, as well as an internal break-up caused by community members who started to approach the issue of 3D printing from an entrepreneurial stance. This latter point adds another facet to the general notion of contrast and conflict, which shapes my general understanding of institutions and fields. Although I still believe that the concept of subpopulations helps to inform the analytical investigation of issue-based fields by clustering rather homogenous groups into coherent meso-level entities, as such they are principally subject to conflict and struggles over power as well.

Indeed, the community only exists as long as its members practically implement and symbolically appreciate values of openness and accessibility of knowledge in an exclusive and orthodox way. Only a strict adoption of open source principles leverages the strength of internal cohesion, which is required to appeal an otherwise loosely coupled group of actors, and empowers them to develop notions of a collective identity. Finally, such principles motivate them to contribute to the constitutive patterns of generalized exchange constantly. However, since the corresponding set of legitimate practices fails to offer viable means for entrepreneurial action, any related efforts promotes the proliferation of the business logic and thus reveals the structural vulnerability of innovation communities.

6.3 Materiality and the Tragedy of Open Hardware

Although I consider the disruptive effects of business logics on innovation communities a general pattern likely to occur in any context of CBI, I also believe that the particular case of desktop 3D printing reveals some specific properties that require more elaboration.

One conceptual bottom-line of this book's arguments draws on several cases of open source software, as these shed light on the principal foundations of community-based innovation more broadly. Indeed, lighthouse cases like the ones of Linux, Mozilla, or Apache as well as the massive variety of projects that can be traced on repositories like Github or sourceforge prove evidence for the innovative capacities that stem from open source communities. Still, the tensions between the open source and private domains become highly visible in OSS-related contexts as well—the friction between the provision and appropriation of software code widely resembles the entrepreneurial dilemma observed in the 3D printing field (see e.g. Fitzgerald 2006a; Dahlander 2007).

Nevertheless, what clearly distinguishes OSS as the core reference for community-based innovation from OSH applications like desktop 3D printing field refers to the materiality of its particular outcomes. As mentioned above, software moves throughout in the digital realm without any physical representations. In the case of any open hardware devices, digital blueprints are just one facet of the whole artifact, which always needs a tangible application for completion. This material transition affects the dynamics of community-based innovations in hardware related fields in three critical ways:

- Regarding the aspects of product development first, while coding requires only a personal computer and a smart mind, the creation of tangible devices generally necessitates more specific skills (electro engineering, mechanics, tooling etc.) and higher monetary investments in facilities (components, tools etc.). Although sharing of expertise and manufacturing tools in contexts of shared machine shops like hackerspaces represent a common practice within open hardware communities, still not everybody has access to such infrastructures.
- Secondly, in terms of commercialization, it is much easier to sell a tangible product like a 3D printer instead of a piece of code or a certain software application, which is not allowed under most open source software licenses anyway. Here, the almost pervasive entrepreneurial opportunities that arose during the proliferation of 3D printing are comparably rare within the OSS realm.
- Thirdly, the gap between digital blueprints and physical printers also affects the reproduction of open and generalized exchange. While software code can be shared easily almost without any extra resources, the exchange of blueprints for open source hardware always requires efforts toward documentation, 3D modelling, and transcripts of manuals—efforts that often annoy the hands-on tinkerers. However, if community members refuse to document and publish their blueprints in the public domain, the knowledge flows that constitute generalized exchange in innovation communities are subsequently interrupted.

Taken together, these three aspects create material roadblocks for a thriving application of open source principles to contexts of community-based innovations that focus on tangible, product related outcomes. My empirical findings show how these roadblocks also affect the founders' attitudes and decisions on their business practices in a way that potentially harms the community. While some founders indicated uncertainty as to whether or how their blueprints are actually utilized, others expressed their disappointment about the fact that essentially no external community contribution really informed their product development. Therefore, they developed the feeling that they were publishing their blueprints into the wild, which made sense neither for them nor for the community.

