Why makers make what they make: motivations to contribute to open source hardware development

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Open source software (OSS) and hardware (OSH) are two expressions of one broader concept and its related movement. One of the most fundamental questions relating to these phenomena is why developers contribute their private resources to these public goods. While this question has been discussed, theorized, and empirically investigated in the context of OSS, there has been no research so far in the context of OSH. Can we really assume the motivations behind the development of the OSH to be the same as those behind OSS? Based on the self-determination theory (SDT), we provide original insights into the motivations behind contributions to OSH development. We collected data from the most common and active 3D printing communities, which are the main loci of OSH development. We thus have a unique cross-sectional data set with participants from over 30 different countries using all kinds of different OSH platforms. Our analysis reveals several important findings: firstly, the motivations are in some aspects very similar to those in open source software notwithstanding different possibilities, hurdles, and incentives regarding the OSS and OSH. Above all, enjoyment-based intrinsic motivation is a major factor affecting contribution levels. Secondly, among internalized extrinsic motivations, expected private benefits through improving own skills stands out. Thirdly, different factors of internalized extrinsic motivations can have different moderating effects on the effect of enjoyment-based intrinsic motivation. Given the imminent changes in business models throughout manufacturing industries in order to adapt to the challenge that OSH will increasingly pose, our findings have important implications not only for OSH communities and 3D development platforms, but also for businesses that want and probably soon have to engage in open innovation.

1. Introduction

Chesbrough (2003) described some common ‘erosion factors’ in the context of firms making increasing use of external knowledge and exploring external ways to markets, something of which he recently reminded us (Chesbrough and Bogers, 2014). The phenomenon of open source is a further erosion...
factor, of which two distinct variations, open source hardware (OSH) and open source software (OSS), emerged contemporaneously about 40 years ago (although not under these labels). While the OSS can be considered a success, eroding the traditional ‘closed innovation’ model, for OSH we are not so sure yet (Spaeth and Hausberg, 2016).

Driven by its success, the OSS has attracted intense research interest, examining the motivation of participants in the context of the OSS (Hertel et al., 2003; Lakhani and von Hippel, 2003; Ghosh, 2005; Lakhani and Wolf, 2005; Lattemann and Stieglitz, 2005; Roberts et al., 2006; Osterloh and Rota, 2007; von Krogh et al., 2012). OSH has existed so far only in the shadow of OSS. Few studies ask questions with regard to OSH. First insights suggested that the economics and organization of the OSH communities differ from their software equivalent (Raasch et al., 2009).

Both phenomena share the characteristic of being almost non-rival, non-exclusive public goods (Lerner and Tirole, 2002); both are often developed in online user communities, yet they differ in several important aspects. Firstly, copyright applies automatically, whereas hardware developers have to apply for patents, which is not only a costly and lengthy process, but also uncertain in its outcome and requires mostly absolute novelty of at least some key aspect of the invention. Secondly, copyright law controls the distribution of the source code, whereas patent law controls manufacturing. Thirdly, OSH development is much more localized than the mainly virtual development communities of OSS. Important examples are the FabLabs and the RepRap communities, but also groups without any particular affiliation exist that use particular ‘maker-spaces’ to meet and work together.

It is important to understand the motivations of the contributors to the OSH communities in order to verify whether these differences in nature between the OSH and OSS also translate into differences in the motivations to contribute. Therefore, the question as to ‘What motivates highly skilled and formally educated people with oftentimes closely related and demanding daily jobs to contribute to the development of open source hardware projects also in their spare time and without any monetary incentives?’ has important implications for companies trying to integrate OSH into their business models (Lock, 2013).

Hence, the aim of our study is to highlight some basic similarities and differences between the role of different types of motivational factors for OSS and OSH development, which will have important implications for collective and open innovation. Moreover, we aim at providing evidence for the potential moderating effects that enjoyment-based intrinsic motivation might have on internalized extrinsic motivations.

