Can I Commercialise? Norms Regulating Commercialisation Behaviours in Open Source Hardware Communities

1 Introduction

"[…] the unwritten rules of Open Hardware and rule #1 is you don't copy, you innovate. […] One thing I've learned about the OSHW[1] community, after years of following it with intense interest: the unwritten rules can sink an OSHW business!"

Quotes like these have aroused our interest in the way open source communities, where household innovators share their innovations freely, regulate the behaviours of those, both from within and from outside the community, who exploit the entrepreneurial opportunities created by free access to these innovations. What these quotes suggest is that commercialisation behaviours are regulated by unwritten rules.This is striking because open source communities have licences that spell out explicit rules for how these innovations and inputs can be used. The motivation of this paper is thus to study whether open source communities have norms for regulating commercialisation behaviours and if they do what these norms are.

To explore these questions, we decided to investigate a particular Open Source Hardware (OSH) community—the RepRap community. Created in 2005, following the launch of an OSH project aiming to democratise 3D printing technology by enabling the production of cheap and easy to build 3D printers,[2] this community has existed long enough to enable norms to emerge, evolve and operate. It is also a community of a significantly large size, and a 'successful' one, since it has led to the development of several major players in the 3D printing market, as has been an inspiration to virtually all desktop 3D printers. A further interest in the choice of an Open Source Hardware community as opposed to an Open Source Software one, is – beside the fact that the former still stands rather understudied in the literature in comparison to the latter – that unlike Open Source Software, for which commercialisation is purely optional because of the low/negligible diffusion

[1] Open Source Hardware

[2] RepRap literally means "*Re*plicating *Ra*pid *P*rotoypers" – Rapid Prototyper was the generic name of 3D printing at the time – and aimed to design 3D printers that could 'print' other 3D printers.

cost of software, the significant cost of replication of hardware makes commercialisation a necessity for innovation to diffuse, hereby creating a dilemma between free sharing and commercialisation.

To investigate the role played by norms related to commercialisation in this community and answer the research questions at hand, we have used a multi-method approach consisting of semi structured interviews and of a large-scale netnographic study. Our main findings are that norms relative to commercialisation indeed exist in this community and effectively regulate commercialisation behaviours. Interestingly, a key result of ours study is that these norms entail the notion that those commercialising should reciprocate with valuable benefits for the community in one way or another. However, rather than one particular set of 'rules' defining what is, in the eyes of the community, an acceptable commercialisation behaviour, we found a rather complex set of norms at play that enable to define a 'grey area' enabling to account for different commercialisation contexts and to foster the wide range of contributions required for the community to sustain and thrive. A further finding is that a range of sanctions exist within the community to ensure that commercialisers indeed comply with those norms.

Our research makes contributions to the literature on norms, open source communities, and household innovation by uncovering unknown aspects of the governance of open source communities and pointing out a common, yet largely understudied, behaviour among household innovators. We believe our findings can be generalised to any open source – and specifically open hardware – communities in which household innovators share freely their creations. Because the commercialisation of household innovations is likely to become an even more common phenomenon in the near future – if just for the fact that access to technologies such as 3D printing and digital manufacturing enable virtually anyone to start commercialising without a significant investment – our findings are very important for two reasons. First, they enable to understand the mechanisms through which household innovators will pursue freely sharing their innovations despite the frequent commercialisation of products that build on their inputs (including by them). Secondly, they are key to understand the new forms of commercialisation that can be acceptable by household innovator communities and to establish in which respect these forms differ from traditional forms of commercialisation, as well as the consequences this may have.

Our paper is organised as follows. We first begin by reviewing the literature on household innovation and the literature on norms, which enables us to identify a gap related to the regulatory role of commercialisation norms within open source communities. Section 3 introduces the context

of the study—the RepRap community. We then present, in turn, the two parts of our multi-method approach – the first one, exploratory, used to identified norms and sanctions at play is discussed in Section 4. Section 5 follows with a discussion of the findings of the study, highlighting our contributions to the literature and considers the limitations of this research.

2 Literature review and theory

2.1 Household Innovation and the challenge of commercialisation

Household innovators are individual consumers who develop or modify consumer products to answer their own needs or those of their relatives or friends. These innovations are often made at private expense and outside of organisations. (Ferran, 2000; Oliveira and von Hippel, 2011; von Hippel et al., 2012; von Hippel, 2017). Although being invisible in the national statistics, household innovation is an important source of innovation that is conducted by tens of millions of consumers in the world who spend tens of billions of dollars annually on this activity (Franke and Shah, 2003; Lüthje et al., 2005; Baldwin et al., 2006; von Hippel et al., 2012).

A remarkable fact about household innovation is that it is typically not protected by property rights (von Hippel et al., 2012; von Hippel and Katz, 2002; Ogawa and Pongtanalert, 2011; Kuusisto et al., 2013; de Jong and de Bruijn, 2013) and often shared freely (Lüthje et al., 2005; Franke and Shah, 2003; von Hippel and Katz, 2002). Free sharing of household innovations has been argued to take place for different reasons, one of which being that household innovators benefit from their innovations by using them or seeing others use them and thus do not further need to recoup their investment (e.g. von Hippel and Katz (2002)). It has also been noted that household innovators benefit because they are able to get feedback and inputs from others (Franke and Shah, 2003; Hienerth, 2006; von Hippel and Katz, 2002). A key implication of sharing freely is that it allows for innovation to accumulate and therefore to develop at a rapid pace. This allows for easy downloading of software code or hardware blueprints, as well as for easier user interactions about the innovations.

Free sharing can take place ‘offline’ when household innovators meet face to face, typically in the context of user or hobbyist communities (e.g. Franke and Shah (2003), or ‘online’ when they share their innovations on platforms, typically in the context of open source communities (von Krogh and von Hippel, 2006). Digitalisation is seen having a positive effect on consumers being involved in

household innovation (Rayna and Striukova, 2016b). It also significantly improves the conditions for sharing both household software and hardware innovations because innovations are codified in digital forms. Recently, access to 3D printing technology, which helps lower the cost of manufacturing for household innovators (Rayna et al., 2015; Rayna and Striukova, 2016a), has also become one of the key drivers behind this phenomenon.

Although the literature commonly contrasts the free sharing model of household innovators with the commercial model of manufacturers (e.g. von Hippel and von Krogh (2003); von Hippel (2017), commercialisation of household innovations is not absent. Entrepreneurial opportunities offered by household innovations have indeed been reported to be exploited by manufacturers (e.g. Hienerth (2006); von Hippel et al. (2011); Bonaccorsi et al. (2006) as well as, more marginally, by household innovators themselves (Shah and Tripsas, 2007; Autio et al., 2013; Hienerth and Lettl, 2011). Most of the interest in commercialisation however has been focused on the benefits of integrating household innovations by manufacturers (e.g. von Hippel and Katz (2002); Hienerth (2006), implicitly assuming that was not affecting free sharing amongst user communities.