Against this background, the matter of materiality shapes the reproduction of innovation communities in crucial ways. Materiality, however, is tightly linked to the general classification of goods and related aspects of excludability and subtractability (Hess and Ostrom 2003). Indeed, while innovation communities by definition reject formal means of excluding people from participating (at least as long as they align with the foundational principles of open exchange and accessible knowledge), subtractability represents a variable which differs among the communities that engage in digital value creation and those that have tangible outcomes. For instance, since software remains in the digital realm, the marginal costs of their reproduction, once created, are essentially zero. Hence, outcomes from OSS communities are "nonrival" in the sense that one person's consumption subtracts nothing from the quantity available to others (Benkler 2006, 36). Moreover, the information-based representation of open source software also enables legal protection by licenses like the GPL, which are additionally backed by corresponding open source foundations that represent accountable entities to look after the rights of related communities and its public domains. In the contrasting case of innovation communities engaged in contexts of open hardware or other collectively developed physical goods, the outcomes also include subtractable aspects like tangible components or monetary investments in the production process, which do not apply to common open source licenses.

Put in the light of discussions on the commons, the early phases of RepRap's community development and related approaches to the peer-to-peer provision of components among community members both proved evidence for collective self-organization, capable of actually sustaining a commons-based approach to tangible goods. Plus, Adrian Bowyer's initial idea of the self-replicated machine that allows for revolutionary ownership and "Darwinian Marxism" (Bowyer 2006b, see also Sect. 5.1) offered a general vision on how physical goods such as 3D printers could be provided as a true common in the context of an innovation community. Although this approach worked out for the early phases of the community, it subsequently failed to scale in order to meet the increased demands for 3D printers or their components. The empirical insights of this study thus prove, at least from an economical point of view, that an innovation community can hardly self-organize a lean, well-packaged, and scalable production process. In the case of RepRap, this essentially pushed a growing number of startups to carry out the emerging entrepreneurial process of commercialization.

Thus, the dilemma of entrepreneurship in open hardware reflects a very foundational issue. On the one hand, the cultural-cognitive bonds that sustain the innovation community rely on the reproduction of collective rationalities that inform the practical adoption of open source practices—as well as shared understandings that desktop 3D printing should be approached in non-proprietary and minimal-exploitive ways. On the other hand, due to the principal matter of physical materiality, the actual production of 3D printers from open and accessible blueprints transforms the commons-based knowledge into physical objects that insofar resemble tradable private goods. Allocating investments to produce them in professional quality, setting up reliable manufacturing processes, and sell them in order to gain return for the investments is something the community seems unable to accomplish.

My findings show that the founders of 3D printing startups, which enter this gap, are not inclined toward free-riding behaviors but instead keep contributing their blueprints back to the collective pool of knowledge in one manner or another. Although most of them made concessions to open source principles in order to comply with the requirements of commercial businesses, none of them did it in such a clear-cut way as Makerbot did, for example. In this respect, the decline of the RepRap community in the field's diversification phase adds no direct evidence to the traditional notions in connection with the tragedy of the commons. Still, from the community's perspective, the transformation of the desktop 3D printing field alongside the increasing commercialization of the RepRap project in general entails tragedy rather than promise.

As my analysis shows, the disruptive tendencies on innovation communities are no results of direct harm caused by offensive divergent actions but rather unintended consequences of startup founders trying to solve their personal entrepreneurial dilemma of creating viable business models from open source knowledge on 3D printing. However, from a broader macro-institutional point of view, the threats that foster the latent meso-level disruption of innovation communities result from the communities' very own institutional idiosyncrasies. Since these obviously contradict dominant (capitalist) logics of innovation, they become structural vulnerabilities, which, at least in the context of the contemporary economic system, seem almost impossible to cure.

Chapter 7
The Perils of Innovation Communities

Abstract This last chapter starts with a brief summary of this book's findings. Furthermore, it wraps up its key contributions in conceptual, theoretical, and practical terms. The final section concludes with an outlook on how the principles of innovation communities extent their reach to processes that foster hardware innovation in rather competitive business realms. Drawing on two related examples, I reconsider how my analytical concept of innovation communities can nurture a more elaborated understanding of open and distributed innovation.

The aim of this book was to elaborate a conceptual understanding of innovation communities and explain the dilemma of entrepreneurship as a consequence of the institutional idiosyncrasies that typically shape processes of community-based innovation. Although there have been sporadic attempts to tackle related notions before (Shah 2003; Lee and Cole 2003; Füller et al. 2006), these approaches focus on the functional principles or potential means for economic utilization of related types of innovative action. Thus, the concerned state of research broadly resembles the body of knowledge on open and distributed innovation, which essentially contrasts two streams of research. The one promotes open business models and the relevance of external stimuli for corporate value creation (Chesbrough 2003, 2006) and the other emphasizes more decentralized modes of innovation taking place within actor constellations that lack guidance of a focal firm (von Hippel 1986, 2005).