2. Theoretical background

Lerner and Tirole (2002) once asked what motivates software programmers to contribute voluntarily to a public good. Since the open source phenomenon could not be sufficiently explained neither by the private action model nor by the collective action model, Hippel and Krogh (2003) developed the private-collective model of innovation. In this model, individual user innovators provide a collective good by expending private resources. They show that rational choice can explain this private provision, once one assumes that private benefits continue to exist even after the free contribution. Others have followed this argument (Spaeth et al., 2008; Nagle, 2018). Yet, more often, theories not only relying on rationality have been used to explain volunteer contributions. Hence, we have gained a good understanding of the motivations of volunteer software developers (Krishnamurthy, 2006; Janzik and Herstatt, 2008; Aksulu and Wade, 2010; Crowston et al., 2012; von Krogh et al., 2012).

Motivation theories have come up with different groups of motivations for human behavior, most prominently extrinsic and intrinsic motivation of the self-determination or cognitive evaluation theory (Deci, 1971; Deci and Ryan, 1985; Lindenberg, 2001). This distinction is also very prominent in the literature on the motivations to contribute to open source projects (Lakhani and Wolf, 2005; Bitzer et al., 2007), where the categories have been largely verified. On this basis, several subcategories have been identified in a broad range of studies (for a review, see von Krogh et al., 2012), most notably into intrinsic, extrinsic, and internalized extrinsic motivation (the latter being extrinsic by definition, but can be internalized, leading to a self-regulating behavior). In OSS, a wide range of motivations ranging from ideology (Haruvy et al., 2003; Stewart and Gosain, 2006) to labor market signaling (Bitzer et al., 2017) have been examined.

Given the differences between the OSS and OSH, it is far from certain that the OSS and OSH belong to the same social practice. Lattemann and Stieglitz (2005) suggest that primary motivations to join a project and thus contribute to OSS development differ by the roles the developers have – in the case of the OSS communities, for example, they list bug fixers, programmers, and managers. In many complex technological OSH projects, like the development of
3D printers (e.g. the RepRap-project), communities have to develop also software that runs the hardware. OSH projects thus potentially exhibit all developer roles of the OSS projects and some additional ones of people exclusively occupied with tasks specific to this context. Most prominent among these is certainly the development of the design files. We can further distinguish in exclusively technical, exclusively esthetical, and mixed design tasks. The diversity of the roles and the tasks in the OSH is mirrored therefore also in the professional backgrounds of the ‘makers’, the term often used for members of the OSH development communities. The plethora of contributor roles thus affects contributor motivations.

Moreover, research on open innovation communities has shown that motivations are not independent of the context in which volunteers operate: seeing volunteers as participants of a social practice (von Krogh et al., 2012) has been a powerful explanation of motivations for volunteers and academics (Baer and Shaw, 2017). Achieving excellence and increasing standards within that community becomes an internal good to the practice (Knight, 1998, 2008) and a means and a motivation in itself (Shah, 2006).

3. Open source hardware

In the scholarly literature, open source production is described as a new method of innovation (Osterloh and Rota, 2007) or as a ‘community-based model’ of innovation (Shah, 2005). The open source initiative (OSI) developed an ‘open source’ definition of the OSS that is widely accepted by practitioners. It lists the following criteria in order for software to qualify as open source: it allows free redistribution, source code availability, derived works, and integrity of an author’s source code through patch files; it demands the distribution as well as technology-neutrality of license; and it prohibits discrimination against persons, groups, or fields of endeavor, productspecific licenses as well as restrictive licensing.\footnote{Several distinct sets of standard licenses are available to developers in order to assure that their products are licensed as open as they intend (e.g. GPL, CreativeCommons, etc.).}