Little or no interest, however, has been directed towards discussing commercialisation behaviours per se in terms of both their benefits and drawbacks. Yet, we believe that commercialisation of household innovations needs to be addressed explicitly for several reasons. First, commercialisation can hurt household innovations' free sharing nature if household innovators believe their innovations are misappropriated by others. This urges to think of how commercialisation can, in theory and then in practice, be compatible with free sharing. The literature offers some hints by describing the original business models that have been developed around open source software, in particular creating additional value, that can be monetised, beyond the open source code (e.g. Bonaccorsi et al. (2006). Yet, these lessons hold only partially when hardware is concerned because whereas commercialisation of open source code would make no sense - as the commercial and open source versions would be identical- commercialisation of open source hardware can in fact make a lot of economic sense. The reasons are threefold. Firstly, open source versions of hardware can be rather different from their commercial versions in terms of quality and reliability. Secondly, hardware development is costly and innovation costs may need to be recouped beyond the usage value exploited by the innovator, thus creating incentives for commercialising. And finally, commercial versions can in fact cost less than what it would cost to build an open source version oneself, thus having benefits for users, including community members. As a result, incentives to

build on open source hardware should be different from what they are in open source software, and thus creating possible misappropriation of household innovations freely shared. In summary, hardware has properties that make the lessons learned from open source software only partially transferable and all the most when commercialisation is concerned. In other words, we need to reconsider our thinking on commercialisation to accommodate the different areas of household innovation, beyond low cost user innovations and open source software which do not represent valuable entrepreneurial opportunities.

In the next section, we argue why we think that norms relative to commercialisation are likely to exist in the communities where household innovators publish and share their innovations, most specifically their hardware innovations. Amongst these communities, open source communities are likely to be those where these norms are needed and observable.

2.2 The role of norms in communities of household innovators

2.2.1 The insufficient regulation of commercial behaviours by licences

The last decades have seen the emergence of a "general trend toward open-source innovation by collaborative online communities" (e.g. de Jong and de Bruijn (2013)). The value these communities create lies in the motivations of thousands of creative people to invest efforts in making and sharing inputs that build on the contributions of others. This allows for the production of collective goods that everyone can use and benefit from for free (e.g. von Hippel and Katz (2002). As open communities are now being acknowledged as a new powerful locus of collective creativity and innovation, that affects the way digital, and increasingly hardware, products are conceived and disseminated (Lee and Cole, 2003), they are attracting a lot of attention from researchers who aim at understanding how these communities are governed and can sustain themselves (e.g. O'mahony and Ferraro (2007); Faraj et al. (2011).

Indeed, the governance of these communities is different from that of the markets. For instance, in comparison to the software vendors, who restrict access to the source code, open source code is available to everyone (von Hippel and von Krogh, 2003). This, according to Benkler (2002, p.7), 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". Another difference is motivations behind community members' desire to

contribute. Market innovators' main motivation is to gain return on their investment through temporary monopoly (commercialisation), for which intellectual property is usually required. On the other hand, in open source communities innovators are not lead by profit expectations, but rather expect others to contribute to the innovation process and to have these contributions freely available to the rest of the community. In this regard, intellectual property does not help the open source community to protect their contributions, but quite the contrary ensures that any contribution could be shared, as well as modified, enhanced or extended (West and Dedrick, 2001). These conditions are further reenforced by various licenses (Rosen, 2004).

Despite the fact that unlike market actors, open source communities grant free access to their contributions, commercial activity does still take place within these communities. These activities are carried out either by 'community firms' created by community entrepreneurial members or by external actors who use inputs made freely available by communities (Lüthje et al., 2005). Commercial activity can be motivated purely by potential profit, for example when an external company decides to make a commercial version of an open source hardware, or by the willingness to recover innovation costs, such as when a 'community firm' has made investments to develop an innovative hardware. As, in order to be used, open source versions often require some kind of effort efforts from the users, commercialisation can in fact add great value to users both within and outside the community, in the form of easier to use kits and cheaper parts.

Communities typically do not preclude commercial activity, since licences such as the GPL, used both for open source software and hardware, state that commercialisation of results of open source projects is acceptable and within the licence, provided that any improvements to the commercialised version are also released as open source products. However, despite offering this guideline, cases of community reactions to commercial behaviours suggest that commercial behaviours that respect the licence may be considered unacceptable by community members in some cases. This is evidenced by multiple examples discussed in the law literature regarding behaviours being contested and then forced to change by local communities, because the behaviour was against a norm while being perfectly legal (Posner, 1996).

2.2.2 Norms in open source communities

Unspoken rules or norms play an important part in many different situations and contexts as they regulate behaviour in a way that favours acceptable behaviour and tends to discourage unacceptable one, therefore resulting in better collective outcomes for groups and communities (e.g. Lee and

Cole (2003); Merges (2004); Fauchart and von Hippel (2008); Bauer et al. (2016). Specifically, norms have also 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 are 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 driver (Stewart and Gosain, 2006). Based on analysis of archives, texts, or blogs content, Stewart and Gosain (2006) identified three more specific norms regulating behaviour in open software 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 behaviour relative to aspects of contributions such as how contributions are done, distributed, or credited. Lee and Cole (2003) emphasize that open and collaborative communities rely in part on written rules to regulate various aspects of their functioning, such as the open source software license, which stipulates that changes to the code must be made public. They also point out that there are norms that allow collaborative and open communities to self-organize in a way that ensures high quality collective outcomes.

Among 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 whose work is being used or extended. This allows for traceability and entices people to contribute. Another strong norm is that of "external peer review" that entices people to check codes they have not written in order to identify bugs and mistakes and to make "patches". 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 (Lee and Cole, 2003). This norm is associated with the fact that critical evaluation is essential to ensure code quality and is perfectly acceptable as soon as it is done in a constructive manner. Community members are motivated to contribute since their contribution is well documented and therefore is recognised. Lakhani and Wolf (2005) also emphasize the norms that derive from the hacker culture and the strong identification of contributors with the open source and hacker movements. This identification ties individuals to collective identities and helps them select appropriate behaviour and understand their responsibilities as community members.

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 contributions of the community by avoiding misappropriation of these contributions and therefore making sure that incentives to contribute are not decreased (Benkler, 2002). In particular, the norm "eschewing property rights" (Merges, 2003, p. 20) is specifically central in these communities as it implies that contributors accept that others use their contributions with an intention to improve or extend them.

In summary, the literature provides evidence that open source communities are crisscrossed by norms that regulate the behaviour of community participants. These norms play a key role in promoting behaviour that helps these communities achieve better collective outcomes.

2.2.3 The likelihood of norms regulating commercial behaviour in open hardware communities

Commercialisation could be harmful to communities if it creates disincentives to share freely. For instance, failure to credit the community or its members could create resentment among members and lead them to turn to other communities, or even worse to stop sharing altogether. Additionally, the fact that individuals or firms may appropriate private returns from collective efforts might discourage members to pursue sharing their innovations. In fact, anecdotal evidence exists that community members expect firms, using open source contributions to behave in certain ways. In particular community members expect firms to clarify ownership,to give back source code (despite creating potential competition) or to credit community members (e.g.Dahlander and Magnusson (2008). This indicates that communities might consider that commercialisation needs to follow certain implicit rules if it is to be compatible with the open source ideology.

At the same time, open hardware communities are highly likely to be involved in commercialisation, either by its members commercialising the open source contributions or other members purchasing commercialised products. For example, even freely available open source hardware requires efforts from the users, such as sourcing the parts, assembling, etc. and some community members would rather pay for these services, thus creating opportunities for entrepreneurs. Commercial versions may also carry embedded innovation or help diffuse the technology, thus bringing additional value to community members and popularising the work of

the community. Given these benefits, it is likely that commercialisation would be found to be a common behaviour in open hardware communities.

Yet, despite the potential benefits of commercialisation, its potential drawbacks for the community, such as the perceived misappropriation of community inputs and / or the lack of value added of the commercial products as mentioned earlier, suggest that it is likely that commercialisation behaviour needs to be monitored and regulated in order for commercialisation to provide benefits without endangering open source communities.