While my own research especially draws on the latter notions of decentralized, user-based innovation and the related strands of literature, my ambition with this book goes further as it aims to develop a better understanding of the principles that enable community-based innovation and reproduce innovation communities as a distinct meso-level order. Indeed, the topic of desktop 3D printing turned out to be an exceptional starting point for elaborating on this line of argumentation. It provides evidence and valuable insights for the study of innovation communities, interlinks macro-, meso-, and micro-levels of institutionalization and thus offers some provoking findings on contemporary innovation society. The subchapters of this conclusion first wrap up my line of argumentation by providing a brief summary of this book (Sect. 1), then suggest related potentials for generalization by reconsidering its conceptual, theoretical, and practical contributions (Sect. 2), and finally outline links for further research (Sect. 3).

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7.1 Summary

Throughout the previous chapters, I emphasized the very nature of social interaction within innovation communities. I grounded this endeavor within the theoretical perspectives of New Institutionalism and field theory in order to derive the institutional and structural idiosyncrasies of community-based innovation and their implementation in the 3D printing field. The open and non-proprietary exchange of potentially innovative knowledge reflects both the core value and practical imperative for CBI-related modes of action. Drawing on insights derived from the study of self-organization in the context of common-pool resources thus revealed that this self-organization is a both symbolic and ideological endeavor that indeed entails practical advantages in terms of innovative outcomes but often contradicts established patterns of economic thinking.

In order to theorize this gap, I applied an analytical framework that draws on the institutional logics perspective and relates it to the meso-level order of fields. Since fields that emerge around CBI-related issues usually link to both community and business logics, the emerging meso-level orders also become melting pots for their ambiguous practical and symbolical implications. Hence, since the relationship between different logics usually entails notions of conflict, fields also contain contradictive rationalities and understandings that contest the symbolical definition and practical implementation of the particular issue at stake.

Hence, the analytical layer of subpopulations represents an opportunity to disentangle these heterogeneous assemblages as it groups likeminded and similar situated actors, which share a common understanding about the central issue of the field and draw on similar rationalities in approaching it. While subpopulations reproduce rather coherent sets of material practices and symbolic constructions, the conflicts between them shape the institutional structure of the field, which subsequently constitutes an arena of power relations between different actors and their particular interests. In the context of community-based innovations, related struggles take place between community- and business-based subpopulations, which indeed apply their very own understandings and rationalities on how to deal with the particular innovation at stake. While the former e.g. promote the open, non-commercial exchange of related knowledge, the latter ideal-typically trade potentially innovative knowledge as a commodity and potential means to increase economic competiveness.

The dilemma of entrepreneurship, which usually occurs when community members develop entrepreneurial ambitions to exploit community-based innovations commercially, heats up at the intersection between both subpopulations. Trying to establish business models that merge aspects of both realms, founders of community spin-offs are challenged by contradictive expectations that stem from the tensions within their institutional environment. Thus, I discussed the actors' practices and strategies for relieving these tensions in terms of their individual agency. In this regard, a key factor lies in the founders' knowledgeability to reflect on the surrounding conditions for their entrepreneurial activities—they become the agents who reproduce the field's institutionalized rules, resources, and conflicts that recursively constitute their scope of actions.

To answer the question of how the institutional and organizational idiosyncrasies of CBI affect entrepreneurial actions carried out by members of 3D printing communities, I proposed an empirical operationalization that grasps related frictions mainly as a cultural matter. This perspective particularly emphasizes the symbolic values, norms, rules, beliefs, and taken-for-granted assumptions that are apparent in the corresponding field. My methodological approach was thus marked by a triangulation of empirical scopes. This approach allowed me to trace the institutional and structural change of (and within) the field, derive the contradictive understandings on legitimate entrepreneurship that essentially constitute the dilemma of entrepreneurship in the particular context of 3D printing, and delineate the founders' practical strategies for relieving the resulting tensions.