Early attempts to formalize open source hardware, e.g. ‘The Open Hardware Specification Project’, in 1999, did not spread widely. Despite OSH being described in practitioners’ journals as early as 2004 (Salem and Khatib, 2004; The Economist, 2008), it took a few more years of technical progress to popularize the concept. Two streams contributed to its success: the creation and usage of OSH for scientific purposes (Pearce, 2012, 2016) and the progress of 3D printers and the creation of communities surrounding these technologies. Defined as hardware ‘shared […] by providing the bill of materials, schematics, assembly instructions, and procedures needed to fabricate a digital replica of the original’ (Pearce, 2016, p. 192), OSH resembles OSS in many ways. OSH licenses often are directly derived from its software equivalent. Yet, differences in intellectual property protection mechanisms and the need to physically create the product to experience it (and develop it further) lead to differences regarding the creation of virtual assets. For instance, copyright automatically applies to all software, while 3D objects are subject to patent protection, for which inventors need to apply explicitly (and expensively). Higher costs (and effort) to duplicate physical assets have also proven a hurdle to successful collaboration on and the diffusion of physical artifacts.

In analogy to the OSI, the Open Source Hardware Association provides a widely accepted OSH definition\footnote{In analogy to the OSI, the Open Source Hardware Association provides a widely accepted OSH definition\textsuperscript{2} that translates the above criteria into the realm of hardware. In the case of software, the licensed source is the program code, whereas in the case of hardware, it refers to the object design files (e.g. 3D-printable STL-files) necessary to replicate the hardware, which can usually be protected through patent law. However, many patent law frameworks are relatively permissive in terms of private replication and significantly harder to obtain than the automatic application of copyright on software. This was no major problem when individual users did not have any economically feasible way to replicate artifacts.} that translates the above criteria into the realm of hardware. In the case of software, the licensed source is the program code, whereas in the case of hardware, it refers to the object design files (e.g. 3D-printable STL-files) necessary to replicate the hardware, which can usually be protected through patent law. However, many patent law frameworks are relatively permissive in terms of private replication and significantly harder to obtain than the automatic application of copyright on software. This was no major problem when individual users did not have any economically feasible way to replicate artifacts.

Most recently, 3D printing gained enormous momentum and became an enabling factor for the open innovation model (Rayna and Striukova, 2015; see West and Kuk, 2016 for a review of the history of 3D printing). In particular, the falling cost of desktop 3D printers allowed many consumers of the manufactured products to become prosumers and hence get involved in the outside-in and coupled mode of open innovation (Enkel et al., 2009). This acceleration in the development of the 3D printing technology revitalized the maker movement. By now, OSH communities develop even very complex products, which until recently appeared to be the exclusive terrain of big corporate R&D departments (Spaeth and Hausberg, 2016). Among these products are as complex ones as notebook computers, microchips, and entire cars. Also, 3D printers themselves are subject to collective innovation through globally dispersed, open development communities. Given the above, our focus on OSH extends to every physical artifact that can be developed, shared, and manufactured using 3D printer and accompanying tools.
4. Hypotheses

4.1. Obligation-based intrinsic motivation

The identification with the so-called ‘hacker culture’ can be an important driver to contribute to the OSS (Bonaccorsi and Rossi, 2003). This culture is rooted equally in software and hardware development communities and the open source movement more generally (Levy, 1984). In case of the open source movement, such identification often leads to explicit rejection of proprietary products and sometimes even intellectual property altogether. Empirical studies in fact found evidence in support for the impact that this identification with the open source movement has on the intention to join Linux user groups (e.g. Bagozzi and Dholakia, 2006), or for the effect of their specific identification as a Linux developer on their commitment (Hertel et al., 2003).

An important aspect of these communities with which developers identify is the idea of reciprocity and that developers contribute also because they expect to receive something back from the community (von Krogh et al., 2012). In order to make this work at large, they have hence to engage more if they have already received something and feel the obligation to give something back to the community. This effect is closely related yet distinct from the effect of altruistic motives, which are part of the community-based motivations found previously by Lakhani and von Hippel (2003). Both effects are, however, at the core of what some describe as the open source ideology, which has a positive effect on contribution to the community (Stewart and Gosain, 2006).

These effects should be observable in the OSH context just as in the OSS context. A lot of the communities’ work happens offline in small, geographically concentrated communities of tinkerers and makers. The relationships that develop offline in these communities can be assumed to be a lot closer and the observation of individual contributions is very direct. This might create a strong social motivation and feeling of obligation to contribute to the local community. We can thus hypothesize the following:

Hypothesis 1: The more makers feel an obligation-based intrinsic motivation, the higher their contribution to the OSH community.