In fact, a common assertion is that norms emerge if they are instrumental for the goals of a community (Opp, 2001) and are required to ensure group survival (Feldman, 1984). Furthermore, a widely held view is that norms tend to emerge when the actions of individuals can bear costs (i.e. negative externalities) or benefits (i.e. positive externalities) for other community members (e.g. Demsetz (1967); Coleman and Coleman (1990); Ostrom (1990)). Also, norms tend to arise when these externalities manifest recurrently and need to be addressed on a continuous basis (Williams, 1968, p.206). Finally, explicit rules (as in law) require research in and establishment of the harmful consequences of behaviour in order to specify in advance whether that behaviour will be penalised. Norms, on the other hand, often appear when the consequences of a behaviour is either uncertain or difficult to establish precisely and thus left for the collective to put in place (e.g. Posner (1997). These elements further imply that norms around commercialisation should be found within open source communities, since commercialisation begets externalities, both potentially positive and negative as argued earlier. Therefore, it seems realistic to argue that it should be quite difficult to evaluate accurately and definitely, the consequences of commercialisation in general, beyond the general understanding that systematic failure to share could be detrimental in the long term.

If norms regulating behaviour in a collective derive from more general norms operating in society, they often develop gradually and informally as the collective encounters problems and / or learns what behaviour best helps it achieve its common goals or ensure it is well functioning (e.g. Feldman (1984). In this respect, critical events can play a particular role in shaping norms as they induce collectives to reflect on behaviour that may threaten the missions or goals of the collectives.

Finally, it has been widely argued that for norms to effectively regulate behaviour there needs to be some incentives for the individuals to comply with the norm rather than to deviate from it, for instance in the form of free riding (e.g. Ellickson (1991); Etzioni (2000); Ostrom (2000). In fact, it only makes sense to talk of a norm when most individuals share the norm and adhere to it. The

literature has argued that at least two important mechanisms ensure that norms are respected by individuals (e.g. Etzioni (2000). First of all, the 'intrinsic force' argument suggests that individuals will comply with a norm due to their intrinsic motivation to do so. This motivation can be founded in rational calculus –e.g. complying is economically profitable- or in the personal values and ideology of the person. Secondly, the 'environmental' argument suggests that social pressure induces individuals to comply, because failure to comply would lead to their being ostracised by their community. In this case, the literature argues, close-knit communities are better at inducing individuals to comply with norms because behaviour can be observed more accurately and because sanctions can be more efficient (e.g. Ellickson (1991). In any case, compliance with norms is more likely when lack of compliance induces high costs and sanctions are effective in inflicting the costs. An additional condition is that some individuals accept to invest in sanctioning (e.g. Oliver (1980). It is therefore realistic to argue that conditions are met in open source communities in order for commercialisation norms to be complied with. Firstly, not complying with norms can induce important costs to deviators in the form of sales loss and being deprived from community benefits, such as community help. Secondly, social pressure is often present within online open source communities. Community members can voice their opinions easily and even anonymously if they want, and a significant number of them identify themselves strongly with the open source ideology and are willing to express their concern or disagreement.

Thus, because commercialisation raises recurrent issues within open source communities, and most specifically open hardware ones (potentially creating both negative and positive externalities), and potential consequences of these issues are difficult to evaluate with accuracy, we expect commercialisation behaviour in communities to be regulated by norms (in addition to basic rules such as those implied by the GPL).

In order to study the existence of norms regulating commercialisation, we have studied a specific open hardware community, the RepRap community for 3D printing (see next section). This community offers a relevant setting because it is an open hardware community, it has commercialisation from both community firms and external companies, and it was created in 2005, thus letting enough time for norms to emerge and operate. In line with previous studies investigating communities of user or household innovators – such as Franke and Shah (2003); Oliveira and von Hippel (2011); Füller et al. (2013); van der Boor et al. (2014) – a multi-method approach was used to identify the norms relative to commercialisation, to examine the agreement in the community

surrounding these rules, and to assess their effectiveness. Indeed, unlike situations when rules are clearly stated, norms are more likely to be implicit, (to some extent) heterogeneous, and changing. Furthermore, communities often have diverse shareholders, who may have very different objectives and incentives, histories, and, therefore, perceptions of what the norms are. As noted, in Santoro and Chakrabarti (2002), multi-method approaches are particularly useful when investigating complex phenomena, such as the one at hand. Also, as noted in Füller et al. (2013), using multi-method approach enables to increase the robustness and validity of the results. The first stage of this approach has consisted in an exploratory study, whose detailed method and findings are presented in Section 4, aimed – by means of semi-structured interviews of 'commercialisers' – to identify what those commercialising believe are the norms relative to commercialisation. The second stage of the approach (detailed in Section 5) relies on a netnographic study and a further set of semi-structured interviews to confirm the existence and validity of the norms identified in the first stage.

3 Context: the RepRap Open Source Hardware Community

With over 6,000 active contributors, RepRap is nowadays one of the largest and most successful Open Source 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, which consists in melting a plastic filament, which is then processed through a nozzle and deposited layer by layer on a plate by a computer controlled motorised head to form a 3D object. The RepRap project officially started just after the last patents for this technology had expired. 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. 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, others correspond to commercial releases of companies who have decided to adopt the open development paradigm.

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 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 Exploratory study

4.1 Methodology

The first stage was an interview-based exploratory study that aimed at identifying the most critical aspects of norms and commercialisation within the RepRap community from the perspective of the commercialisers. Indeed, this type of approach is recommended when the research issues are still evolving (Yin, 2003). In an exploratory study, the choice of the sample may affect the results of the study and is, therefore, critical (Miles and Huberman, 1994). In particular, representativeness and exhaustiveness of the information collected during the interviews are important. According to Guest et al. (2006) saturation is reached rather quickly, and after 12 (and even often six) interviews saturation is generally total. In total, during the first stage of research, 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.[3] Diversity was ensured by selecting a variety of companies: some of them clearly presented themselves as being a part of the RepRap community. Others initially had ties with the RepRap community but then developed models independently. 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). 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.

4.2 Preliminary Findings

Though the open source license used within the RepRap community requires only new modifications to be shared with the community, our findings show that expectations of the community were more complex than that.

4.3 Commercialisation can be acceptable if the commercialiser contributes back [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 commercialising company contributes back in some way. Respondents mentioned various types of contribution that can be classified as either direct or indirect.

[3] the remaining interviewee was one of the company's head managers

4.3.1 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.

[…]But in the process of commercialisation, we must abide by the rules. For example, our contribution to open source projects must be made public.

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 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. Moreover, interviewees believed that 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.

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.

4.3.2 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]. 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', as the community bears the burden of technical support.

Two interviewees also mentioned, that indirectly commercialisation could benefit the community by providing access to cheaper resources[N1.2.2]; for example ordering large volumes of parts leads to economies of scale and is beneficial to 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.

[…] and other printers like it improves the 3D ecosystem by driving down costs and increasing demand. […] Every clone sold builds good will and trust towards the still-nascent concept of 3D home printing.

Likewise, three interviewees mentioned that commercialisation helps diffuse innovation, which is an indirect benefit for the community [N1.2.4].

4.4 Commercialisation May Be Acceptable Even Without Contribution [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 radical, one of the interviewees mentioned that he believed contributors would be proud to see commercial firms using their inputs even if they were not crediting them [N2.3].

Table **Error! Reference source not found.** summarises the norms identified at interview stage.

Table 1: Norms related to commercialisation identified at interview stage.