My analysis revealed that although the field of 3D desktop printing began as an ideal-typical innovation community, the proliferation of the general topic of 3D printing as well as the growing economic relevance of the community's innovative outcomes triggered the increasing relevance of the business logic. Consequently, the community, which initially made up the field by applying the very principles of CBI, developed into a subpopulation complemented by another subpopulation that rather embraced capitalist interests to appropriate the technology and establish markets for 3D printing devices or companies. Between these parties, struggles over the purpose of the 3D printing technology as well as legitimate ways to push it forward subsequently created an arena, in which actors from the distinct subpopulations negotiated over the field's symbolic and practical premises.

The dilemma of entrepreneurship in 3D printing takes place at the center of this arena as the community members' becoming of startup founders essentially takes place at the intersection of the community and business domain. While their community background informs their scope for potential agency with the cultural values of open and generalized exchange, the growing influence of the business logic instead induces considerations on appropriate business models that withstand commercial competition. However, while some of the founders take middle courses that comply with understandings and rationalities of both business and community realms, others are very aware in choosing paths, which lead them in the one or the other direction. Depending on their practical approaches toward these emerging tensions, their entrepreneurial actions recursively affect the subpopulations in which they are embedded. In this regard, the bonds that sustain innovation communities entail particularly critical degrees of vulnerability to entrepreneurial efforts, which may harm the entire collective.

Consequently, the dilemma of entrepreneurship not only reveals a practical and symbolic controversy that founders of corporate community spin-offs are likely to face, but also a principal shortcoming of innovation communities that lack legitimate means to exploit their outcomes in commercial ways. While this is a minor problem in digital contexts of CBI, where the collective outcomes reveal nonrival properties, the orthodox rejection of commercial activities becomes a recursive threat for communities, which engage in contexts of physical product innovation.

Here, involved actors usually need to invest in raw materials, prototyping, and manufacturing to turn the collective efforts into tangible outcomes. The open and accessible knowledge that circulates as a common within the innovation community then transforms into private and potentially tradable goods. In constellations, in which the market increasingly asks for these goods, community members, who are capable of satisfying the commercial demands, subsequently face promising and low-threshold opportunities for entrepreneurship. As soon as they begin to carry these out, the business logic enters the community realm. Since the reproduction of innovation communities mainly relies on cultural cohesion and the rather strict application of their constitutive understandings and rationalities, increasing entrepreneurial efforts tend to disrupt them gradually.

7.2 Key Insights and Contributions

In my introductory chapter, I delineated the scope of this book by distinguishing the conceptual, theoretical, and practical notions of its guiding questions. According to this threefold distinction, I want to wrap up my key insights and contributions along these points.

7.2.1 Conceptual Contributions

With regard to the conceptual dimension, the current state of research on the one hand admits the growing relevance of community-typed interactions for open and distributed innovation, but on the other hand does not elaborate the link between communities and innovation in sufficient depth. Yet, there is already valuable work that distinguishes the coordination of communities from established forms of markets, firms, and networks by describing their specific features in terms of "collective, small-scale, decentralized, and lateral organizing processes" (O'Mahony and Lakhani 2011, 5), "fluid, informal peripheral boundaries of membership" (Seidel and Stewart 2011, 49), or the premier relevance of "modern trust" (Heckscher and Adler 2006, 227). Indeed, my study of innovation communities in the context of desktop 3D printing proves evidence for each of these points.

However, since this body of literature discusses the specific properties of community-based interactions only in descriptive ways, my own approach emphasizes the conditions for their reproduction as distinct social systems. I believe that this dynamic perspective on communities is especially applicable to explain the idiosyncrasies, which constitute them as unique settings for innovation. Merging the sketched state of research with Gläser's (2001, 2006) rather general notions on the governance implications of communities, I defined innovation communities as non-commercial actor constellations that consist of self-selected members, who implement means of generalized exchange in order to engage in the collaborative development, improvement, or application of novel entities, like e.g. certain products or software program. The communal mode of interaction is thus enabled and recursively stabilized by the constitutive values of openness and accessibility of knowledge, which are symbolically acknowledged and practically implemented by the actors involved.