4.2. Enjoyment-based intrinsic motivation

Enjoyment is the core aspect of intrinsic motivation (Deci and Ryan, 1985) and enjoyment-based intrinsic motivation has been found to be among the prime motivations in the OSS context (Lakhani and Wolf, 2005), although a mere correlation analysis might not reveal a significant relationship between hedonistic motivations and effort (Hertel et al., 2003). Research finds various factors contribute to the enjoyment of work and an ensuing higher effort. The most important ones are intellectual stimulation, fun, enthusiasm, and curiosity about the subject, as well as flow (Hars and Ou, 2002; Lakhani and Wolf, 2005; Shah, 2006).

Although the OSH movement emerged around the same the time as the OSS movement, it experienced its fastest and most noteworthy development only since very recently. Therefore, there are many new members as well as new technological developments in the OSH communities and a lot of the desktop 3D printing technology is available only now. Thus, a lot of the development going on now seems playful exploration of possibilities to at least the same degree as in the software context. An important part of the enjoyment is the satisfaction perceived when others give positive feedback to their own contributions, which is why the OSS developers often monitor mailing lists and online discussions related to their work (Shah, 2006). Such feedback should be even more direct in the local maker communities.

The strongest expression of enjoyment of work, however, is probably the experience of ‘flow’, which is so very pleasant and rewarding that people lose the feeling of time while working on their project. The concept of flow was originally coined as the ‘holistic sensation that people feel when they act with total involvement’ (Csikszentmihalyi, 1975, p. 4, cf. Fullagar and Kelloway, 2009). In order to develop the possibility to work in flow, people have to reach a level of mastery of their field that most people usually reach only after about 10 years or more. This often goes hand in hand with a particular fascination for the field without which such an intense, continued occupation with a field would hardly be possible. These highly skilled experts are also those that take every occasion to work on what they are good at. Hence, flow can be regarded as an important element of enjoyment-based intrinsic motivation (Amabile et al., 1994) that induces higher levels of contribution to open source projects.

Hypothesis 2: The more the makers feel an enjoyment-based intrinsic motivation, the higher their contribution to the OSH community.

4.3. Pure extrinsic motivation

Extrinsic are those motivational factors that try to regulate individual behavior from the outside. The classical economics view of the *homo oeconomicus*,...
or the rational man, assumes that humans are primarily driven by monetary incentives or other tangible external rewards. Therefore, the case of developers contributing 'for free' to open source projects was such an intriguing one (Hars and Ou, 2000; Lerner and Tirole, 2002). The self-determination theory with its distinction between intrinsic and extrinsic motivations offered a very plausible explanation for this behavior (von Krogh et al., 2012). However, the total effect of payment on the overall contribution levels remains elusive. While in some open source communities payment remains acceptable (Henkel, 2006), in many other cases norms against payment emerged and can moderate the impact of payment (Alexy and Leitner, 2011). Studies found negative effects of payment or professionalism in open user innovation and OSS development communities (Hars and Ou, 2002; Jeppesen and Frederiksen, 2006). Such a negative effect could result from a reduction of intrinsic motivation. The self-determination theory suggests that some extrinsic motivators like payment can crowd out intrinsic motivation (Deci, 1971; Frey, 1994). However, Roberts, et al. (2006) find no evidence of a crowding out of intrinsic motivation by extrinsic factors, but they still find a negative effect of use value on contribution levels. The direct effect of payment, on the other hand, is considered to be positive in general, which studies in OSS have confirmed (e.g. Lakhani and Wolf, 2005).