N1	Commercialisation is acceptable if the commercialiser *contributes* back			
N1.1		directly		
N1.1.1			by *sharing* exhaustive *documentation*	
N1.1.2			by *sharing improvements*	
N1.1.2.1				that are *significant*
N1.1.3			by *providing resources* to the community	
N1.1.4			by *providing support and guidance* (especially to newcomers)	
N1.2		indirectly		
N1.2.1			by developing *skills and knowledge* in the population	
N1.2.2			by providing *access to cheaper resources*	
N1.2.3			by *growing the market*	
N1.2.4			by *diffusing innovation*	
N2	Commercialisation is acceptable even when the commercialiser *does not contribute* back			
N2.1		if the commercialiser's *size* relative to the market is *small*		
N2.1.1			because the *market is growing*	
N2.1.2			because the company is *genuinely small*	
N2.2		if the work of *contributors* is *acknowledged*		
N2.3		even if the work of *contributors* is *not acknowledged*	because it makes them happy people use their creation	

4.5 Sanctions When Deviating from the Norms

As noted in the literature, and discussed in Section 2.2, the existence of sanctions when deviating from the norms is a critical aspect of their effectiveness. In this respect, the interviews enabled to identified a range of sanctions at play in the RepRap community in cases when commercialisation is found unacceptable because it does not confirm to the norms identified above:

- boycott and public calls to boycott the products of the commercialiser[S1];
- stop contributing to the projects carried out by the commercialiser [S2];
- make damaging public statements against the commercialiser to tarnish its reputation [S3].

5 Confirming the Norms

In order to confirm the existence and validity of the norms identified through semi structured interviews in the exploratory phase of this research, we decided to carry out a netnographic study of posts of RepRap community blogs and forums.

5.1 Presentation of the Netnographic Study

The second stage of this research aimed to confirm the existence, validity, and prevalence of the norms identified in the first (and exploratory) phase (and presented in Section 4) by investigating the community itself. A traditional means to do so is to use surveys (as was done in Franke and Shah (2003); Füller et al. (2013)) and this was indeed what we set out to do first. We designed an online scenario-based survey enabling to test the validity of the norms identified and publicised it on the RepRap forum. However, this led to a rather hostile reaction from key members of the community[4] and, as a result, the response rate was insufficient to obtain any stastistically significant result.

However, it turned out that in this particular case, a quite significant quantity of empirical evidence, enabling to verify the validity of the norms we had identified, was available in the form of posts on the RepRap forum and other blog posts and comments by members of the RepRap community. While many of those posts are, of course, not related to the topic at hand, we found that there was nonetheless a large number of them discussing issues related to sharing and commercialisation norms. In particular, two events triggered rather abundant (and heated) discussions on this topic in both RepRap forum and blogs of RepRap community members.

Both events relate to a company named MakerBot. Nowadays still one of the market leaders of the desktop 3D printer market, MakerBot was founded in 2009 by three members of the RepRap community. Strong and vocal proponent of the Open Source Hardware, and being one of the first successful company to commercialise 'desktop' 3D printers[5], MakerBot and rapidly became a poster child to the RepRap community (West and Kuk, 2016).

[4] https://reprap.org/forum/read.php?1,829614,829614\#msg-829614

[5] i.e. smaller size 3D printers to be used in an office, as opposed to 'traditional' industrial 3D printers of much larger size used in prototyping facilities and factories. The advent of 'desktop' 3D printers was highly instrumental in the diffusion and democratisation of 3D printing technologies.

In August 2012, a newly founded company announced it would start supplying clones of the Open Source Hardware MakerBot "Replicator" 3D printer – then flagship model of the MakerBot company – for a significantly lower price than MakerBot. While Tangibot announced their printer would be too released as Open Source Hardware (i.e. they would publish the related blueprints, bills of materials and documentation), hereby conforming to the "Creative Commons Attribution Share Alike" licence under which MakerBot released its printer, there were some heated debates within the community as to whether releasing a straight clone of an existing OSH product without making a single improvement, and undercutting in price a long-time and highly active contributor to the community was something acceptable.[6]

A couple of months later, in September 2012, MakerBot, announced that its fourth 3D printer model and upgrade to its previous "Replicator" model, named "Replicator 2", would be released as closed source hardware. This sudden switch to closed source from one of the most vocal proponent of open source hardware created quite a stir in the RepRap community, not just because it appeared to negate what MakerBot always stated it stood for, but also because this improved – and closed source – version of the open source Replicator embedded improvements and upgrades made by the community to the original Replicator. Heated discussions in the community ensued, with some members insisting on 'giving a break' to MakerBot in light of their past contribution to the community, while others insisted this move towards closed source was simply not acceptable.

Thus, we decided to conduct a netnographic study of the RepRap forum and of the main RepRap blogs. In this day and age when so many user interactions have become observable on the Internet through Social Media, netnography has become a methodology of choice to leverage this empirical material (Kozinets et al., 2014), including in innovation communities (Füller et al., 2007) and multi-method studies combining interviews and nethography have become increasingly prevalent.[7]. Netnography (a portemanteau word of 'Internet' and 'ethnography') is a qualitative research method that uses content, social and cultural data shared freely by individuals through the internet. Because it is based on *existing* data, as opposed to (artificially) generating new one, netnography is more naturalistic than survey, focus groups, experiments and interviews (Kozinets, 2002, 2015).

[6] Incidently, the uproar in the community was such that the Tangibot founder eventually abandoned the idea of commercialising such a clone.

[7] See for instance Jafari et al. (2015), Anderson et al. (2016), Gatzweiler et al. (2017), Durgee and Agopian (2018), Essamri et al. (2019).

Yet, there is content and data online aplenty, and one of the main challenges associated with netnography relates to finding ways to select relevant material. In the case at hand, the RepRap forum alone contains over 300,000 posts (it started in 2007). Traditionally, methods used to select material for netnography include focusing on a particular event or set of events, particular users, defined time periods, particular media, and keywords. This is the latter that we decided to use.

Of course, although our interest lies in uncovering norms related to commercialisation, it is quite obvious that it is not the way this topic is addressed in posts in the RepRap forum.[8] Considering the controversy within the RepRap community caused by the two events mentioned above, we decided, instead, to use "MakerBot" and "TangiBot" as keywords to select the material. Furthermore, as our goal was to confirm norms identified at the interview stage, the names of the 15 companies involved in the interviews were used as keyword to identify relevant posts on the forum.

Using the keyword "MakerBot" led to 3,422 threads on the RepRap forum, 111 of which contained relevant material.[9] The keyword "Tangibot" yield 3 threads, all of which were relevant. Searching for the names of the 15 companies involved in the interviews lead to 908 threads identified, 39 of which were relevant. Since the aim of this research stage was to confirm the norms identified at the interview stage, deductive coding was used, i.e. the norms listed in Section 4 were used to build the codebook. However, since it was possible that not all norms had been identified at interview stage, we left the door open to the codebook being updated if new norms were to be identified.

Coding was carried out independently by three researchers using the NVivo software. To insure consistent coding, each researcher was asked to code the same piece of material,[10] after which coding patterns were compared for consistency. No significant differences in coding patterns were observed at this stage. Further on, regular consistency checks were carried out, as researchers on the project examined the coding carried out by other researchers on the project. Ambiguous cases encountered by researchers were discussed within the team. Finally, 'new' discovered norms were validated by the team before being added to the codebook.

In addition to the RepRap forum, we decided to make use of blogs of members of the RepRap community. Indeed, we had noticed that some of the posts hosted on these blogs could lead to a

[8] Searching for "norm" and "commercialisation", as well as their synonyms, yield very limited results, few of which were relevant – and those that were could be identified with the keywords we eventually used.

[9] Only posts in English were considered.