My research revealed that the community-based modes on the one hand put strong emphasis on the explorative aspects of knowledge creation and thus spur fast and vast variations of 3D printing applications and designs, while they on the other hand place less of an emphasis on the diffusion and commercial application of their outcomes. Still, since exploration and exploitation represent mutually dependent preconditions for new artifacts to become innovative and spread within the broader markets, the innovation community covered in my investigation contained several key shortcomings. Indeed, the immense explorative capacity of the RepRap community created a vacuum for commercial exploitation, which yielded multiple entrepreneurial opportunities for both external corporate companies and community members seeking to turn their hobbies into decent businesses. In each case, these means of private appropriation are socially challenging because entrepreneurial ambitions, which exploit collective knowledge, are potentially critical for the community's constitutive mode of generalized exchange. Although for instance OSS communities proved their capabilities to develop powerful means for protecting themselves from unilateral commercial exploitation, I believe that commercial efforts generally impose potential threats for the solidarity and reciprocity that sustain innovation communities and their immanent interactions. The extent to which communities can cope with these disruptive tendencies essentially remains a matter of their self-organizing capacities and the degree of their cultural cohesion.

7.2.2 *Theoretical Contributions*

Generally, to explain the tensions that usually accompany CBI, I draw on a heuristic that emphasizes conflict as source for institutional and practical dynamics. These conflicts thus play out on every level of social order. Rooting them on the macro-level of institutional order, I discussed them as outcomes of frictions between the society's dominant institutional orders and their corresponding logics (Friedland and Alford 1991). This perspective suggests that "institutions cannot be analyzed in isolation from each other, but must be understood in their mutually dependent, yet contradictory relationships" (ibid. 241). Since institutional logics link the macro conflicts between a society's dominant institutional orders to particular sets of material practices and symbolic constructions, which are "available to organizations and individuals to elaborate" (ibid.), these general conflicts in principle affect the micro-level of individual action, too. However, I criticized Friedland and Alford for two main reasons:

First, their notions of material practices and symbolic constructions lack analytical depth. I suggested closing this gap by aligning the facet of material practices with Weber's general concept of rationality and linking the notion of symbolic construction to mutually acknowledged criteria for legitimacy, which I conceive of a primarily cultural matter. I believe that contrasting common patterns of how actors connect their ideas and intents with complementary types of social action offers an analytical way to sharpen Friedland and Alford's understandings of material practices as "patterns of human activity by which individuals and organizations produce and reproduce their material subsistence" (Friedland and Alford 1991, 243). Furthermore, I refer to the concept of legitimacy as "a generalized perception or assumption that the actions of an entity are desirable, proper, within some socially constructed systems of norms, values, beliefs, and definitions" (Suchman 1995, 574) in order to expose the key cultural-cognitive content carried by a particular logic's "symbolic systems through which [actors] categorize [...] activity and infuse it with meaning" (Friedland and Alford 1991, 232). Although it becomes obvious that the mutual linkages between material practices and rationality as well as between symbolic constructions and legitimacy involve certain theoretical overlaps, analyzing them requires different methodological approaches. While the concept of rationality is tightly linked to actors and practices, corresponding methods need to capture personal ideas, intents, and beliefs as well as the justifications and explanations that individuals attach to their actions. In contrast, shared understandings on legitimacy reflect group-level attitudes that necessarily require rather discursive methods to be unearthed.

My second critique essentially tackles the issue of more immediate social contexts for action as it highlights the missing meso-level layer in Friedland and Alford's institutional logics perspective. However, I generally conceive of the meso-level as an analytical scope, in which the "organizing principles" provided by institutional logics are brought into immediate effect. While there have been several attempts to locate institutional logics within fields and processes of "selective coupling" (Pache and Santos 2013) "selective synthesis" (Chen and O'Mahony 2006), or "hybridization" (Westenholz 2011), these approaches neither address the original macro scope of the theoretical perspective nor do they elaborate the theoretical foundations of fields or the constitutive conditions for their reproduction.

Drawing on state-of-the-art field theory, I identified notions of collective rationalities and shared understandings as concepts that sustain a distinct meso-level order's internal cohesion and thus offer means for external differentiation. Since fields usually imply references to various institutional orders as well as related sets of practices and symbolic constructions, they constitute rather versatile and multifaceted layers of diffraction that re-shape and re-assemble distinct, yet often heterogeneous institutional logics. Hence, I expanded the institutional logics framework by adding a theoretical understanding of meso-level orders as sketched in Fig. 7.1.

