Is selling caring? Norms regulating commercialisation and sharing behaviour with the open hardware RepRap community[1]

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Résumé :

Founded in 2005 by Dr Adrian Bowyer, the RepRap open source/open hardware community has been highly instrumental in the democratisation of 3D printing technologies. By designing a 'self-replicating' 3D printer made of 3D printed elements (for 70% of it) and readily available parts and electronics, the RepRap team was able to bring down the cost of a 3D printer from well above €35,000 to less than €500. Yet, the first RepRap printers were notoriously finicky and unreliable, but because hardware blueprints and computer codes were released under the "open source" GPL licence, this gave birth to a large community that improved the original printer model and created new ones (over 70 models nowadays). Two

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of the current desktop 3D printing market leaders, Makerbot and Ultimaker, have emerged from the RepRap community and the work of this community has been an inspiration for countless startups and companies, to the point that it can be argued that virtually all desktop 3D printers commercialised today owe something to the RepRap community.

While this is not the first time commercialisation and sharing coexist within a large-scale open innovation community, such communities have been generally related to software and content (e.g. open source software). Because RepRap is related to hardware, this causes two significant issues. The first one is that Intellectual Property is of little relevance (unlike for software and content, where copyright offers a relatively strong protection). The second one is that, in contrast with software and content, for which diffusion is essentially costless, hardware entails significant diffusion costs. Simply putting a blueprint of a new 3D printer online makes it highly unlikely that anyone will adopt it, as a substantial investment (sourcing and manufacturing of the parts, product assembly) is required. Thus, unless the innovators invest in diffusion, by commercialising their invention (as a kit or assembled product), it is doubtful that diffusion will take place.

Thus, in contrast to software and content, commercialisation in open hardware communities is an option, but a requirement. Because commercialising and free sharing do not usually go along well, this is a source of conflict within the community that undermines its viability.

This paper argues that in such a context, norms within the community play a fundamental role, as they enable to define what forms of commercialisation are acceptable and, as a result, promote free sharing. The methodology used is explorative. 15 semi-structured interviews of funders of companies that commercialise desktop 3D printers were conducted to identify the norms related to commercialisation and sharing. To confirm the existence of the norms identified, a detailed case study of MakerBot commercialisation history and a content analysis of resulting blog posts from community members were conducted. Results are that while norms related to commercialisation and sharing, as well as punishments when not conforming to the norm, indeed exist, they are multidimensional and encompass a variety of factors. This enables us to explain while companies that seemingly abide the ‘rules’ were shunned, while other that did not conform to the norm were not.

Mots-clés : Collaborative communities, sharing, norms, open innovation, 3D printing

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1 INTRODUCTION

In 2010, Bre Pettis, co-founder of MakerBot wrote: "sometimes an individual or a company makes a derivative of an open source project, goes to market with it and then doesn't share their derivative designs with their changes. This is not only against the licence, but it's also not ethical. It is a dead end for the innovation and development which is the heart of the open-source hardware community. […] 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." This quote, along with many others we collected through interviews of members of the RepRap community, suggests two critical things. First, that commercialisation is not absent from the life of open and collaborative communities, despite the strong emphasis on nonmarket behaviours conveyed by the literature. And secondly, that this commercialisation tends to be regulated by strong norms.

In this paper, we focus on the norms regulating commercialisation in the context of open and collaborative communities and show that commercialisation is tolerated as long as it is done in a certain way, in particular in regard to what can be commercialised and how it can be commercialised. The quote above suggests that when it comes to commercialising 3D printers based on inputs borrowed (even partially) from the contributions that members of the community have made freely available to all, some behaviours are proscribed while others are favoured. Norms are critical, we argue, to ensure that commercialisation behaviours do not threaten the commons that open collaborative communities collectively produce. In particular, they entice those who commercialise not to misappropriate the intellectual property of the community, and in contrast, to contribute back.

This paper contributes to the literature by emphasising commercialisation as a significant behaviour in the context of open collaborative communities and by singling out the conditions

that make commercialisation an acceptable behaviour within open communities. Whereas in the literature, free sharing of innovations and creative productions with commercialisation have generally been thought as being incompatible, we show that these two behaviours can indeed coexist as long as commercialisation follows specific norms. This is an important result because commercialisation has generally been left out of focus in the research work devoted to open software and other digital products, because such products can be reproduced and distributed at a negligible marginal cost. In contrast, commercialisation is a prevalent and, most likely, necessary phenomenon in the realm of open hardware, where reproduction and distribution are significantly costly. In a context where open and collaborative communities will increasingly frequently engage in the conception of hardware and physical products, it is critical to understand how free sharing and commercialisation can coexist harmoniously.

In the following sections, we explain how we have identified the norms relative to commercialisation that prevail within the RepRap community, the first and largest open hardware community related to 3D printing technology. We then detail the norms that we have identified as well as the conditions required for them to be effective, and conclude by a discussion of our results.

2 LITERATURE REVIEW AND THEORY

The very essence of collaborative and open innovative communities is the free sharing of innovators and contributors' inputs. As soon as they are made freely available these inputs become public goods that in principle anyone can use to its convenience, especially if for private use. Typically, other passionate people use these contributions to make new contributions that they also share. Yet, it is not rare that commercialisation takes place in the vicinity of these collaborative and open communities. That is individuals or groups of individuals use community's inputs and possibly their own inputs too to conceive of commercial products that they then sell. The question is how does a collaborative and open community react to the emergence of commercialisation in its vicinity? Does this emergence threaten the openness of the community and the willingness of contributors to keep freely sharing their innovations and inputs as others do appropriate returns out of their efforts? Or is commercialisation tolerated and why?

2.1 LITERATURE REVIEW

Historical examples have tended to support the idea that collaboration in knowledge production and openness in knowledge sharing tend to be a transitory situation, found when

technological uncertainty is very high and it is therefore rational for innovators to share their ideas and developments to advance the technology more quickly (Osterloh and Rota, 2007). In these "collective invention" examples, where a community of firms does share knowledge extensively early in the development of the technology, comes a moment when the technology has become sufficiently advanced and standard for independent innovators or firms to appropriate returns from the technology. At this moment innovators tend to stop sharing their further developments and to start appropriating privately the returns from their individual efforts (Allen, 1983).

Yet, other evidence suggests that, in some communities, openness and sharing coexist with some private appropriation of efforts, meaning that the free sharing of inputs keep going despite the fact that some individuals or firms do design commercial versions based on these freely shared inputs. The most documented example is the field of software where open source projects tend to coexist with commercial software based on open source (e.g. Osterloh and Rota, 2007). This coexistence tends to be attributed to a number of factors. First, a strategic perspective points out the hybrid business models that private companies can adopt in an Open Source field and that can be tolerated by the community (e.g. Bonaccorsi, Rossi, Giannangeli, 2006; West, 2003; Grand et al., 2004). For instance, firms can live on selling services to users (for lack of selling the software itself) or they can sell versions that differ from the open source versions, typically versions more suited for non-expert users. Second, some literature points out the adaptations that both open collaborative communities and commercial firms tend to operate in order to find peaceful ways to coexist. Typically, commercial firms tend to adopt the "codes" of the field and to reveal some of the codes that they have themselves developed in compensation for the codes taken from the community (e.g. Henkel, 2006). And open communities tend to adopt forms of protection, such as specific licences, to prevent others from misappropriating their contributions (e.g. O'Mahony, 2003). As both types of actors adapt to the rules of the other, hybrid forms of field organisation and rules emerge that allow for the coexistence of free sharing and commercialisation (Osterloh and Rota, 2007). Third, the innovation management literature emphasises the relationships that firms can develop with knowledge communities, either by establishing new communities around the firm or by engaging with pre-existing communities (Dalhander and Magnusson, 2008). In these situations, a firm commercialises products based on the freely shared contributions of independent innovators and creative people. These contributors thus accept to volunteer efforts in contributing knowledge to a company that is

going to appropriate private returns from their contributions. The motivations of these contributors are generally variegated and stem from learning and intellectual stimulation, having an interesting hobby, signalling one's competences, and even possibly getting some financial reward (e.g. Lakhani and Wolf, 2005). But as emphasised by Dalhander and Magnusson, communities tend to expect firms to behave in certain ways. Typically they expect firms to develop and codify licensing practices that clarify ownership and, in this regard, practices that are "too proprietary" tend to be discarded by communities; also some of the companies using community contributions tend to give back some source code to their community despite the potential competitive drawback of doing so, which denotes some sense of obligation; in addition, communities expect to be recognised for their contributions in a way or another and they expect firms to "abide by the rules of the community" whatever this means (p. 641).