[10] A blog post related to MakerBot that contained numerous comments.

significant engagement of the community, who would in some cases comment profusely on the original post.[11] Consequently a search of relevant blog posts was carried out, which led to 8 blog posts, containing overall several hundreds of comments, identified and coded using the same codebook. Overall, 224 'documents' (whether RepRap forum thread or blog post) were coded in this second stage of the research, leading to 620 extracts of text directly related to the norms. On the RepRap forum, 367 different community members contributed to the discussion (out of around 6,000 registered community members on the RepRap website – i.e. around 7%), with different levels of activity – 121 members contributed to two threads or more, whereas 246 members contributed to just one thread on the forum (though they might have written more than one post in this particular thread); 158 members wrote just one post that contained material related to norms. Hence, while some community members were more 'vocal', we noticed nonetheless a rather 'democratic' debate on these issues, since many community members who typically do not usually express themselves on these issues decided to share an opinion on the matter with the rest of the community.

5.2 Findings of the Netnographic Study

This netnographic study enabled us to confirm the existence of all the norms identified through interviews in the first stage of the research, as well as to identify a limited number of additional 'subnorms' that had not been mentioned – at least not explicitly enough – by either of the 15 interviewees.

A first interesting point is that the vast majority of extracts coded support the view that commercialisation of Open Source Hardware is indeed acceptable – 459 extracts relate to commercialisation being acceptable to some extent, while only 69 coded extracts discuss arguments opposing commercialisation by default. However, our netnographic study shows that commercialisation, while acceptable, generally does not come without strings attached, as a smaller number of extracts (whether on the RepRap forum or blog posts and comments) – 128, overall – mention commercialisation being acceptable without some kind of contribution.

[11] For instance, the blog post "Tangibot and the Perils of Open Source Hardware" posted on the blog Hackaday following the announcement that Tangibot was entering the market, led to 125 comments posted between August 12 and August 25, 2012.

This second stage of the study enables to shade a light on what kind of contribution is expected by the RepRap community in exchange for commercialisation. A surprising outcome of the first part of the study was the prevalence of indirect forms of contributions mentioned by interviewees – one would have expected direct forms of contributions, as implied by the OSH licenses, to be 'the rule'. However, since all interviewees were themselves 'commercialisers', it was tempting to attribute this rather surprising finding as being the result of a particular view of 'commercialisers' – some of which appeared to put forward indirect contribution as an excuse/justification for a lack of direct contribution on their part – and not something shared by the rest of the community.

Instead, the result of this netnographic study highlights that while direct contribution is indeed expected by many community members (211 extracts), indirect forms of contribution are also frequently mentioned (87 extracts), which tends to show that the community, as a whole, is aware that there are many ways – even unintentional ones – people commercialising OSH contribute to the RepRap community.

5.2.1 Direct Contribution

Looking into details, the existence of most norms related to *direct* contribution [N1.1] are confirmed by the netnographic study. There are, however, differences, some of which are particularly insightful. The licences (e.g. GPL, Creative Commons) used in the RepRap community do require *sharing exhaustive documentation* [N1.1.1], so it is rather logical to find that many coded extracts (104) relate to this particular norm. What is more surprising is that the greatest number of extracts relate to another norm, i.e. *sharing improvements* [N1.1.2] (139 extracts, overall).

Thus, whereas none of the licences used explicitly mention the necessity of making improvements when commercialising a product based on Open Source Hardware design, such improvements are expected by the community, which goes to show that, as we suspected, the norms in play in the community go beyond the publicised licences. This means that, as mentioned on numerous occasions by community members, there are indeed "unwritten rules"/"unspoken rules" that regulate commercialisation in the RepRap community, for instance:

[…] the *unwritten* rules of Open Hardware and rule #1 is you don't copy you innovate

And even by Bre Pettis himself mentions:

[…] one of the *unspoken rules* of open source hardware […] the one that states that "cloning ain't cool".

Yet, and interestingly, some within the community, albeit a minority, are critical of such rules, although admitting their power:

"The idea that there are "*unwritten rules*" is very wrong, and very bad. If it is not written, it is not a rule. The rules of Open Hardware are in the licence text, and nowhere does it say "you must not copy, only innovate".

However, while the results of the netnographic study support the idea that making (and publishing) improvements is required for commercialisation to be acceptable, the extent of such improvements is not actually discussed. Thus, unlike at the interview stage, where *sharing significant improvements* [N1.1.2.1] was identified as a (potential) norm, this further study did not confirm it indeed exists within the community.

Besides sharing documentation and improvements (whether significant or not), two other forms of direct contributions were identified in the first stage of the research: *providing resources to the community* [N1.1.3] and *providing support and guidance (especially to newcomers)* [N1.1.4]. We did not find significant support for either of them (in all fairness, both had been mentioned only once at interview stage). While some extracts could be linked to *providing resources to the community* [N1.1.3], they all relate to access to cheaper/more diverse resources thanks to the publication of the B.O.M. (bills of materials) – which lists all parts, suppliers and prices – which is very much tied to norm [N1.1.1] *sharing exhaustive documentation*. Likewise, overall, we could only find one mention of something that could be identified as an expression of norm [N1.1.4] *providing support and guidance (especially to newcomers)*, but it was made by a 'commercialiser', so we can assume that, while (some) commercialisers would want this to be the case, such a norm is in fact not supported by the community.

In addition to disproving the existence of some norms related to direct contribution making commercialisation acceptable, this second stage of the study enabled to uncover a new one: sharing profits with contributors [N1.1.5]

"I am concerned that a business entity might produce one of my designs and sell it without me getting a slice of the pie."

Considering that commercialisers potentially making a profit is one of the issues at hand, we were rather surprised to hear no mention of this in the interviews. However, we thought that this could be linked to the fact that only commercialisers were interviewed. While this may have been the case, this second stage of the research tends to show that while some members in the community

would want to be financially rewarded in case of commercialisation of a product based on their contribution, this is by far not as prevalent as other forms of direct contribution.

5.2.2 Indirect Contribution

As noted above, a key outcome of this netnographic study is to highlight the support within the community (albeit to a lesser extent than *direct* contributions) that *indirect* contributions (i.e. unintended/byproduct contributions by commercialisers) can make commercialisation of products based on OSH designs acceptable. In particular, three norms related to indirect contribution identified at interview stage are regularly mentioned in both blog posts and on the RepRap forum. The most prevalent one is [N1.2.4] *Commercialisation is acceptable if the company contributes back indirectly by diffusing innovation*, followed closely by [N1.2.3] *Commercialisation is acceptable if the company contributes back indirectly by growing the market*. Hence, while members of the community might well be aware of commercialiser 'cheating' by using OSH designs without contributing back, the benefits of commercialisation, both in terms of diffusion of innovation and market growth (i.e. increasing the number of users) is often seen as sufficient to make commercialisation acceptable:

"I don't see a way that the community loses; none at all. The single best thing we can do for 3D printing specifically, and open source in general, is to expand the market for it."

Or in relation to helping the market grow:

"These products need to get into everyones hands. Not just the upper class. "

"[…] copy the designs, produce and sell the products and give nothing back. This is fine - you are supplying a paid service to the community, and raising publicity - indirect gain for the community."

Furthermore, the benefits, in terms of growing the user-base and technology diffusion, of commercialising 'ready to use' versions of OSH designs are highlighted by the community:

"What about all of the people out there that would love to use 3D printing but have no desire/time to kit up a reprap and source parts? "

Interestingly, one of the benefits of a larger diffusion of innovation and a larger user base enabled by commercialisation identified in the posts relates to getting more OSH contributors on board:

"Copying costs the community nothing - and gains publicity, and more chance of another contributor joining up. Copyers and contributors add to the sum knowledge of the community. "

Two additional indirect benefits of commercialisation – that it contributes to *developing skills and knowledge* [N1.2.1] and enables to*provide access to cheaper resources* [N1.2.2] – were identified

at interview stage. However, although such benefits were indeed mentioned, they were so rather infrequently, attesting that these benefits – alone – were unlikely to be recognised by the community as sufficient to make commercialisation acceptable.