However, payment is just the most explicit form of external motivation. The job use value of the OSH project, as well, may lead to the entry of users with particular needs. However, whereas payment has a durable effect, contribution due to job use value does not. In this case, developers contribute not for the sake of the work itself, but for the fulfillment of their idiosyncratic job needs. This does not mean that they cannot contribute during their office hours – probably most of them are doing so – but that the job that they are paid for does not explicitly state that they should contribute to such an OSH project. Instead, they recognized a way in which they can use the OSH in their job. The higher the job-related use value, the more likely this value was the main reason for joining the project in the beginning, but effort levels drop once the project developed sufficiently. Therefore, the higher the job-related use value is at a given moment of the project, and hence, the more the project already corresponds to the job requirements, the less incentive remains to contribute any further.

Hypothesis 3a: Paid contributors exhibit higher levels of contribution to the OSH community.

Hypothesis 3b: The higher the job-related need for the developed hardware (job-use value), the lower the average weekly contribution to the OSH community.

4.4. Internalized extrinsic motivation

Besides the mentioned pure extrinsic motivations, there are some that are by definition extrinsic, but might be internalized, which means that they are potentially self-regulated (Ryan and Deci, 2000). Own-use value is an example of such an extrinsic motivation that can qualify as internalized (von Krogh et al., 2012). While this is not that obvious for paid OS developers, almost everyone working without any monetary compensation on the development of OSS or OSH is also a user (von Hippel, 2001). Hence, one could easily conclude that the own-use value of the final product potentially is a pervasive motivation to participate in the development. Several studies of the OSS communities report that own-use value can be a motivation to contribute (Lakhani and von Hippel, 2003; Ghosh, 2005; Lakhani and Wolf, 2005).

However, some argue that long-term membership in a community will change participants’ self-identification and motivation (Shah, 2003, 2006) and make participation a goal in itself (Elster, 1986, p. 132). Moreover, contribution levels could also diminish over time. Roberts et al. (2006), for example, found a significant negative relationship between personal use value and contribution levels. Own-use value can be an entry motivation. Developers might see participation in the project as the best way to influence the development of the open source project into the direction of their idiosyncratic needs. In OSS projects, interpersonal ties between core and peripheral developers are relatively loose due to the virtual nature of collaboration. In case of the OSH projects, however, makers meet in their local communities physically, which makes ties much more tangible even for sporadic contributors. Hence, for the OSH projects, there should be a higher barrier to exit from the local community after the fulfillment of the own development needs, so that developers often are left with the option to reduce their contribution level. It is also after the fulfillment of the own development needs that the own-use value of the OSH project is highest. In a cross-sectional setting, we should hence observe a negative effect of own-use value.

Hypothesis 4a: The higher the personal need (own-use value) for the developed hardware, the lower the average weekly contribution to the OSH community.

Another example of an extrinsic motivation that individuals can self-regulate and thus internalize is the desire and expectation to learn and acquire new skills through contributing to OS projects. Learning
can be an important driver of contribution to open source projects (Lerner and Tirole, 2002), as has been found for OSS development (Ghosh, 2005). Previous research found learning as the primary reason to contribute to open source communities (Lakhani and von Hippel, 2003; Lakhani and Wolf, 2005). Likewise, Hars and Ou (2002) find human capital enhancement among the most cited reasons to contribute to the OSS projects. On the other hand, learning in the context of OSS development has also been found to be very limited if tasks are fragmentary and piecemeal (Shah, 2006). However, in the case of OSH development, we can expect that modularization is still less developed than in OSS. Extant research shows that the OSS is more modularized than closed source software (MacCormack et al., 2012). Since OSH has been a niche for a long time, the now growing OSH communities have yet to learn how to modularize the OSH beyond the levels of closed-source hardware. This, hence, offers more opportunities to learn.

Moreover, extant research suggests the main mechanisms behind the efficacy of learning and hence also learning-based motivation is the intense peer-review process through which contributors receive feedback for their work (Oreg and Nov, 2008). In the case of local maker communities, such feedback can even be more direct and hands-on and facilitate also the transfer of tacit knowledge. Therefore, we should be able to observe a pronounced positive effect of expected learning through contribution to the OSH project.

Hypothesis 4b: The more makers expect to improve their skills, the higher their contribution to the OSH community.