Interestingly, independently of the perspective adopted, it emerges, in an impressionistic manner, that open collaborative communities can tolerate commercialisation, and especially commercial products based on or using contributions made available freely by an open community, but at certain conditions, typically resulting from unspoken rules. Yet we miss a systematic account of those unspoken rules that seem, however, to play a rather crucial role in explaining when communities tend to tolerate commercialisation. In this paper, we aim at studying systematically the set of implicit rules or norms that regulate community acceptance of commercialisation.

2.2 THEORY

Unspoken rules or norms play important roles in many different situations and contexts as they regulate behaviours in a way that favour acceptable behaviours and tend to discourage unacceptable ones, therefore resulting in better collective outcomes for the concerned group (e.g. Lee and Cole, 2003; Merges, 2004; Fauchart and von Hippel, 2008). Norms have been shown to play a role in collaborative and open communities, and in particular in open source software communities, which are the communities that have attracted most interest (e.g. von Hippel and von Krogh, 2003). In particular, it has been argued that norms were a component of the "open source" ideology in many communities, with the norm of sharing and openness and the notion that "information should be free" as central behavioural drivers (Stewart and Gosain, 2006). Based on analysis of archives, texts, or blogs content, Stewart and Gosain identified three more specific norms regulating behaviours in OSS communities: (i)

"Forbidden to forking": norm against splitting a project into a number of different projects; (ii) "How code should be distributed": "norm against distributing code changes without going through the proper channels"; (iii) "Crediting": "norm against removing someone's name from a project without that person's consent". These norms regulate behaviours relative to aspects of contributions, like how contributions are made, distributed, or credited. Although they emphasise that open and collaborative communities rely in part on written rules to regulate various aspects of their functioning, such as the open-source software licence, for instance, which stipulates that changes to the code must be made public, Lee and Cole (2003) point out the important norms that allow collaborative and open communities to self-organise in a way that ensures high quality collective outcomes. Amongst the strongest norms is the one which assumes proper citation and recognition of the contributors. In the Linux development community, for instance, it is required to properly cite the contributors which work is being borrowed or extended. This allows for traceability and it entices people to contribute. Another strong norm is that of "external peer review" that entices people to check codes they haven't written in order to identify bugs and mistakes and to make "patches". This norm is associated with the fact that critical evaluation is an important input for code quality and is perfectly acceptable as soon as it is done in a constructive manner. Motivation is driven by the fact that checks and corrections are documented as well and that therefore that work is recognised too. External peer review is important for code acceptance by project leaders as the likelihood of acceptance increases with the number of external reviewers who have checked the code. Lakhani and Wolf (2005) also emphasise the norms that derive from the hacker culture and the strong identification of contributors with the open source and hacker movements. Identification tie individuals to collective identities that are structuring as shared meanings help individuals select appropriate behaviours and understand their responsibilities in the community.

More generally, from an intellectual property perspective, informal institutions like open and collaborative communities, are fundamentally concerned with appropriability issues which give rise to norms of "proprietariness" that relate to what can and cannot be claimed as proprietary by members of the community (Merges, 2004). In particular, these norms aim at "protecting" the commons that the community collectively contribute to by avoiding misappropriation of these contributions in a way that would threaten the commons (i.e. by reducing incentives to contribute) (Benkler, 2002). For instance, the norm "eschewing property rights" (Merges, 2003, p. 20) is specifically central in these communities as it

implies that contributors accept that others do use their contributions to improve or extend them.

The prevalence and strength of norms aimed at facilitating or protecting open collaborative innovation has driven observers to emphasise the non-commercial dimension of these collective innovation attempts and to contrast them with markets. For instance, for Benkler (2006, p. 7): (this results in) "a flourishing nonmarket sector of information, knowledge, and cultural production … subject to an increasingly robust ethic of open sharing, open for all others to build on, extend, and make their own". Also for von Hippel and von Krogh (2003): "Because commercial software vendors typically wish to sell the code they develop, they sharply restrict access to the source code of their software products to firm employees and contractors. The consequence of this restriction is that only insiders have the information required to modify and improve that proprietary code further. In sharp contrast, all are offered free access to the source code of open source software." However, it seems that a more accurate description is in many cases that of open and free sharing coexisting with commercialisation behaviours. In the case of open-source software previously cited, community firms created by some hobbyists have developed and sometimes prospered. Also, in the case of 3D printing technology, which is the context we have studied in this research, an important community has established over time that is composed of both hobbyists who freely share their contributions and of community firms that commercialise 3D printers. The interesting observation is that these commercial firms tend to keep sharing their own developments with the community despite their commercial orientation. Our argument is that commercialisation can coexist with free sharing and openness because it is a certain form of commercialisation, more specifically commercialisation that respect certain norms relative to what can be commercialised and how it can be commercialised.

In fact, it should not be too surprising that open collaboration and free sharing tends to be considered as involving institutions opposite to markets since incentives work very differently in those two contexts. In addition, commercialisation and free sharing tend logically to be thought of as two antithetical behaviours: either you share freely and thus give away for free what you have contributed or you sell it. And when you aim at selling an innovation you typically seek to protect it in order to avoid it being copied by others willing to make money out of the same technology or the same ideas, and this is incompatible a priori with free sharing and openness. Yet, our argument is that commercialisation can be compatible with free sharing when commercialisation takes on a specific form and is behaved in a certain way.

Specifically, if commercialisation is performed in a way that does not violate the fundamental principles of open communities and does not threaten the commons, it should be acceptable. Also, if commercialisation brings benefits to the community that outweigh its disadvantages, it should be found to be acceptable. For instance, commercialisation may help build better versions of the technology and may foster innovation, in particular in the case when hardware is involved. These elements tend not to be written anywhere such that it is typically norms related to commercialisation that should be found to regulate commercialisation within open and collaborative communities. These norms, if they are strong enough and can be enforced, would indicate what is appropriate to do and what is not. In the following section, we explain how we have tested that general hypothesis that norms related to commercialisation should be found to exist and play an important role in open and collaborative communities.

3 DESCRIPTION OF THE STUDY FIELD

With over 6,000 active contributors, RepRap is nowadays one of the largest and most successful open design/open hardware community. The RepRap community has given birth to well above 60 'official' models of 3D printers, and has been an inspiration to countless more, including most models of the 'desktop 3D printer' market leaders (such as MakerBot and Ultimaker).

The RepRap project itself was initiated in 2005 by Dr Adrian Bowyer, then a Senior Lecturer in Mechanical Engineering at the University of Bath (UK). Bowyer's goal was to create an open design (open source software and hardware) 'self-replicating' 3D Printer (meaning that one should be able to manufacture as many parts as possible of a RepRap printer with another RepRap printer), thereby enabling to significantly drive down the cost and increase the diffusion of the technology.

The first RepRap printer was based on an extrusion 3D printing technology,[2] which consists in melting a plastic filament (usually ABS or PLA), which is then processed through a nozzle and deposited layer by layer on a plate by a computer controlled motorised head[3] to form a 3D object. This 3D Printing technology was first developed by S. Scott Crump towards the end of the 1980s and released under the name 'Fused Deposition Modelling' (FDM). Crump funded Stratasys (nowadays the 3D Printing market leader, with about ½ market share) in

[2] Nowadays the vast majority of RepRap model are still based on this particular 3D printing technology.
[3] Some models have an animated build plate and a static nozzle instead.

1989 and filed two patents covering the FDM technology, which were granted respectively in 1992 (U.S. Patent 5,121,329) and 1994 (U.S. Patent 5,340,433).

The RepRap project officially started just after the last of these two patents had expired. To avoid legal issues, the technology underlying the RepRap project was named "Fused Filament Fabrication" (FFF). [4] However, Fused Deposition Modelling (FDM) has become the generic term to designate this particular 3D Printing technology and the FFF denomination is seldom used.

Since the launch of the RepRap project, four flagship models of printers have been officially released: Darwin (2007), Mendel (2009), Huxley (2010), Prusa Mendel (2010). While each new model is (as expected) an improvement over the previous ones, none has completely superseded its forebear and there are still ongoing development projects based on the original Darwin machine, for instance. In addition to these four models, over 60 other models—some extensions of the aforementioned models, others entirely original ones (e.g. the 'Delta' printers)—have been developed by the RepRap community. While some of these models, just like the original RepRap models, have been developed by active members of the community, other correspond to commercial releases of companies who have decided to adopt the open development paradigm.[5]

While most RepRap machines are still based on FDM technology, new releases and ongoing projects within the RepRap community are now making use of different 3D printing technologies (e.g. powder melting/sintering, UV resin).

Overall, the RepRap community is quite vibrant and diverse. While more and more companies have entered the 3D printing market, new projects are still emerging from within the RepRap community and the number of contribution remains high (above 1,000 contributions monthly).