More importantly, the netnographic study enabled to identify an additional norm that had not been mentioned at interview stage, i.e. that commercialisation – through competition – fosters innovation and quality improvements [N1.2.5]

"We need to give thanks to [Tangibot] even if all [they do] is spur the MakerBot crew to evolve and stay competitive."

This is interesting because while the community mentions this rather frequently, none of the commercialisers we interviewed did, showing they do not typically welcome competition (though, interestingly, many mentioned the poor quality of RepRap machines and their own capacity to innovate as a key reason behind their decision to commercialise).

5.2.3 No Contribution

As noted in Section 4, four interviewees mentioned that commercialisation may even be acceptable without any contribution – either direct or indirect. One of the arguments brought forward was the community would accept such commercialisation if the company commercialising was of a *small size relative to the market* [N2.1], either because the *market is growing* [N2.1.1] or because the *company is genuinely small* [N2.1.2]. We did not find support for either, neither in the blog posts and comments, nor on the RepRap forum. Thus, it appears that such a belief may be due to a commercialiser's bias.

In contrast, although only on interviewee had mentioned this, we found some support to the claim that community find a commercialisation acceptable provided that the commercialer *acknowledged the work of the contributors* [N2.2]:

"I find larger joy in that my development is used than I find it terrible that someone earns money on my work."

"I don't have a problem at all with someone copying my design, I was going to release it anyway. My probem, is when someone [claims it] to be their original work. "

Yet, we could only find one post of a community member claiming that commercialisation without acknowledgement was even acceptable *because this made him happy to see people using his creation* [N2.3]

"I make things because I enjoy it and if I design something and others copy it then I am delighted - I like but don't require acknowledgement. "

Table 2: Norms related to commercialisation identified and confirmed at netnographic stage.

	Norms identified				Netnography
N1	Commercialisation is acceptable if the commercialiser *contributes* back				
N1.1		directly			
N1.1.1			**by *sharing* exhaustive *documentation***		**Confirmed**
N1.1.2			**by *sharing improvements***		**Confirmed**
N1.1.2.1				that are *significant*	Not confirmed
N1.1.3			by *providing resources* to the community		Not confirmed
N1.1.4			by *providing support and guidance* (especially to newcomers)		Not confirmed
N1.1.5			***by* sharing profits *with contributors***		***Added***
N1.2		indirectly			
N1.2.1			by developing *skills* and *knowledge* in the population		Not confirmed
N1.2.2			by providing *access to cheaper resources*		Not confirmed
N1.2.3			**by *growing the market***		**Confirmed**
N1.2.4			**by *diffusing innovation***		**Confirmed**
N1.2.5			***by fostering* innovation *and* quality improvements *through* competition**		***Added***
N2	Commercialisation is acceptable even when the commercialiser *does not contribute* back				
N2.1		if the commercialiser's *size* relative to the market is *small*			Not confirmed
N2.1.1			because the *market is growing*		Not confirmed
N2.1.2			because the company is *genuinely small*		Not confirmed
N2.2		**if the work of *contributors* is *acknowledged***			**Confirmed**
N2.3		even if the work of *contributors* is *not acknowledged*	because it makes them happy people use their creation		Not confirmed

Table **Error! Reference source not found.** provides a summary of the norms identified at interview stage – and indicates which were confirmed through the netnographic study – as well as the additional norms identified at netnographic stage. Overall, this study shows that the norms regulating commercialisation in the RepRap community are indeed rather complex. Not only both direct – i.e. intended by the commercialiser – and indirect – a byproduct of the commercialisation activity itself – can make commercialisation acceptable, but we even found some evidence of support within the community for commercialisation even without any kind of contribution, for as long as the work of people who have participated in the Open Source Hardware project is acknowledged.

Yet, these are not *just* "unwritten/unspoken rules" and further complexity arises from the fact that there are multiple *and* that they overlap, as any commercialisation activity is likely to relate simultaneously to different kinds of contribution (e.g. a commercialisation that has hardly any *direct contribution* may, at the same time, result in a significant *indirect* contribution). As a result, whether a particular commercialisation activity is finally deemed acceptable by the community heavily depends on the context – some commercialisers might find their activities supported by the community, while others, doing exactly the same thing, may not. And this is not just a matter of

'who has done it', but also relates to the timing of the commercialisation – what may be acceptable at a certain point in time may not be acceptable at other times.

Regarding the norms identified at interview stage that were not confirmed by the netnographic study, it is interesting to note that they relate to all kind of contribution (including 'no contribution'). This is interesting because we could have expected commercialisers to have a different view from the rest of the community in regard to a particular *kind* of contribution – e.g. they would think that indirect contribution was key, whereas the rest of the community would think that direct contribution is instead necessary, which is not the case. Instead, it appears that commercialisers may see a greater range of contributions resulting from commercialisation activities (whether direct or indirect and including 'making people happy' by 'robbing' their contributions) than the rest of the community does.

5.3 Sanctions Identified in the Netnographic Study

Three types of sanctions were identified at interview stage – boycott [S1], cease contribution [S2], damage reputation [S3]. The netnographic study enabled to confirm the existence of two of them – [S1] and [S3] and to uncover other forms of sanctions that had not been mentioned in the interviews.

The first sanction *boycott and call for boycott* [S1] is frequently mentioned on both blog posts and comments, and on posts on the RepRap forum, in particular in relation to the infamous Makerbot case:

"If I can make a suggestion, we can also make a difference in whenever someone comes to one of us asking what 3D printer to buy (ie they don't want to build one), we point them to good solutions that are not Makerbot. "

So do we boycott Makerbot for putting these in?

"[…] whenever a person talks to a friend with a 3D printer on which to buy, they get a resounding NO GO on the Makerbots."

"I am calling for a boycott of Makerbot due to: a) their betrayal of the open source community. b) their use of the community's technology as a marketing tool. c) the threat that they pose to continued development in the field."

Furthermore, boycott threats are used to bring back transgressors onto the 'righteous' path:

"Hearing that you've chosen to abandon the ideals of open software is discouraging and ensures you've lost a fan, evangelist and potential customer. "

Besides *boycott and call for boycott* [S1], we found evidence of attempts to damage offender's reputation [S3]. Besides relatively frequent episodes of insults and expletives, attempts are made to cast the offender under a bad light:

"And of course that yes, WE CAN BLAME Makerbot for closing what many people have contributed to in many ways and being where they are thanks to the open source community. "

In contrast, although retaliation by *stopping contributing* [S2] was mentioned as a sanction in the interviews, we found little evidence of it in either blog posts and comments, or RepRap forum posts. This can be explained by the fact that stopping contributing to a project, even if it is 'free-rided' by a commercialiser, effectively hurts the community as much (if not more) than the commercialiser itself. Interestingly, the only mentions of punishment that can be identified as stopping contributing were not related to contribution to product development, but, instead, to contribution to support:

"[…]if you need support [with a Makerbot printer], nobody here [would help] because makerbot left the open source area, and the way they behaved about it. I am speaking for myself, frankly even if I could help a user with [a Makerbot product] I would *not* help him."

Interestingly, two additional sanctions were identified thanks to the netnographic study. The first one relates to *banning offenders* [S4] from the community. While it is, of course, not feasible to prevent anyone from accessing community resources or from interacting with its members, it is possible to 'de-list' offenders from the 'official' RepRap catalogue:

"We have no obligation to maintain links in the [official RepRap wiki to [the offender's product] […] the first thing we should do stop rewarding the counterfeiters and re-sellers of counterfeiters by removing them completely from the [RepRap] wiki and forums."