Reputation is usually classified as ‘peer reputation’ and ‘outside reputation’ (von Krogh et al., 2012). Reputation is also one of the core values of open source ideology (Stewart and Gosain, 2006). Several studies in the OSS communities provide empirical evidence that reputation is a major motivation to freely contribute to OSS development (Ghosh, 2005; Lakhani and Wolf, 2005). A direct link between contribution to open source projects and reputation has been found in an empirical study by Spaeth et al. (2008) who show that reputation can be gained as a by-product of contributions to the community in the form of positive mentions. Lakhani and Wolf (2005) find only a limited influence of reputation.

However, as Lerner and Tirole (2002) emphasize, economic theory suggests that signaling to seek peer recognition depends on the observability of the performance, the impact of effort on performance, and the information value of performance regarding talent. We can assume that all three of these contingencies are present in the context of the OSH projects to at least the same degree as in the OSS projects. Due to the geographical proximity and local community-based nature of the OSH project, they should be even higher. Therefore, reputation should have a positive effect on the developers’ effort.

Hypothesis 4c: The more makers expect to gain reputation through their work, the higher their contribution to the OSH community.

4.5. Interaction: enjoyment-based intrinsic and internalized extrinsic motivation

The classic hypothesis of the self-determination theory that extrinsic motivations in general crowd out intrinsic motivations has been analyzed also in the context of open source projects (Roberts et al., 2006). The crowding effects of internalized extrinsic motivations may affect intrinsic motivations. Previous studies found enjoyment-based intrinsic motivations among the most important drivers of contributions to open source projects. It is therefore important to understand how this motivation might be related to other factors.

Tasks that are mundane but nonetheless necessary for the successful completion of a project are less chosen (Lakhani and von Hippel, 2003). This suggests already that technologically challenging tasks offer something ‘gratifying’ to the developers that mundane tasks cannot offer. Such intellectual gratification has been suggested as motivation also by Bonaccorsi and Rossi (2003). However, open source communities are effective also in tackling these mundane and not so enjoyable tasks. We argue that reputation can compensate in fact for a lack of intrinsic motivation. In other words: while reputation might not motivate those that are already motivated by fun, it might motivate those that lack enjoyment-based motivation. This means that the interaction effect should be negative.

Although also an internalized extrinsic motivation, the contrary holds true for learning. Lakhani and von Hippel (2003) find that 98% of user-to-user assistance provides direct learning benefits to the supporting user. However, if there the topic of assistance is mundane and unpleasant, developers might forgo the chance to learn in this unattractive niche. If, however, assistance can be offered around an enjoyable topic, learning might be an additional driver and might contribute more thoroughly to the community. Hence, the interaction effect should be positive.
Hypothesis 5a: When makers are highly motivated by reputational benefits, the positive effect of enjoyment-based intrinsic motivation is crowded out.

Hypothesis 5b: When makers are highly motivated by learning benefits, the positive effect of enjoyment-based intrinsic motivation is bigger.

We illustrate all hypotheses in our conceptual model in Figure 1.

5. Methodology

We collected data from January 26 to February 26, 2015, by means of an online questionnaire sent out to a range of different communities. This cross-sectional survey included mainly FabLabs and RepRap maker- and hackerspaces, but as well a few university-based 3D printing groups/spaces and online communities or forums, like those of sites like thingiverse, ultimaker, and youmagine. Since our contacts distributed the invitation to participate within their respective communities, we have no possibility to estimate the response rate. However, 279 clicked the link, and 169 of these responded to at least some questions and 119 (42.6%) sufficiently completed the questionnaire to include the responses in the sample.

We operationalized our items based on previous survey studies, primarily Lakhani and Wolf’s (2005). Lists of all continuous and categorical variables with their descriptive statistics are available in Appendix A (see Tables A1 and A2, respectively). The correlations of the variables used are displayed in Table A3.

Our scales for obligation-based and enjoyment-based intrinsic motivation as well as that for reputation are common, unweighted averages of the respective underlying items.