In regard to the purpose of this study, a key feature of the RepRap community is the diversity that prevails amongst its members. Indeed, the community is made off hobbyists, entrepreneurs, user innovators, employees of commercial companies. A further interest for this particular community is that it combines software and hardware development, with some

[4] Indeed, while FDM patents have expired, "Fused Deposition Modelling" is still a valid trademark owned by Stratasys.

[5] Often because their commercial models derive from other RepRap printers, whose licence often requires to publish subsequent developments.

members engaging only in either, while others engage in both. Consequently, it is interesting to observe how norms have emerged in such a diverse environment.

4 METHODOLOGY

The purpose of this empirical investigation was (1) to find out whether norms existed in the RepRap community, in particular with respect to commercialisation (2) to identify those norms (3) to assess their effectiveness. In order to achieve these objectives, it was decided to conduct the research in three stages.

The first stage is an interview-based exploratory study that will aim to identify the most critical aspects of norms and commercialisation within the RepRap community. The second stage will involve a, larger, second round of interviews that will be coded using the outcome of the first stage. The outcome of the second stage will enable to design a survey that will be then largely distributed to confirm the findings of the two previous stages. These three stages are described in greater details below. The current paper aims to present the results obtained in Stage 1.

Since this is the first study investigating the norms in the RepRap community, an explorative approach was chosen for Stage 1. Indeed, this type of approach is recommended when the research issues are still evolving (Yin, 2003). Stage 1 consists in an explorative study aiming to identify the norms in RepRap communities (in particular those related to commercialisation and openness).

In an exploratory study, the choice of the sample may affect the results of the study and is, therefore, particularly critical (Miles and Huberman, 1994). In particular, representativeness and exhaustiveness of the information collected during the interviews are important. Representativeness usually relates to how accurately diversity is represented in the population, whereas exhaustiveness is generally associated with the sample size (i.e. how many interviews were conducted).

According to Guest et al. (2006) saturation (i.e. the point at more interviews do not result in new information) is reached rather quickly, and after 12 (and even often 6) interviews saturation is generally total. Therefore, it was decided that to ensure a high level of capture of critical information at least 12 interviews would be conducted.

Because of the focus on commercialisation, the first stage involved conducting a series of interviews with companies commercialising 3D printing. In total, interviews with 15 companies were conducted. In all but one case, the person interviewed was either the CEO or

one of the founders of the company (the remaining interviewee was one of the company's head managers). Diversity was ensured by selecting a variety of companies: some of them clearly presented themselves as being a part of the RepRap community (by commercialising existing RepRap models, or by themselves leading the development of a RepRap model). Others initially had ties with the RepRap community but then developed models independently (some as open hardware, other as closed hardware—in some cases, a mix of both). Finally, companies that did not have official links with RepRap, but whose products displayed obvious similarities with RepRap models or that were founded recently (and, hence, could have benefited from the knowledge developed and spread by the RepRap community) were also included in the sample.

Interviews stopped once theoretical saturation had been reached, that is when no additional insights were gained by additional interviews (Corbin and Strauss, 1990). In order to triangulate interview data and decrease the risk that the collected data are biased, secondary sources of information, in the forms of archives, blog discussions, and news articles related to RepRap were also collected.

For the purposes of our research we have decided to conduct semi-structured interviews, one of the most common interview types (Alvesson and Deetz, 2000), as they are generally viewed as one of the most effective methods of gathering information (Kvale and Brinkmann, 2009). Interviews lasted between 40 and 60 minutes and were based on an interview guide developed by the authors. Each interview was conducted at least by two researchers in order to ensure the reliability of information (Denzin, 1970). Interviews were integrally recorded and then transcribed.

This first stage of research enabled to identify key aspects related to commercialisation of 3D printers in relation the RepRap community (motivations, norms) that will be presented in the following section.

The second stage of the research will focus on the norms related to commercialisation in the RepRap community, their effectiveness, as well as the consequences of deviating from these norms.

Based on the norms identified in the first stage, a new interview guide will be written. A second round of interviews, involving this time both respondents commercialising 3D printers, as well as (non-commercialising) contributors to the RepRap projects, will be carried out. The resulting interviews will be coded using Nvivo. Both open and axial coding will be carried out. Open coding enables to develop concepts, categories and properties (Miles &

Huberman, 1994; Strauss & Corbin, 1998), whereas axial coding allows to examine the relationships between the central phenomenon of interest and the causal conditions that relate to this phenomenon, as well as the context in which the phenomena exist, and any of its consequences or strategies related to it (Crook and Kumar, 1998).

Based on the outcome of Stage 2, a questionnaire will be designed and will be sent to the widest number of members of RepRap community. The main objective of this survey is to collect quantitative data on the existing norms and their effectiveness to confirm the results obtained with the qualitative phases.

5 PRELIMINARY FINDINGS

5.1 WHY COMMERCIALISE?

Leaving aside the question of the norms related to copying and sharing, which will be discussed in the following section, the interviews conducted during the first stage of this research provided useful insights about commercialisation and contribution.

Since all the interviewees in this initial stage were chosen because they themselves were commercialising 3D printers (whether RepRap or not), all interviewees were asked about the reasons to engage in commercialisation. Unsurprisingly, all respondents indicated that they had perceived a market gap. The nature of the gap perceived, however, differs amongst interviewees.

At the time the RepRap project was launched (in 2005), 3D printing (a.k.a. 'Additive Manufacturing) had existed in one form or another for already a significantly long time (the first '3D printing patents' were filed in the mid to late 1980s). However, back in the mid 2000s, prices of 3D printers were still very high and even the simplest and crudest model cost well above €5,000. Hence, it is not surprising that several respondents (4 out of 15) have mentioned that producing cheaper 3D printers was a key motivation behind their decision to commercialise 3D printers.

As a matter of fact, the RepRap project provided just what was needed for that. Beforehand, it would have been very difficult to commercialise 'cheap' printers, as the technology was still held tightly in the hands of the market incumbent (such as Stratasys, 3DSystems) and the costs of developing a new 3D printer alone would certainly have deterred the entry of even the bravest entrepreneurs. Once the FDM patent had expired and the technology had been reversed engineered, the subsequent public release of all the information required to

manufacture a 3D printer created countless opportunities for hobbyists and entrepreneurs alike.

However, the free diffusion of the information related to the RepRap project was simply not enough for a large diffusion of the technology itself. Indeed, unlike what happens with software, diffusion of hardware entails a significant cost (since manufacturing, storage and transportation are significant). Consequently, diffusion was mentioned by 8 out 15 of the interviewees as a key motivation to commercialise. In some cases, while the 'information was out there' and anyone could see how to build a RepRap 3D printer, it happened that there was simply no local distributor enabling to source the necessary parts easily and for a reasonable price. Amongst the interviewee, three were the first distributors of RepRap components and kits in their respective country. In these three cases, the market gap was clear. In two other cases, interviewees explicitly mentioned that commercialisation enabled to significantly decrease the cost of parts.

A third motivation mentioned by close to half of the respondents (7 out of 15) was to increase the quality of the 3D printers. The first RepRap models were notoriously hard to build and unreliable. By designing and commercialising better parts, or by designing sturdier models, respondents felt they could do better than what was available at the time on the market. This extended beyond the sole RepRap machines. Some respondents declared that they were convinced they could even do better than what the incumbent machines were doing, since even 'professional grade' machines in the late 2000s/early 2010s were, besides being costly, unpredictable and hard to use and to maintain. In regard to the RepRap machine, respondents mentioned that often the very nature of the RepRap project (that is the self-reproducibility of the machines) was at the heart of the reliability issues. This led to four of the respondents to distance themselves from the RepRap project (although they might still engage in open hardware) by commercialising machines that are hardly self-reproducible, since they involve machined parts (such as the chassis) in wood, polycarbonate or aluminium, that simply cannot be 3D printed.

While most respondents declared their aim was to serve the market at large, four of them mentioned that they decided to commercialise in order to serve a niche, whether related to quality, materials, features (e.g. multi-function 3D printers) or size. Finally, two respondents mentioned enabling further innovation as a reason to commercialise. In one case, commercialisation enabled the company to fund future R&D. In the other case, the respondent

believed that if there was not a cheap access to reliable and standardised parts, innovation within the RepRap community would be hindered.

Interestingly, 9 out 15 interviewees can be considered as User Innovators, either because they innovated as a result of using 3D printers as a hobby (five of them) or as a part of their professional activities (four of them). In the case when interviewees acted as user innovators, once they had innovated for themselves, the additional cost of commercialisation was seen as fairly minor and enabled them to recoup their initial R&D costs. This is particularly the case for two of the companies interviewed who already benefited from a well-established distribution network. In this respect, six of the 15 interviewees mentioned that they already operated a related business (e.g. software or design service) and saw an opportunity to expand their activities in a new direction. Finally, two of the respondents could be described as 'serial entrepreneurs', while three of them come from an academic environment.