A final additional sanction identified through the netnography is the threat to *reverse-engineer and publish* [S5] improvements a defector would have made without sharing them with the community, so that little commercial gain can be obtained by not following the norm:

"So when someone does this… this sneaky underhanded thing… IMMEDIATELY reverse engineer and make a fully open source version. […] So before they can ramp up, feel absolutely free to make a BETTER one, cheaper. "

In regard to the effectiveness of those sanctions, we firstly found little evidence of defection, besides the well-known (and abundantly discussed) Makerbot and Tangibot cases. For the latter,

there is clear evidence that sanctions were indeed effective, since the uproar in the community, as well as the associated threats of retaliation, led Tangibot to give up commercialisation before it had even started. As noted in a blog post by prominent RepRap community member Joseph Prusa:[12]

"Community loyalty can protect you from clones. … The Makerbot community a few weeks ago totally smashed the Tangibot. We all saw that as huge win for open hardware and consumer loyalty. So, there is no need to fear clones that much."

Beside this widely know case, we found, overall, hardly any evidence of any other defection. We only found another (single) case of a defector, who ended up getting back on the 'righteous' track following threats of sanctions. This commercialiser somehow sought to gain commercially by purchasing the RepRap.com domain name – very similar to the 'official' RepRap.org domain that hosts the RepRap wikis and forums – to commercialise his new 3D printer online. Following a heated discussion on the RepRap forum were he was the subject of insults and threats, the commercialiser posted the following messages:

"[I] will disconnect the Domain www.reprap.com... I don't want to hurt somebody. I didn't think that can be a problem for the RepRap people."

Thus, overall, our netnographic study enabled to find evidence of sanctions at play in the RepRap community and indications – both through cases of offenders backtracking following threats of sanctions and in light of the fact that we found only few cases of defection – that such sanctions were effective in preventing commercialisers from deviating from the commercialisation norms that prevail in the community.

An interesting finding, however, is that sanctions can only relate to boycott and attempting to publicly tarnish the reputation of the offending commercialiser. Retaliating by no longer contributing to projects related to the commercialised product does not appear to be an option, as it simply hurts the community. This means that the community has to be really influencial for such sanctions to be effective, which means that the community either has to make up a significant part of the market, or has to have the might to bear on decisions taken by outsiders.

[12] To this day, by far, the most prevalent RepRap model is the "Prusa i3", which was initiated and is still actively maintained by Joseph Prusa.

5 Discussion

5.1 Discussion of the findings

Our study has revealed a number of findings that we discuss in turn.

Firstly, as intuited, we find that norms are a key mechanism for regulating commercialisation behaviour in open source hardware communities. As expected, because commercialisation brings value to community members and users yet can threaten the very existence of communities, certain types of commercialisation behaviours are acceptable while others tend not to be. Overall, acceptable commercialisation entails giving back to the community in one form or another (keeping the project open source, contributing directly or indirectly, popularising the technology). However, even acceptable behaviour may be tolerated to different extent, e.g. contributing directly yet being closed source or publishing information in open source with a delay may be less tolerated than keeping the product fully open source. Thus, our findings suggest that reciprocity is a key condition for accepting commercialisation behaviour, as it implies that what is taken from the community and privately appropriated is compensated for by bringing new value to members or to the cause the community defends or promotes (here popularising 3D printing technology). Interestingly, we find that the range of reciprocity actions displayed by commercialisers and accepted by community members is rather large. The explanation may be twofold. On the one side, community members themselves may have rather variegated motivations for being part of an open source community. Some may identify strongly with the open source ideology while others may just be interested in or passionate about the technology or product. In fact, future research could further study the extent to which members' identification with the open source ideology might affect their level of tolerance for various types of commercialisation behaviour. On the other side, open source communities create different types of opportunities for entrepreneurial individuals or firms, which inevitably attracts actors with different motivations and behaving according to different logic. Future research could investigate further how the motivations of those commercialising tend to affect the types of reciprocity adopted.

Additionally, our findings support the argument developed earlier in the paper that norms tend to prevail when the consequences of the regulated behaviour are uncertain or difficult to assess, thus preventing the establishment of explicit rules or laws. In particular, our data revealed that there is

no clear consensus on which commercialisation behaviour would be most damaging for the community nor on the extent to which it would be damaging. One reason it is difficult assessing the consequences of commercialisation on open source communities is because commercialisation also provides benefits and value to communities, thus rendering difficult the evaluation of its potentially net damage. In contrast, there is a consensus on the absolute necessity to impel participants to 'share alike' their own developments and innovations; a concept which is congenital to the very existence of these communities. There is also a clear understanding of the essential damages that would be incurred in case of the systematic failure to reciprocate 'sharing alike' of what is borrowed from the community, thus explaining why a 'share alike' explicit rule is found to exist in open source communities. However, an implication of our findings for the governance of open source communities is that while norms indicate that various types of commercialisation behaviour are tolerated, a widely shared norm is that a commercialiser is expected to make significant improvement to the existing model and to keep his / her product as open source, thus sharing alike. This, we claim, could become an explicit rule in open source hardware communities. Secondly, our findings suggest precisely that explicit rules such as the 'share alike' rule do not however perfectly regulate commercialisation behaviours in open source communities for several reasons. First, the share alike rule does not prevent copycats who would undercut people having spent significant resources in R&D, thereby discouraging innovation, since clones can be released in open source and thus respect the licence. Second, the 'share alike' rule keeps at bay people who do not respect the rule but contribute directly (i.e. by providing resources such as import parts, hosting forums and repositories…) or indirectly (i.e. lowering prices, improving quality, growing the market..) thus creating value for the community and users in general. Third, licences are too costly to enforce for 'marginal' deviators, such as very small firms commercialising a handful of printers per year, especially in situations where the market is growing and the "well-behaved" manufacturers cannot meet the demand. Finally, by being applicable to all at all times, the share alike rule does not offer the flexibility to treat deviators differently. For instance, a community might like to treat differently deviators who have had a past of strong contribution to the community, like MakerBot, versus new comers. In contrast, commercialisation norms seem to offer more flexibility as they define a grey area where multiple behaviours are tolerated and boundary conditions for those behaviours can be accommodated.

Thirdly, our findings confirm that an important aspect of the effectiveness of norms in open source communities, as in general, relates to the expectation that deviating from the norms will incur some negative consequences for the deviator (Bauer et al., 2016). We find that threats to the reputation of the deviating commercialisers, in particular in the form of bashing and negative word of mouth, as well as threats not to purchase the product, are the most prevalent indications of sanctions towards those who do not comply with the commercialisation norms. Furthermore, the episode with Tangibot, suggests that these threats and pressures can be sufficient as to force a deviator to withdraw its offer and even refrain from staying in the market. A critical point discussed in the literature on norms is that sanctioning raises a second-order free riding problem (Oliver, 1980) that can make investment in sanctioning too weak, and thus norms inefficient in their regulating behaviours. However, in the online community we studied this seems not to be a problem because sanctioning is in fact cheap and even costless (e.g. Panchanathan and Boyd (2004). An additional problem raised in the literature is the notion that if sanctioning is economically costless it may be psychologically and socially costly: shaming others is not the most agreeable thing to do (e.g. Wiessner (2005). However, our data points out to a rather low effect of these costs on sanctioning as community members seem to voice their opinions quite extensively. This could be explained both by the online context, which allows more anonymity –given that members may even use fake names-, and by the fact that these communities tend to be imbued with ideology. Finally, a recurrent debate in the literature addresses the extent to which close-knit as compared to loose-knit communities make social norms efficient (Ellickson, 1991). In particular, it has been argued that sanctions such as threats to reputation should only be operant in close-knit communities and would have no effect on outsiders (Ellickson, 1991). However, our data reveals a striking fact: outside firms may in fact also comply with commercialisation norms as the case of the Chinese firms we interviewed suggests. Interestingly these firms reported fearing reprisal in case of no compliance with what they understand are community norms. This could suggest that the norms we identified may in fact be common to other communities and that open source communities may in fact exert their influence beyond their active members. In addition, as the Makerbot example illustrates, it is possible that the boundary conditions of norms' effectiveness lie less in being a 'community' versus 'non community' firm than in being an early stage company relying much on and needing the community support versus a more developed company catering at a larger market and selling more

standard products. Future research could indeed researched this question as it is key to understand the scope of norms' effectiveness.