Considering these theoretical extensions, I elaborated my understanding of communities as a distinct type of meso-level order. The identified idiosyncrasies of communities highlight the relevance of reciprocity and trust for symbolic construction of legitimacy and emphasize the impact of substantial values like

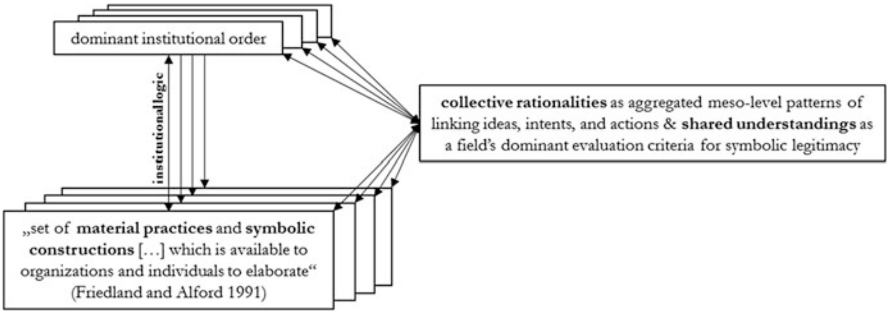

Fig. 7.1 The formerly missing meso-level of the institutional logics perspective

openness and accessibility of knowledge on the material practices of collaborative, generalized exchange. Regarding the macro references of innovation communities, my analysis of the field of desktop 3D printing revealed that these link primarily to the dominant institutional logic of science, which promotes a communitarian approach to knowledge distribution and bottom-up coordination through the mutual adjustment of independent contributions.

However, since CBI-related fields usually entail institutional implications of the business logic, too, I consider them to differentiate in two, analytically distinct subpopulations, one community- and the other business-based—each of them backed by its own collective rationalities and shared understandings in connection with the broader field's issue. Consequently, the macro-level conflicts between the dominant institutional orders of science and capitalism translate into meso-level arenas, which emerge at the intersection of these subpopulations and play out the institutional conflicts in terms of struggles over the definition of the field's particular issue or appropriate ways to deal with it. Depending on which material practices and symbolic construction reproduce the dominant collective rationalities and shared understandings, the fields that incorporate both community and business logics focus on either exploration or exploitation and either support or reject the entrepreneurial efforts of their stakeholders.

According to this latter point, my study also contributes to a theoretical understanding of agency in terms of startup entrepreneurship, which neither overemphasizes the actors' capacities to shape their institutional environment nor discusses the matter in the solely economic terms of business models. Indeed, my empirical analysis revealed that entrepreneurship is a complex and reflexive matter, which mutually affects various layers of meso-level orders. Considering the recursive effects of entrepreneurship with the theory of structuration allows conceiving the structural properties of any of these layers as "both medium and outcome of the practices they recursively organize" (Giddens 1984, 25). Hence, my analysis of startup entrepreneurship in the context of desktop 3D printing suggests that not only the startups become a variable for reflexive entrepreneurial action but also the broader structures of related field settings. Put this way, the disruptive tendencies that affected the RepRap community represent an unintended outcome of an increasing number of members engaging in business-related practices. However, the gradual infiltration of the business logic into the formerly community-based field was also caused by internal structural shortcomings of the RepRap innovation community, which became increasingly unable to serve as a platform for entrepreneurial activities that at least tried to incorporate the constitutive rationalities and understandings of the community as much as possible.

7.2.3 Practical Contributions

While there are already significant insights on decentralized, open, and commons-based innovation in the digital realm of open source software, research on the relatively new phenomenon of open source hardware is still in its infancy. However, in the course of the ubiquitous and pervasive digitalization of value creation, the application of community-based modes of innovation are likely to become more important. The findings from this study add evidence for the innovative potentials of such approaches and identify possible shortcomings as well. Regarding the potentials, communities that engage in tangible product innovation also imply strong capacities for the collaborative exploration and further development of novel ideas. However, especially the transformation of collectively developed ideas into physical products has a nuanced twist that seriously challenges innovation communities.

Like in any other constellation that deals with common pool resources, the private appropriation of collectively provided goods like pastries, scientific knowledge, or innovative ideas leads to social dilemmas. In the story of this book, the dilemma of entrepreneurship heats up because the actual production of OSH devices like 3D printers usually requires considerable monetary investments and thus offers multiple opportunities for commercialization. As soon as community members start to take investments in order to carry the entrepreneurial opportunities out, they switch at least partly from the community-based mode of generalized exchange to rather discrete market rationalities. From this point on, any efforts to nurture the community by e.g. documenting and sharing the latest designs may be considered a potential risk for market competiveness and business efficiency as well.