5.2 Norms Related to Commercialisation

During the interviews, all the respondents were asked about their view on commercialisation of open hardware (including commercialisation of hardware based on open hardware). As could be expected, respondents whose company is directly involved with or closely related to RepRap expressed a clearer opinion on this matter.

Overall, interviewees expressed that commercialising open hardware (e.g. the RepRap Prusa Mendel) or hardware based on open hardware (e.g. a 3D printer that is partly based on RepRap design) is acceptable as long as the company contributes back. While this is by no means surprising, what is interesting is that interviews revealed a wide range of types of contributions, as well as intensity. Furthermore, respondents also mentioned cases when commercialisation of open hardware is acceptable even if the company does not contribute back at all. Finally, some interviewees mentioned cases when commercialising is never acceptable (presumably even if the company contributes back).

The following sections detail the norms related to commercialisation of open hardware identified in the interviews.

5.2.1 Commercialisation can be acceptable if the company contributes [N1]

Interviews showed that one of the most widespread norms is that commercialisation of open hardware or hardware based on open hardware is acceptable for as long as the company

commercialising contributes back in some way. Interestingly, respondents mentioned various types of contribution that can be classified as either direct or indirect.

5.2.1.1 Direct Contribution [N1.1]

Respondents mentioned that commercialisation was acceptable if the company commercialising contributes to open-hardware development. As noted by the respondents, the most straightforward way to do that is to share all details of the commercialised machine [N1.1.1] as well as improvements made [N1.1.2] with the rest of the community. This norm is certainly the most obvious one, since it is at the core of the open hardware philosophy. It is also embedded in various open hardware licences, as well as in the GPL (GNU Public Licence) which is widely used within the RepRap community.

While such norms have also been observed in Open Source software communities, interviews revealed differences that stem from the fact that physical products are involved. For instance, as noted by several interviewees, contributing back is not just about sharing improvements. Indeed, unlike compiling a piece of computer code to make software, building a 3D printer requires far more details, as the specifications of every single part need to be known. While this may not be an issue for the parts that are to be 3D printed (because, arguably, all information needed is embedded in the digital blueprint enabling to print the part), it is critical for the other parts. For instance, one needs to know precisely which circuit board to use, what the exact dimensions of the threaded rods are, which kind of nozzle is to be used. Such information is so critical that several respondents mentioned that the Bill of Materials (BOM) related to a particular printer model should not only be fully exhaustive in regard to the parts used, but should also provide precise information about where these parts can be obtained. Indeed, in regard to quality, not all parts are made equal and some of the flimsiness and unreliability of RepRap printers also stems from the inability to source good enough parts (e.g. threaded rods that do not bend). Some respondents even mentioned that the price of the parts should be disclosed in the BOM, so to enable the community to get access to cheaper resources.

While contributing back is not just about sharing improvements, publishing modifications made to open hardware printers or parts is seen as essential by the RepRap community. In this respect, several respondents have noted that, besides publishing an exhaustive BOM, companies that commercialise RepRap printers may be required to make significant improvements [N1.1.2.1] and, hence, take an active part in the R&D effort, as otherwise they

might be seen as free-riders and might be shunned by the community. One interviewee even mentioned that gaining community acceptance was one of the reasons behind their decision to develop an entirely new RepRap printer model.

Besides sharing back information, interviewees also mentioned other forms of direct contributions that can make commercialisation acceptable. For instance, one respondent mentioned that providing resources to the community [N1.1.3], such as hosting an online forum or an online sharing platform, or providing support and guidance to the community in general (especially to newcomers) [N1.1.4] can make commercialisation acceptable even if the company does not 'share back' and adopts a closed source strategy.

5.2.1.2 Indirect contribution [N1.2]

Interviews revealed that beyond direct contributions (whether contributions to product development, information sharing or providing resources), there are some forms of indirect contributions that make commercialisation acceptable.

For instance, commercialisation may be acceptable because by commercialising the company helps develop skills and knowledge [N1.2.1]. This is a typical spill over/positive externality case. By providing support to their own customers, companies help build the skill and knowledge base of the community, hereby decreasing training and assistance costs to others. To this respect, it can be noted that one interviewee mentioned not providing support to one's customers as being, from the community's perspective, the worst 'betrayal'. When asked about companies that sell straight RepRap clones (i.e. that do not make improvements) of poor quality without conforming to open hardware licences (e.g. without releasing the BOM and other blueprints), this interviewee mentioned that what the community was really unhappy about was that, because of the lack of support provided by such companies to their customers, the community had (through online forums, IRC chat, etc.) to bear the burden of technical support.

Two interviewees also mentioned, as an indirect contribution, that commercialisation could benefit the community by providing access to cheaper resources, parts in particular [N1.2.2]. Although this is especially the case when the commercialising company releases the details of the suppliers and the costs of parts in the BOM, respondents noted that even without that commercialisation had a positive effect simply because larger volumes of parts ordered led to economies of scale that benefited the whole community.

Another indirect contribution mentioned by four interviewees as making commercialisation acceptable is simply that commercialising, even without sharing anything back or contributing in any way, helps grow the market [N1.2.3] by raising awareness about 3D printers. Likewise, three interviewees mentioned that commercialisation helps diffuse innovation, which is an indirect benefit for the community [N1.2.4].

5.2.2 Commercialisation May Be Acceptable Even Without Contributions [N2]

Four of the interviewees consider that even commercialising a closed source RepRap clone without any improvement could be acceptable under some circumstances. One of those respondents mentioned that the market was growing and that there was space for everyone anyway, which meant that the market share of obedient companies was not competed away by deviant ones. Also, related to market size, one of the interviewees told of the case of a 'deviant' whom they caught commercialising straight clones of their products under closed licence and without any acknowledgement of the source, but said it did not matter because it was a one-man operation that produced very low volumes. Hence, commercialisation may be acceptable even if the company does not contribute if the company's size in relation to the market is small [N2.1], either because the market grows faster than the company [N2.1.1] or because the company is genuinely small [N2.1.2].

Finally, although this opinion was really not prevalent amongst interviewees, one respondent mentioned that commercialisation even of straight clones without any sort of contribution could be acceptable for as long as the work of the creators was acknowledged by the commercialising company [N2.2]. Being even more tolerant, one of the interviewees mentioned that he was OK with companies commercialising his work even when he was not credited, simply because it made him happy to see people using his creation [N2.2.1].

5.2.3 Commercialisation May Never Be Acceptable

Interviewees also mentioned cases when commercialisation was simply not acceptable. This was in particular the case of two respondents who had recently switched from the totally open GPL licence for their printers to a far more restrictive 'NC' (Non-Commercial) licence. In both cases, the aim was simply to prevent other companies from commercialising clones of their products. Both respondents indicated that they would only allow commercialisation of add-ons and specific parts based on their designs, but not entire printers [N3.1].

Another case when commercialisation of open hardware or hardware based on open hardware is when the company carrying out this commercialisation is a large company. One interviewee

expressed the concern that such a company could undercut in price smaller and more innovative companies and, hereby, stifle innovation [N3.2].

Finally, while some respondents reported a very lax attitude of members of the community even towards firms that clearly appear to be free riding, other community members appear to be biased against commercialisation. For them commercialisation is never acceptable [N3]. Respondents have for instance mentioned the case of a member of the RepRap community castigated by other members for commercialising a printer part he had personally led the development of and which would never have been released otherwise. [6]

5.2.4 Other Norms Related to Commercialisation: Going Closed Source and Patenting

Two norms within the RepRap community related to commercialisation had been identified prior to the beginning of the first stage of this study. Indeed, one of the starting points of this research was the controversy within the RepRap community that was caused by the company Makerbot when they switched from open hardware to closed hardware for its new printer and appeared to have patented innovations that had been developed jointly with the community (the Makerbot case is discussed in detail in section 6).

Thus, it appears that for the RepRap community, it is not acceptable for a company to release closed source products if this company had beforehand released products as open hardware [N4]. The logic is quite clear: a new product is necessarily based on the previous ones and, hence, is at least partly based on contributions made by the community. Secondly, it is not acceptable for a company to patent inventions that have been developed jointly with the community (nor is it, a fortiori, acceptable to patent inventions that have been developed independently by the community) [N5]. These two norms were also mentioned during the interviews. Interestingly one of the respondents stated that while Makerbot going closed source was an issue for the community, the patenting of community innovations was really what turned the community against Makerbot.

5.2.5 Summary of the norms identified

5.2.5.1 Norms related to commercialisation

N1 Commercialisation is acceptable if the company contributes back

N1.1 Commercialisation is acceptable if the company contributes back *directly*

[6] The part in question could not be 3D printed and had to be manufactured in a regular factory.