Fourthly, our findings support the argument put forth in the theory section that norms tend to be revealed or shaped by critical incidents, as exemplified by the Tangibot and Makerbot incidents, since what is acceptable or not is usually not agreed upon beforehand and thus not explicitly broadcasted to community members. This suggests that norms may both need some time before they are established and fail to prevent destructive behaviours before they produce some damage, even if participation of members in several open source communities may help transfer norms more quickly in new and across communities. In fact, future research could study the extent to which norms 'circulate' across communities, depending for instance on individuals' multiple memberships, and if newer communities tend to be equipped more quickly with norms than earlier ones and, if true, how this occurs.

5.2 Contributions to the literature on household innovation

Our study and findings make several important, and interrelated, contributions to the literature on household innovation. More specifically, our contribution is threefold.

First, by pointing out the role of household innovators in commercial innovation, specifically through community firms started by active community members, we depart from the conventional view that there is a division of labor between users / households and producers in innovation (Gambardella et al., 2016; von Hippel, 2017). Specifically, we concur with the scarce literature that has emphasised the vertical integration of household innovators in the commercial arena (Shah and Tripsas, 2007; Hienerth and Lettl, 2011) and suggest that this prompts to reconsider the key issue of intellectual property rights. In fact, the focus on household innovators as specialised in making, rather than producing, innovations has spurred researchers to see intellectual property rights as barriers to household innovation (von Hippel, 2017). In contrast, a focus on household innovators as producers too should impel to reconsider the role of property rights in the contexts of household innovations. In fact, a motivation for commercialisation might be that commercialisation favors diffusion, most specifically in the case of hardware. Therefore, supporting the commercialisation of household innovations, yet possibly specific forms of commercialisation, might help address the diffusion failure that has recently been pointed out and studied (e.g. de Jong et al. (2015). A solution, revealed by our study, to the seemingly contradictory effect of property rights as both

limiting – by restraining the cumulativeness of innovation- and enabling –by creating incentives to produce and commercialise – household innovations precisely reside in the presence of commercialisation norms aimed at circumscribing commercialisation behaviours in forms that are compatible with both the formation and diffusion of household innovations. If norms might be seen as an alternative to intellectual property rights, they may however reach a higher efficiency when spelled out in the form of explicit rules. So, rather than condemning all forms of innovation protection, it would be more efficient to promote and broadcast explicit rules regarding the commercialisation of household innovations.

Second, by emphasizing an online context in which freely shared household innovations are highly visible, we highlight important differences with the offline contexts in which free innovation has traditionally been studied (e.g. Franke and Shah (2003); Hienerth (2006); von Hippel and Katz (2002); von Hippel (2017). Specifically, we point out that visibility as well as the digitalization of innovation (i.e. that the innovation's features can be downloaded through digital blueprints or programs) makes free sharing of household innovations less trivial than usually assumed. In fact, in online contexts, household innovations are typically parts of innovation commons. As in any commons, free riding is an important issue that can threaten the very existence of the commons (Ostrom, 2000). We point out a key aspect of free riding which is the misappropriation of household innovations through commercialisation. Yet, our study suggests that commercialisation can take forms that are compatible with maintaining the commons, which is an especially important finding given the prevalence of commercialisation behaviours based on open source hardware. Also, our study emphasizes the role of norms in regulating the behaviours of household innovators. Future research could in fact dig deeper into that matter and study, for instance, whether norms are also present in offline contexts. Furthermore, it would be interesting to know whether those norms are similar to those found in online contexts, and if they depart why is this the case.

Third, by contending that commercialisation of household innovations is undertaken by different types of entrepreneurs, who build companies that have distinct relationships to the open source communities which provide them with content, our study raises the question of the personal and social identities of these entrepreneurs (Fauchart and Gruber, 2011, 2019). In fact, the literature on household innovation is rather silent on the identity question, although there is no reason to believe that household innovators would have similar identities and thus would behave similarly. For instance, variance in the extent to which household innovators decide whether or not to

commercialise their innovations is likely to not merely depend on rational factors such as the expected profitability of that decision, or its opportunity cost. In particular, it might depend on the extent to which they identify with the open source movement and the community on which they draw content. In this respect, the step that consists in moving the field from user to household innovation implies, among other things, to acknowledge the variety of identities held by the innovators. In addition, a very promising area of research resides in studying whether receiving help from outsiders while conceiving the innovation affects the decision, other things being equal, to commercialise the innovation. More generally, we know very little about the identities of household innovators and how they affect their behaviours, in particular with regard to commercialisation, and future research could study more thoroughly how the context in which individuals become household innovators affect their attitude towards commercialisation and their entrepreneurial intentions.

5.3 Limitations of the study

Aside from the usual limitations related to the methodologies used – whether interviews or netnography (Kozinets, 2002, 2015) – the main limitation of this study relates to the language used – i.e. only posts in English were considered in the netnographic study. As a result, what we observe mainly relates to the wide 'western'/North American market, where issues related to sharing, commercialisation, and more largely, diffusion of innovation, may be significantly different than in the rest of the world (for instance in China, just to take one example). As a matter of fact, several of the norms identified at interview stages that were not confirmed by the netnographic study were mentioned by commercialisers located in non-English speaking countries (e.g. Argentina, China, France) and who were catering mainly for the local market.

In regard to the traditional issue of the generalisation of the findings, it is important to emphasise that any community involved in Open Source Hardware is likely to encounter the same kind of issues related to commercialisation (i.e. little relevance of IP and significant cost of diffusion of innovation effectively requiring commercialisation) and while an avenue for further research would indeed be to extent the current research to other OSH communities (such as the Arduino community or the GnuBee community).

Besides hardware, any user innovation community where physical products are involved, and that does not chiefly rely on 'large' players to commercialise and diffuse innovation (as is typically the

case for instance in the scientific equipment or the sports equipment market) is likely to face the same issues, which makes the findings of this study relevant as well. In this respect, the current trend of easier and cheaper access to manufacturing capabilities (either locally, thanks to 3D printing/digital manufacturing technologies, through manufacturing online platforms such as Shapeways, or through outsourcing) will undoubtedly foster the growth of this kind of community, making the findings of our research both timely and useful.

7 Conclusion

Our study uncovers the main norms relative to commercialisation in a specific open source hardware community: the 3D printing community 'RepRap'. In particular our findings show that the commercialisation norms prevailing in the RepRap community are surprisingly complex. This complexity is due to the necessity of creating a grey area that enables an 'optimal' trade-off between innovation and diffusion. Commercialisation is therefore not antagonistic with free innovation and the two can coexist peacefully if commercialisation is properly regulated by norms.This is a key finding because household innovators, as well as manufactures, use more and more content, freely shared by open source communities, to design novel products. Our study therefore also demonstrates that commercialisation of household innovations by household innovators is not only an indisputable phenomenon in a world where commercialisation so far has been the domain of producers, but also could be beneficial to innovation community when properly monitored.

Hence, in a purely decentralised environment, devoid of policy or state intervention, the complex set of norms identified in this study enable to answer the age-old and traditional dilemma between motivation to innovate and maximising social welfare.

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