Another trait that distinguishes digital from physical realms of community-based innovation is that the former established strong and enforceable licenses like the GPL or CC, while the latter still lacks similar means to protect its commons-based outcomes legally. Therefore, the social cohesion that reproduces hardware-based innovation communities depends even more on a culture of mutually acknowledged values, joint member identities, and shared ideologies. Hence, the rather informal and value-based bonds that sustain related forms of interaction turn out to be especially vulnerable to divergent actions.

However, while this particular case supports a rather tragic than promising interpretation, the general approach of applying open source principles to hardware developments can still succeed. Indeed, there are plenty of OSH stakeholders attempting to adapt OSS licenses to hardware devices more effectively—or at least circumvent the current patent law in a way that protects them against external appropriation or unjustified lawsuits. Such efforts in the legal dimension can surely relieve pressure from the cultural-cognitive bonds and add more formal and reliable facets to the meso-level structures of innovation communities. Indeed, an increasingly settled framework for community-based innovation and collaboration could help to guard its constitutive principles and would thus offer reliable guidance for participating actors to become clear about the scope of appropriate corresponding actions.

7.3 The Utopia of Community-Based Innovation

Although the previous analysis elaborated a couple of insights on the general properties of innovation communities and the corresponding modes of CBI, it also reflects a rather unidirectional point of view, which emphasizes the impacts of business logics as intruders to community settings. While the state of research suggests that these dynamics indeed represent a prevalent pattern for other occurrences of CBI, too, this last chapter sketches an outlook from the other way around.

Since open innovation approaches proliferated ubiquitously with the spread of digital technologies, open source ideas and corresponding organizing principles expanded as well. Indeed, while large corporate companies like Adobe, IBM, Sun/Oracle, and even Microsoft already engaged in open sourcing strategies in order to spur decentralized collaboration in the context of their software developments, this trend recently approached the hardware-based endeavors of comparatively big corporations as well.

For instance, the Open Compute Project (OCP) represents Facebook's effort to create "a collaborative community focused on redesigning hardware technology to efficiently support the growing demands on compute infrastructure" (Open Compute Project 2016). With the pervasive rise of the internet, the need for massive and reliable data centers, which build the hardware-based backbones for digital infrastructures, became urgent, too. Because firms like Google, Amazon, or Microsoft had the feeling that they could "no longer rely on typical hardware from the likes of Dell, HP" they began to develop the hardware for their data centers from scratch (Metz 2016). While these early efforts were shaped by high degrees of secrecy, Facebook broke with this practice by establishing the Open Compute Project. In addition to companies like Intel, which joined the initiative from the beginning, other giant technology leaders like Apple, Cisco, and also Microsoft and Google, who initially watched Facebook's open source effort with skepticism, started to participate in this collective endeavor as well (Bort 2015). According to OCP's project board, the overall mission of designing a more efficient and flexible commodity hardware is thus enabled by an open exchange of ideas and technological specifications within "a structure in which individuals and organizations can share their intellectual property with others and encourage the IT industry to evolve" (Open Compute Project 2016).

A second prominent example is Tesla Motors, whose CEO Elon Musk announced in June 2014 that they would open all of their electric car patents to outside use. In order to "accelerate the advent of sustainable transport" Musk claimed that "Tesla will not initiate patent lawsuits against anyone who, in good faith, wants to use our technology" (Musk 2014). Indeed, this announcement was recognized as a significant move since the company actually owned 203 patents and had about 280 more pending globally at the end of 2013 (Wharton 2014). The technologies covered by these patents thus represented the very state of the art in the field of electric vehicles and outcompeted potential competitors in terms of performance, usability, and reliability.

Indeed, these exemplary cases suggest that not only innovation communities but also corporate companies are becoming increasingly inclined to apply open source principles to hardware-related contexts. As corporations share their formerly proprietary knowledge even with potential competitors by the means of generalized exchange, they also translate constitutive modes of community-based innovation to contexts which otherwise stick to business logics. This suggests that the general advantages and particular practices of open and non-proprietary innovation, which usually reside in the context of non-commercial communities, are expandable towards business realms, too. Compared to insights derived from the RepRap case, which show evidence for the disruptive impacts of business logics on community settings, this interpretation adds the complementary aspect of the community logic entering commercial firm- and market settings.