N1.1.1 Commercialisation is acceptable if the company contributes back *directly by sharing exhaustive documentation*

N1.1.2. Commercialisation is acceptable if the company contributes back *directly by sharing improvements*

N1.1.2.1 Commercialisation is acceptable if the company contributes back *directly by sharing* **significant** *improvements*

N1.1.3 Commercialisation is acceptable if the company contributes back *directly by providing resources to the community*

N1.1.4 Commercialisation is acceptable if the company contributes back *directly by providing support and guidance (especially to newcomers)*

N1.2 Commercialisation is acceptable if the company contributes back *indirectly*

N1.2.1 Commercialisation is acceptable if the company contributes back *indirectly by developing skills and knowledge*

N1.2.2 Commercialisation is acceptable if the company contributes back *indirectly by providing access to cheaper resources*

N1.2.3 Commercialisation is acceptable if the company contributes back *indirectly by growing the market*

N1.2.4 Commercialisation is acceptable if the company contributes back *indirectly by diffusing innovation*

N2 Commercialisation **is** acceptable **even when** the company **does not** contribute back

N2.1 Commercialisation **is** acceptable **even when** the company **does not** contribute back *if its size relative to the market is small*

N2.1.1 Commercialisation **is** acceptable **even when** the company **does not** contribute back *if its size relative to the market is small because the market is growing*

N2.1.2 Commercialisation **is** acceptable **even when** the company **does not** contribute back *if its size relative to the market is small because the company is genuinely small*

N2.2 Commercialisation **is** acceptable **even** if the company **does not** contribute back *if the company acknowledges the work of the contributors*

N2.2.1 Commercialisation **is** acceptable **even** if the company **does not** contribute back **and does not acknowledge the work of the contributors** *because this makes contributors happy to see people using their creation*

N3 Commercialisation is **never** acceptable

N3.1 Commercialisation is **never** acceptable *if a full printer model is commercialised*

N3.2 Commercialisation is **never** acceptable *when it is carried out by a large company*

5.2.5.2 Other norms

N4 Going closed source after having been open source is not acceptable

N5 Patenting inventions contributed by the community is not acceptable

5.3 WHY CONFORM TO THE NORM?

As discussed in the previous section, the interviews carried out in Stage 1 have enabled to identify a very important norm within the RepRap community: it is acceptable to commercialise open hardware as long as you 'give something back' to the community. Yet, whether it is documentation, blueprints of improvements, or physical resources that are contributed back, this bears a significant cost and it is reasonable to assume that there is a temptation to free ride and appropriate the returns of the contributions of the community without giving back. In this respect, interviews have confirmed that even just 'sharing back' (i.e. publishing Bills of Materials and documented improvements) is indeed costly (because time consuming). So, what drives companies commercialising RepRap open hardware (or hardware based on RepRap hardware) to share and contribute back?

There are in fact purely selfish reasons to share. For instance, one interviewee mentioned that publishing an exhaustive Bill of Materials subsequently enabled to generate significant savings, as members of the community were able to identify cheaper sources for some materials and parts. Likewise, in early product development stages, sharing is a way for small companies lacking critical resources (i.e., cash and access to Intellectual Capital), to make the community contribute to the R&D effort. This is precisely what MakerBot did with its first three generations of 3D printers.

Yet, just as the example of MakerBot shows, once the product has matured enough, the selfish reasons to share tend to dwindle and the temptation to 'defect' gradually becomes stronger. This is evidenced in our interviews, by the fact that a significant proportion of companies have either switched to closed source or adopted more restrictive licences (for instance some that prevent commercialisation) for their third or fourth generation of products. Interestingly, one respondent mentioned that while they had been using a non-commercial licence for their last product, they would switch to the GPL one (which is fully open and allows

commercialisation) for their next product, because it was a far more ambitious development that would require a significant input from the community.

Besides these selfish reasons to share, what are the reasons to contribute back? There is, of course, the threat of punishment (being shunned by the community) if one does not contribute back. However, only one respondent mentioned this as a motivation. In contrast, three respondents declared that they were sharing back because it was for them 'the right thing to do' and they considered it was normal to give back something to the community that had helped them. Unsurprisingly, these interviewees were amongst those who had the closest ties to the RepRap community. Yet, for some, altruistic sharing goes beyond a simple 'tit-for-tat' and one interviewee mentioned that sharing was simply a way to change the world, no less.

Aside from the issue of the cost it entails, one key reason to avoid sharing for commercialising companies is to prevent competition. In regard to competition with users (who would be able to build the printer themselves without paying), however, two respondents declared that this was not a problem because the commercialising company retains a scale-based cost advantage. Indeed, individuals aiming to source the parts on their own usually rapidly realise that it is going to be costlier for them to do so than to buy a full kit from the commercialising company. This also applies to small-scale entrepreneurs attempting to commercialise clones of established models. In this respect, one of the respondents also noted that sharing was not an issue, because the company that developed the original model has brand and reputation that new entrants, cloning its product, do not have.[7] Finally, two respondents mentioned that in order to avoid losing their competitive advantage, they were not publishing improvements straightaway. One was only publishing information about the previous generations, while keeping information about the current generation secret. The other one declared waiting six months before releasing exhaustive information.

A final reason to share mentioned during the interviews is that closed source models are copied and cloned anyway, so companies might simply be better off sharing (since they can benefit from community input). Interestingly, two respondents noted that clones of the Replicator 2, the first closed source Makerbot printer, were widely available. Another interviewee, who works for a company that produces closed source printers with proprietary filament cartridges also reported that users had hacked their printers so that they could use

[7] It is interesting to note that one respondent mentioned a case when a cloner not only copied their printer, but also used the same brand, logo and documentation, which, of course, regardless of the openness of the licence is a clear IP infringement and amounts to counterfeiting,

(much cheaper) generic filament. So, going down the non-proprietary route might indeed have been more effective.

While most respondents provided reasons why commercialising companies should conform to the norm and share, other, in contrast, gave reasons why they should not. Besides the fact that sharing might simply be too time consuming and costly, three respondents mentioned they were not (or had stopped) sharing because they did not expect (or had noticed) any contribution from the crowd. Some respondents, while they had engaged in open hardware, actually questioned its effectiveness, noting that far too few people were using their product for any significant community contribution to take place. Some even noted that suggestions and improvements from the community were either too obvious (and the commercialising company had already thought of it), or responded to far too specific needs to be of any value for the company.

Three respondents declared they were not sharing simply because they believed in closed source and specific development. Interestingly, although two of these respondents denied having used RepRap body of knowledge to develop their own printers, looking at these printers there are clear signs that they did.

Finally, one interviewee mentioned the case of companies that were cloning RepRap models without contributing back. However, because they these printers are white-label products, which are then marketed and sold by other companies, the free-riding cloners do not face the consequence of not sharing.

6 CONFIRMING THE NORMS: THE MAKERBOT CASE

While there have been other cases, the best-known case of deviation from the norm within the RepRap project is related to MakerBot's switch from open hardware to closed hardware and the subsequent attempt of the company to obtain patents related to innovations that had been contributed by the RepRap community.

6.1 THE STORY OF MAKERBOT

Nowadays one of the market leaders on the "Desktop 3D Printer" market, MakerBot was funded in 2009 by Adam Mayer, Bre Pettis and Zack Smith, who was at the time very active in the RepRap community. Unsurprisingly, Makerbot's first 3D printer, CupCake, introduced in 2009, drew heavily on existing RepRap projects. For instance, its electronics was close to identical to the RepRap Mendel 3D printer, to the point that CupCake and Mendel

motherboards could be used interchangeably[8]. CupCake was an Open Source design, and the related files were made available under the GPL licence on the Thingiverse platform.[9] Because if its open-hardware nature, CupCake gave rise to significant user innovation, with the community suggesting improvements and even designing upgrade parts. Makerbot released its second 3D printer model in 2010. Thing-O-Matic included many of the popular CupCake upgrades and the blueprints enabling to manufacture the printer were also publicly released under GPL licence.[10] Several upgrades released during the lifetime of the product were also made publicly available.[11] The third-generation model, Replicator, was released in January 2012. Its blueprints were also released to the public, albeit under a difference licence (Creative Commons Attribution Share Alike instead of GPL). Replicator was quite a popular product and is still nowadays used as a basis by Chinese manufacturers for their products aiming at the low end of the market.

Interestingly, it can be noted that while generations 2 and 3 of MakerBot printers (Thing-O-Matic and Replicator) were Open Source, their development appears to have been conducted in secret rather than openly, as it is traditionally the case.[12] So they were 'open release' but 'closed development'.

In contrast to these three initial models, MakerBot's fourth 3D printer, Replicator 2, released barely a couple of months after its predecessor (in September 2012), was completely closed source, both on the hardware and on the software side. This sudden and unannounced shift from open to closed source created quite a controversy in the RepRap community, as many felt that with Replicator 2 Makerbot had packaged all the improvements and upgrades made by the community to the original Replicator (which was itself based significantly on the work of the community), closed the door, and cashed out.[13]

In addition to the 'betrayal' of going closed source, it also became known at the time that MakerBot had, unbeknownst to anyone, filed and obtained patents inspired by or directly based on the work of people in the RepRap community.[14] This move, perhaps even more than

[8] http://reprap.org/wiki/Generation_3_Electronics#MakerBot_Electronics
[9] http://www.thingiverse.com/thing:457
[10] http://www.thingiverse.com/thing:4973
[11] E.g. http://www.thingiverse.com/thing:3290 and
[12] http://www.hive76.org/hoeken
[13] http://hackaday.com/2012/09/20/makerbot-occupy-thingiverse-and-the-reality-of-selling-open-hardware/, http://josefprusa.cz/open-hardware-meaning/, http://www.hoektronics.com/2012/09/21/makerbot-and-open-source-a-founder-perspective/
[14] See for instance http://blog.reprap.org/2010/07/continuous-belt-production.html

the move towards closed source (which was still seen as acceptable by necessity by some of the members of the RepRap community), was considered as the ultimate breach of trust and led to a massive uproar in the community.

Name	Number	Filling date	Granted
Automated 3D build processes	8,282,380	Aug 18, 2010	Oct 9, 2012
Multi-extruder	8,512,024	Jan 20, 2011	Aug 20, 2013
Three-dimensional surface texturing	8,529,240	Jul 5, 2011	Sep 10, 2013
Networked three-dimensional printing	8,425,218	Jan 12, 2012	Apr 23, 2013

Table 1 Patents filed and obtained by MakerBot before the public announcement of its switch to closed source

Indeed, while MakerBot's betrayal was first attributed by many in the community to the USD 10m investment received from the Foundry Group in August 2011[15]—many claiming this was the Venture Capitalists' doing, not MakerBot's—it became rapidly obvious, considering the filing dates of the patents (as early as 2010), that this strategy was already in the cards much beforehand.

The third controversy surrounding MakerBot occurred as a direct consequence of the two previous ones. In 2008, MakerBot launched Thingiverse, which rapidly became the largest repository of 3D printing blueprints/designs, and a central asset for the RepRap community. In particular, besides arts, objects and accessories, the blueprints of most of the improved parts for MakerBot 3D printers (but also other open hardware printers) were hosted on Thingiverse. Concerned by the move of MakerBot towards closed source, members of the community began to thoroughly examine the Terms of Use of Thingiverse and found that some of the terms appeared to imply a transfer of ownership from the creators of the objects put online on Thingiverse to MakerBot.[16] Interestingly, it turned out that there had not been any change made in Thingiverse Terms of Use since 2011, long before MakerBot's (official) move towards closedness. But the 'betrayals' of MakerBot led the community to become highly suspicious of anything related to MakerBot.

Makerbot was eventually purchased by Stratasys, one of the three market leaders (and original inventor of FDM technology), via a stock deal (estimated at USD 403m), in June 2013.[17] So

[15] http://www.businessinsider.com/foundry-group-invests-in-makerbot-industries-2011-8?IR=T

[16] See http://www.thingiverse.com/thing:30808/#comments and http://hackaday.com/2012/09/20/makerbot-occupy-thingiverse-and-the-reality-of-selling-open-hardware/

[17] http://techcrunch.com/2013/06/19/stratasys-acquiring-makerbot-combined-company-will-likely-dominate-3d-printing-industry/

far, Stratasys has continued operating Makerbot as a distinct brand targeted at consumers and SMEs.

To this day, Makerbot still releases publicly the sources of some of its components (mainly software),[18] but unlike before, it is now impossible for someone to build a Replicator 2 (or its successors) without hacking/reverse engineering some of the components (which would lead to IP infringement if sold).

6.2 THE REACTION OF THE COMMUNITY AS EVIDENCE OF NORMS

Makerbot did not, at first, admitted that they were going closed source. Instead, this information was spread by pillars of the community, such as Josef Prusa, through their blogs. [19] As controversy started to brew within the RepRap community, Makerbot attempted to cool things down by posting justifications of their new strategy on their blog.[20] Such blog entries, but even more, the comments posted by members of the RepRap community in reaction to these blog posts can be used to confirm the existence of the norms that were identified in the interviews.

A first interesting point is that Makerbot, when going closed source, did not by accident breach a norm they were not aware of. Indeed, back in 2010, and as mentioned in the introduction, Bre Pettis wrote on Makerbot blog: "Sometimes an individual or a company makes a derivative of an open source project, goes to market with it and then doesn't share their derivative designs with their changes. This is not only against the licence, but it's also not ethical" and "there is absolutely nothing wrong with creating a derivative and selling it as long as you provide the source files". [21] This clearly corresponds to the norms [N1.1.1] and [N1.1.2] identified in the interviews. Further on in the blog post, Pettis states that "just copying the design doesn't bring much innovation to the community and it's not the classiest move", which means that significant improvements are expected [N1.1.2.1]. Although this blog post is followed by a rather heated debate in the comments section, it is to be noted that all the comments posted tend to confirm the existence of these three norms.[22] Yet, one contributor mentions that "Open Source Hardware is in its infancy, and the community at

[18] https://github.com/makerbot
[19] See for instance http://josefprusa.cz/open-hardware-meaning/
[20] http://www.makerbot.com/blog/2012/09/20/fixing-misinformation-with-information
[21] http://www.makerbot.com/blog/2010/03/25/open-source-ethics-and-dead-end-derivatives
[22] The debate is about whether Pettis had the right to name and shame a company as having breached the norm, when the company representative had declared they were working on providing the necessary documentation.

large is mostly ignorant of how to be good citizens." So, the norms, while already existing did not appear at this time to have completely set.

Fast-forward to August 2012, just a month before the release of the closed source Replicator 2, a blog post discussing the market entry of a company commercialising (from the company's own account) a "one-to-one copy" of Makerbot Replicator for a far cheaper price provides interesting insights into the norms of the RepRap community. [23] 40 of the comments posted as a reaction to this blog post mention norms. The three most prevalent normed mentioned are [N1.1.2.1] (commercialisation is acceptable as long as significant improvements are made), 14 times, [N1.2.4] (commercialisation even without contribution is acceptable because it promotes diffusion), 11 times, and [N1.1.1] (commercialisation is acceptable as long as exhaustive documentation is published).

Hence, following the entry of this "copycat" the debate revolved around whether it was acceptable to commercialise straight clones or not. While some think it is not and significant improvements need to be made [N1.1.2.1], others argued that the "copycat" contributes indirectly by driving prices down and improving diffusion [N1.2.4]. Finally, many noted that Open Hardware only requires to provide exhaustive documentation [N1.1.1] and that commercialising firms have no obligation to make improvements. In this discussion, norms [1.1.3] (direct contribution by providing resources to the community), [N1.1.4] (direct contribution by providing support), [N1.2.3] (indirect contribution by helping the market grow), and [N2.1.1] (commercialisation is acceptable even without contribution because the market is growing) were also mentioned, albeit in a fairly minor extent (respectively, 3, 1, 2, and 1 times). Interestingly, [N2.2] (acknowledgement of contributors) is also mentioned, but rather as a negative aspect. Indeed, it appeared to some that the company was using contributor's acknowledgement as a way to hijack trademark: by mentioning so extensively and so boldly that their printer was a Makerbot Replicator clone, the "copycat" gave the impression that it was riding on Makerbot's reputation and fame.

While the newcomer "copycat" may not have been fully cognisant of the norms prevailing in the RepRap community, it is clear that Makerbot, when releasing Replicator 2 as closed source just a month later, was very much aware that this move was against the norms in the community. By releasing Replicator 2 as closed source, they, as a company, were "making a derivative of an open source project" (Replicator 1, but also by extension the RepRap

[23] http://hackaday.com/2012/08/10/tangibot-and-the-perils-of-open-source-hardware/

project), "[going] to market with it and then [would not] share their derivative designs with their changes", which, taking Bre Pettis's own words in 2010, was "not only against the licence, but it's also not ethical".[24] The fact that Makerbot knew they were breaching the norm is further evidenced by the fact that, while not releasing the sources of the new model, they were also very reluctant to announce publicly that they would simply not do so.

After Josef Prusa 'broke the news' in one of his blog posts, [25] several blog posts of other community members followed,[26] until Bre Pettis of Makerbot eventually felt compelled to post a response to the growing questions of the community members, in which he reluctantly admitted that releasing the sources of Replicator 2 was not in the agenda. [27] This admission led to further blog posts of community members, including one by Zach Hoeken, one of the founders of Makerbot, who had, in the meantime, been pushed out of the company.[28]

Besides the respective views of these prominent members of the community, many other members expressed their feeling about Makerbot's switch to closed source in the comment section of some of these blog posts. Using these blog posts, as well as the comments posted (close to 300), enables to assess the validity of the norms identified in the interviews.