In his announcement, Musk elaborated on the reasons for Tesla's open source strategy by claiming that, "technology leadership is not defined by patents [. . .] but rather by the ability of a company to attract and motivate the world's most talented engineers" (Musk 2014). Quite similarly, Facebook's vice president of infrastructure, Jason Taylor, also noted that, "[OCP is] taking lots of companies that wouldn't have avenues to work together and finding ways to work together and collaborate. [. . .] We've managed to get couple of hundred companies to work together and to let engineers be engineers" (cited from Bort 2015). Essentially, these statements sketch a dichotomy between the restrictive framework of patent- and secrecy-based R&D on the one and the practical preferences of engineering talents on the other hand. Assuming that these talents usually have backgrounds as scientific professionals adds additional weight to my interpretation that this dichotomy breaks down to the institutional clash between capitalist business- and scientific community *logics*, too.

However, since the actual implications of this institutional arrangement take place in the high competitive *fields* of the automotive and digital tech industries, the emerging rationalities and shared understandings that affect the particular *issues* of development (electric vehicles, data centers) differ for instance from those observed in the case of RepRap. On the one hand, attracting talents and spurring collaboration is primarily understood as success factor for innovation. Therefore, even (or: especially) these highly competitive settings become gradually reluctant against knowledge enclosure and increasingly embrace an open spirit, often backed by an ideological mission, instead. On the other hand, since already-existing companies that surely care about their market position, shareholder values, and technological advancement are the ones that launched and supported the initiatives described above, the dominant collective rationalities still reproduce business logics, which adopt open source principles because of their selective functional advantages instead of their supposed moral worthiness. For the case of the OCP, Bort summarized the related weighing of involved interests quite aptly:

> Hardware engineers, no matter who they work for, could collaborate. Ideas could flow. New tech could be invented more quickly. Difficult tech problems could be fixed faster. And everyone would be able to share equally in the results. It would be 180 degrees from the classic culture of patents and lawsuits and trade secrets that has ruled the tech industry for decades. But Facebook didn't make hardware, so there was no risk to its business. (Bort 2015)

Thus, while Facebook's collaborative effort with the OCP helped the company to save about $2 billion in infrastructure costs over the 3 years from inception (Green 2015), Tesla's offer for open patent access probably also implies interests other than altruistic generosity. Instead, Musk clearly refers to his ambition to shape a rapidly-evolving technology platform (Musk 2014), which obviously correlates with his announced open-sourcing strategies. As these are likely to spur an increased rate of adoption for Tesla's signature technologies, the related knowledge can, for instance, encourage other companies to start building charging stations and other products that would support the company's growth (Solomon 2014).

The gradual departure from established modes of knowledge secrecy and patent protection towards more open modes of knowledge creation and dissemination, which are at least inspired by open source principles, indeed indicate a transformation within the dynamics of corporate innovation and thus offer a broad range of emerging research topics. However, I would suggest applying the concept of innovation communities to those settings, which emphasize notions of non-proprietary ownership, extensive openness, and free accessibility of knowledge in rather ideal typical ways. To reproduce innovation communities and sustain their social cohesion, all of these characteristics need to be implemented practically and symbolically. Furthermore, while innovation communities are generally inclusive to anybody who identifies with their constitutive principles, participation in the examples presented above is restricted to those actors, who possess the technological capabilities and financial resources to contribute to these high-tech endeavors in the first place.

Hence, the cases sketched out in this empirical detour offer hints that the evolution of open source hardware follows a similar path as open source software. From a pessimistic point of view, this process is marked by a vanishing value-base for open source principles that yields to the private appropriation of its practical advantages. Framed this way, the commercial assimilation of related approaches essentially feeds the rationalities and understandings that reproduce the capitalist order and its institutional logics spurring the "accumulation and commodification of human activity" (Friedland and Alford 1991, 248). From a rather optimistic point of view, it will be interesting to see whether the ubiquitous effects of digitalization, which immanently favor decentralized over centralized patterns, trigger a broader diffusion of commons-based approaches that now also reach out to contexts of physical value creation. These could gain momentum in order to mitigate the perversion of the current patent system and thus contribute to a more conclusive version of the often-proclaimed democratization of innovation. Whatever the case may be, I assume that the symbolical and practical configurations of openness within the multifaceted contexts of innovation will affect the future of the digital age in significant ways.

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