As could be expected, the norms that are more often mentioned are [N4] (going closed source after having been open is not acceptable) and [N5] (patenting inventions contributed by the community is not acceptable). Other norms are present in the comments, though, in particular [1.1.3] and [1.1.4], as some members of the community sided with Makerbot because they felt the company had significantly contributed to the community by providing resources and support. Another argument used by both Makerbot and its proponents is that this move would enable to grow the market [N1.2.3] and diffuse the technology [N1.2.4]. In contrast, disgruntled community members pointed out that Makerbot had in fact not contributed significantly enough, because the company had not made significant enough improvements [N1.1.2.1], because the documentation it had released in the past was incomplete [N1.1.1], or simply felt that Makerbot's direct contribution was insufficient [N1.1].

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[24] http://www.makerbot.com/blog/2010/03/25/open-source-ethics-and-dead-end-derivatives
[25] http://josefprusa.cz/open-hardware-meaning/.
[26] See for instance, http://makezine.com/2012/09/19/is-one-of-our-open-source-heroes-going-closed-source/ and http://hackaday.com/2012/09/20/makerbot-occupy-thingiverse-and-the-reality-of-selling-open-hardware/.
[27] http://www.makerbot.com/blog/2012/09/20/fixing-misinformation-with-information.
[28] See http://www.hoektronics.com/2012/09/21/makerbot-and-open-source-a-founder-perspective/ and http://makezine.com/2012/09/22/makerbots-mixed-messages-about-open-source-their-future/ .

Some of the arguments mentioned by Makerbot to defend its decision relate to other norms. For instance, the company repeatedly mentions the threat of large companies entering the market and wiping out smaller firms, which corresponds to the norm [N3.2]. Furthermore, Bre Pettis of Makerbot repeatedly complains about cloners, so it appears that for the company, commercialisation of their products by another company is only acceptable if they do not commercialise the full printer [N3.1].

Unlike in the case of the "copycat", norms related to the relative size of the company [N2.1] were not mentioned, possibly because Makerbot was already one of the main market players and was, furthermore, targeting the upper side of the market, with comparatively more expensive printers.

Only two norms identified in the interviews, [N1.2.1] (indirect contribution by developing skills and knowledge) and [N1.2.2] (indirect contribution by providing access to cheaper resources), were not explicitly mentioned in any of the comments or blog posts. However, implicitly, these two norms can be linked with, respectively, [N1.1.4] (direct contribution by support and guidance) and [N1.2.4] (diffusion). For the latter, it is obvious that the resulting sales volumes of the "copycat" smashing prices, would drive the cost of parts down for the whole industry.

Examination of the blog posts and comments did not enable to identify additional norms. However, it provided nonetheless some interesting additional insights. For instance, if not conforming to the norm is indeed not acceptable, can this be tolerated if this happens in reaction of someone else breaching the norm? For some members of the community, it appears that it is, as several of them justified Makerbot's move towards closed-source by the fact that other "copycat" companies had broken the rules.

The analysis of the blog posts and comments also revealed the prevalence of the norms as regulator in the community. Indeed, both Bre Pettis of Makerbot and various commentators refer to "unwritten rules" and "unspoken rules". This is particularly important, as, considering that open source hardware is based on very specific and detailed licences, one could have expected norms to play a fairly minor role. As noted by a commentator: "there is more to the OSHW community than just the schematics and CAD files. There is an entire ecosystem of camaraderie, competition, acknowledgement, praise, disagreement, and sharing of resources. This is what makes OSHW projects actually work. And this is what you lose if you slight that community, even though you obey the written rules." Bre Pettis also mentions that "the cloners are getting better and faster and are ignoring the unspoken rules of open source

hardware". While "copycats" may well satisfy written rules (e.g. GPL licence) by releasing documentation of their hardware (which also corresponds to the norm [N1.1.1]), this may not, in fact, be sufficient to conform to the norm (as a matter of fact, this was confirmed by the analysis of the comments following the entrance of the "copycat", as norm [1.1.2.1], which requires significant improvements to be made, was the most prevalent).

Yet, while the existence of such "unwritten rules" could at first appear to provide a competitive advantage to insider companies over outsiders (for instance, while the "copycat" did abide to the written rules, the project eventually derailed because of a very hostile and extensive campaign of community members), Bre Pettis blames these "unwritten rules" for the discontentment in the community following the move to closed-source. He also criticises norms for being a handicap: "we've started competing with billion dollar companies with arsenals of weapons that make depending on the open-source hardware unspoken rules feel like a vulnerable position". However, one can help wonder how genuine the argument is, since it appears that back in 2010, the "unwritten" rules appeared to be very clear to Makerbot.

As a result, to its move to closed-source, and in spite of numerous attempts made by Bre Pettis to explain the rationale of this strategy, Makerbot has nowadays a bad name and is still regarded as having betrayed the community. This was clearly confirmed in our interviews. This is particularly interesting because some of the companies in our sample could be characterised as having 'pulled a Makerbot', since they have switched from open to closed-source. It does not appear, however, that they had to suffer a large backlash from the community.

From the interviews, two explanations can be envisaged. The first one is that some of these companies switched to closed-source because they obtained little if any contribution from the community, while developing a fairly original product (i.e. not a straight RepRap clone). Since the community has not contributed anything and the company has provided significant R&D, it is unlikely anyone in the community would feel 'ripped-off' by such move. In another case, the company that switched to closed source is a pillar of the community (albeit in its respective country), as, just like Makerbot, it has provided large resources to the community. Unlike Makerbot, however, its closed-source products are significantly different from the open source ones (which, by the way, have remained on sale). So maybe, indeed, there are additional "unwritten rules" in the community, which relate to the significance of the improvements made by the company, as well as of its size, when going closed source.

6.3 SANCTIONS

A final point of interest relates to what happens when norms are violated. As a reaction to Makerbot's move towards closed-source, many members of the community, whether individuals, companies or research labs, mentioned that they would no longer consider purchasing Makerbot products. Others declared that they would no longer contribute to Makerbot's products (while Replicator 2 was closed source, the previous generation products, still, available for some of them at the time, were still open hardware). This strong reaction even concretises into a social movement called "Occupy Thingiverse", initiated by J. Prusa, of the name of the platform set by Makerbot for members of the community to share some of their designs and contribute to posted designs. Campaigns also arise with mottos like "Boycott Makerbot. They are stealing intellectual property from us, the users. Don't let them win!"

More generally, sanctions include: making calls to boycott badly behaved actors and not buying their products [S1]; stopping contributing to their projects [S2]; gossiping against them in the community to damage their reputation [S3]. In addition, some community members suggest to reverse engineer the product and to publish it in open-source [S4]. For instance: "So when someone does this…. This sneaky underhanded thing…. Immediately reverse engineer and make a fully open source version. I am sure you'll find some help. After all, they took all the open source stuff and repackaged it, with the only innovations being a neat GUI on top and a good metal frame. … And let's NOT buy the closed model shall we?" (L.K. 09/23/2012).

It seems these sanctions have some efficiency. According to J. Prusa, one of the most prominent members of the RepRap community, "community loyalty can protect you from clones. … The Makerbot community a few weeks ago totally smashed the Tangibot [Note: a clone of a Makerbot printer launched by M. Strong]. We all saw that as huge win for open hardware and consumer loyalty. So, there is no need to fear clones that much." Prusa even uses the expression "they tangibotted themselves" to designate a company that has cloned an existing open source printer and was sanctioned by the community. (09/2012.) Interestingly this comment by J. Prusa was a response to MakerBot's claim that going closed source was a response to the threat of clones: for Pettis, co-founder of MakerBot (09/2012) "we have to stay nimble to face the increased competition from both the bottom and the top of the 3D printing market" and "I don't plan on letting the vulnerabilities of being open hardware destroy what we've created". Consequences can thus take the form of (i) a failure of the

project or of the company (ii) a loss of valuable employees, like in the case of MakerBot (iii) greater difficulties to get inputs and help from knowledgeable users.

7 DISCUSSION

Informal institutions aimed at providing a framework for agents to share knowledge are typically regulated by norms relative to intellectual property (e.g. Merges, 2003; Fauchart and von Hippel, 2008).

This study emphasises the existence and strength of a related set of norms, norms relative to commercialisation, in an open and collaborative community, the RepRap community. Norms help protect community contributions and community commons from misappropriation and ultimately help sharing communities to persist. Commercialisation, in this respect, tends to be seen as a threat for open and collaborative communities as it is usually associated with behaviours that are opposite to those founding openness and free sharing. Yet, our results show that norms help alleviate the threat of commercialisation because they favour certain types of commercialisation and discourage other. In particular, our findings indicate that commercialisation building on community contributions is acceptable if those who commercialise do contribute back to the community in a way or another, do not wrongly misappropriate community contributions (i.e. like patenting community contributions), and/or publish their own contributions. Our findings also show evidence of these norms by pointing out at episodes of norms' violation and community reactions. Community sanctions include calling to boycott vendors who have misbehaved, gossiping against them, and refusing to further help them develop their products.

7.1 NORMS' EFFECTIVENESS

Are norms effective in regulating commercialisation behaviours? This question is still work in progress (we are in the process of sending a survey to capture norms and their effectiveness) but a few points deserve to be discussed. First, norms are effective if they prevent commercialisation to hurt the community by discouraging contributions and free sharing. In other words, despite the fact that vendors do build on community contributions to define their offer, community members keep contributing freely. They are also effective if they force vendors to adopt constraining behaviours like for instance publishing their own developments despite the cost and effort of doing so and even if competitive disadvantages might follow.

Finally, they are effective if the vendors who deviate from or violate the norms subsequently suffer from their misbehaviour. Our findings show evidence of these different expressions of the effectiveness of norms.

7.2 IMPLICATIONS AND CONTRIBUTIONS

Our findings have implications and make contributions to different strands of literature.

First, it enriches our knowledge of the functioning of open and collaborative communities as it points out at an overlooked set of norms which are critical to the persistence of numerous communities. An important question is to know when these norms might be important sources of community self-regulation. An essential characteristic of the community we studied is that it is an open-hardware community and, thus, that it involves physical products. When physical products are concerned, the cost of reproducing units of the product for adoption by users become a critical issue, absent from situations where only digital products are involved. In such a situation commercialisation brings significant benefits to the community of users (see first part of the findings section) despite its potential drawbacks. Our conjecture is that commercialisation, regulated by norms, provides net benefits to the community of 3D printer users which makes it an acceptable behaviour in certain limits. (Note that hobbyists and expert users might be distinguished from the average user.)

Second, and related to the previous point, our findings contribute to the literature on innovation and diffusion. Observers of open and collaborative communities have tended to neglect the cost of adopting innovations and new products because they have tended to focus on digital products (i.e. open source software communities). Yet, when physical products or hardware is concerned, the cost of adoption becomes non-trivial for the interested users and the cost of diffusion becomes non-trivial for the innovator (e.g. de Jong, von Hippel, Gault, Kuusisto, Raasch, 2014). Commercialisation is beneficial in this context as it motivates innovators or vendors to bear the cost of diffusing the product and thus facilitates adoption by interested users. Efforts to diffuse a 3D printer may for instance include: to make sure the printer works properly, which may not be always the case for self-made open source versions; and simply to be able to use a 3D printer, as it is not always, as we emphasised earlier, easy to make a printer oneself due to lack of expertise and difficulty to source the components. Thus, commercialisation regulated by norms seems to offer an optimal compromise between benefiting from the cumulativeness of innovations, permitted by openness and free sharing, and benefiting from an efficient diffusion, permitted by commercialisation.

In addition, our findings contribute to the literature on strategy as they point out at the business models adopted by vendors willing to build on the inputs of open and collaborative communities. The literature on open business models has emphasised the role and place of communities in the strategy of certain firms but our findings enrich the description of the possible open business models that firms or vendors can adopt. In particular, we emphasise the model where a vendor sells its product while disclosing the knowledge founding his/her offer. Future research, however, should study what the boundary conditions of such models are.

Finally, our findings contribute to the literature on entrepreneurship as they point out at a specific case of entrepreneurs who are "community entrepreneurs". As we leave the careful study of these entrepreneurs for future research, we can, however, report that it seems that these entrepreneurs have motivations and behaviours that differ from those of other types of firms like "copycats" or "big firms". In particular, the entrepreneurs who follow the norms tend to signal schizophrenic feelings as they both aim at being open while managing the constraints of commercialisation.

8 CONCLUSION

This paper identifies and emphasises the role of norms relative to commercialisation in the self-regulation of open and collaborative communities, a prevalent form, in modern economies, of informal institutions supporting knowledge sharing and knowledge commons. Norms relative to commercialisation are critical because while commercialisation provides important benefits to open and collaborative communities, especially when the production of physical products is involved, they also constitute a potential threat for the persistence of these communities. To be an efficient regulator, norms, however, need to be enforced or respected. Our findings suggest that communities react to violations of norms relative to commercialisation by trying to inflict damages to deviant vendors. Yet, while some vendors seem to have internalised the community norms, others, typically from outside the community, do not seem to follow the norms (i.e. "copycats"). Whether you want to be part of the community or not seem to be an important determinant of who respect the norms.

REFERENCES

Allen, R.C. (1983). Collective Invention. *Journal of Economic Behavior and Organisation*, Volume 4, pp. 1–24.

Alvesson, M. and Deetz, S. (2000). *Doing critical management research*. Sage, Los Angeles, CA.

Benkler, Y. (2002). Coase's Penguin, or, Linux and "The Nature of the Firm." *The Yale Law Journal,* 112 (3), pp. 369–446.

Benkler, Y. (2006). *The wealth of networks: How social production transforms markets and freedom*. Creative commons. Available online.

Bonaccorsi, A., Giannangeli, S., and Rossi, C. (2006). Entry strategies under competing standards: Hybrid business models in the Open source software industry. *Management Science*, 52 (7), pp. 1085–1098.

Corbin, J. M. and Strauss, A. (1990). Grounded theory research: Procedures, canons, and evaluative criteria. *Qualitative sociology*, 13 (1):3–21

Crook, C. W. and Kumar, R. L. (1998). Electronic data interchange: a multi- industry investigation using grounded theory. *Information & Management*, 34 (2):75–89

Dalhander, L. and Magnusson, M. (2008). How do Firms Make Use of Open Source Communities? *Long Range Planning*, 41(6), pp.629–649.

de Jong, J., von Hippel, E., Gault, F., Kuusisto, J.H. and Raasch, C. (2014). Market failure in the diffusion of consumer-developed innovations: Patterns in Finland. *Working Paper*.

Denzin, N.K., 2006. *Sociological methods: A sourcebook*, Transaction Publishers.

Fauchart, E. and von Hippel, E. (2008). Norms-based intellectual property systems: The case of French chefs. *Organization Science*, 19 (2), pp.187-201.

Grand, S., von Krogh, G., Leonard, D. and Swap, W. (2004). Resource allocation beyond firm boundaries: A multi-level model for Open Source innovation. *Long Range Planning*, 37(6), pp.591-610.

Guest, G., Bunce, A., and Johnson, L. (2006). How many interviews are enough? An experiment with data saturation and variability. *Field methods*, 18 (1):59–82

Henkel, J. (2006). Selective revealing in open innovation processes: The case of embedded Linux. *Research Policy*, 35 (7), pp.953-969.

von Hippel, E. and von Krogh, G. (2003). Open Source Software and the "Private-Collective" Innovation Model: Issues for Organization Science. *Organization Science*, 14 (2), pp.209-223.

Kvale, S. and Brinkmann, S. (2009). *Inter Views: Learning the Craft of Qualitative Research Interviewing*. Sage, Los Angeles, CA.

Lakhani, K. and Wolf, R. (2005). Why Hackers Do What They Do: Understanding Motivation and Effort in Free/Open Source Software Projects. *Perspectives on Free and Open Source Software*, edited by Feller, Fitzgerald, J.B., Hissam, S. and Lakhani, K. MIT Press.

Lee, G. and Cole, R. (2003). From a firm-based to a community-based model of knowledge creation: the case of the Linux kernel development. *Organization Science*, 14 (6), pp.633-649.

Merges, R. (2004). From Medieval Guilds to Open Source Software: Informal Norms, Appropriability Institutions, and Innovation. *Conference on the Legal History of Intellectual Property*. Madison, Wisconsin.

Miles, M. and Huberman, A. (1994). *Qualitative Data Analysis: An Expanded Sourcebook*. Beverly Hills: Sage.

O'Mahony, S. (2003). Guarding the commons: how community managed software projects protect their work. *Research Policy*, 32 (7), pp.1179-1198.

Osterloh, M. and Rota, S. (2007). Open source software development—Just another case of collective invention? *Research Policy*, 36 (2), pp.157-171.

Stewart, K. and Gosain, S. (2006). The Impact of Ideology on Effectiveness in Open Source Software Development Teams. *MIS Quarterly*, 30(2), pp. 291-314.

West, J. (2003). How open is open enough? Melding proprietary and open source platform strategies. *Research Policy*, 32 (7), pp.1259-1285.

Yin, R. (2003). *Case study Research—Design and Methods*. Sage Publications, Thousands Oaks, CA.