We addressed a potential common-method bias by means of Harman’s single-factor test (see Table A4). A principal component analysis revealed six factors with eigenvalues bigger than 1 and the first factor could explain only 24% and 14% of the variance in the unrotated and varimax rotated solutions, respectively, with varimax rotation being the more appropriate approach here since the underlying factors can be assumed to be related.

We had to substitute for some missing values. These were however so few that we can assume they were missing completely at random (MCAR). We imputed these values with variable means. From the total sample of 119, we had to delete 3 cases that were clear outliers. We had a final sample size of 116.

6. Results and discussion

We used a generalized linear model (GLM), precisely a negative binomial regression, because our dependent variable (average hours per week contributing to open source hardware development, HOURS) is a discrete, overdispersed variable (see Figure A1) which would not fit a Poisson regression. We tested three models: one with the control variables only, one with all the main effects, and a third one with also the interaction effects included. For all the three models, the Omnibus test is significant at the 0.1% level and the goodness-of-fit statistics are within the respective cut-off criteria. The chi-square P-value is not significant and the deviance value/df is always below 1 – see Table 1.

Table 2 shows the results of our regression analysis for the control variables only. As can be seen, everyone seems to contribute less to 3D printing-enabled OSH development than the baseline group, that is those with a technical background like professional hardware developers, engineers, or engineering students (JOBTYPE = 3, omitted baseline expression). However, only for academics (JOBTYPE = 5) and

![Conceptual Model](image-url)
people with no professional relation to hardware development (JOBTYPE = 1), this is highly significant. Moreover, age could possibly affect the contribution levels, but the estimated effect is only at a $P$-value of 0.109. On the other hand, there are significant differences between the regions. Makers from Latin America (REGION 3) seem to contribute significantly more than do their peers from the US, the UK, Canada, New Zealand, and South Africa (Region 2, omitted baseline group).

Table 3 shows the results for the entire model without (Model 2) and with (Model 3) interaction effects. The control variables are about as significant or not as in the controls-only model, only AGE being close to the 5% threshold. We inspected our Model 2 and Model 3 also for heteroscedasticity (see Figure A2) and outliers (see Figure A3). We do not find evidence for heteroscedasticity issues and all residuals were within the range of ±3.

Concerning Hypothesis 1, we cannot find a significant effect of obligation-based intrinsic motivation on contribution. The odds ratio is 0.864 with a $P$-value of 0.301. This finding is surprising since previous studies in the context of OSS development found this kind of intrinsic motivation to be a relevant factor and we expected the OSH communities to exhibit a similar behavior in this regard. However, the geographical proximity and regular and frequent face-to-face interactions could establish close-knit communities in which, paradoxically, high levels of trust may allow people to feel safe to reduce their effort without incurring social costs. This way, very high levels of trust could reduce obligation-based intrinsic motivation.

Regarding our Hypothesis 2, however, we can find a highly significant effect (1% level) of enjoyment-based intrinsic motivation on the contribution behavior. The odds ratio for INTRINSIC_JOY is 1.609, which means that the odds for another half an hour of contribution effort increased by 60% for every one point increase in enjoyment-based intrinsic motivation. This is line with some previous findings in the OSS context (Lakhani and Wolf, 2005; Roberts et al., 2006), where long-term members of the developer core community work on the project out of intellectual curiosity, fun, and enthusiasm for the project. There is also the first research indicating similar mechanisms in hardware development as hackerspaces have emphasized the importance of social aspects (Moilanen, 2012).

We could find no confirmation for our third hypothesis. Neither pay (H3a) nor career-/job-use (H3b) resulted to have any significant effect ($P$-levels of 0.246 and 0.381, respectively) on the degree of involvement. This is in line with similarly insignificant effects in other studies, for example relating salary and job advancement opportunities with hours worked on innovative projects (Sauermann and Cohen, 2010) as well as the contrasting studies finding both positive (Lakhani and Wolf, 2005) and negative (Hars and Ou, 2002; Jeppesen and Frederiksen, 2006) effects of pure extrinsic motivation. A possible explanation could be that these factors are entry motivations. Their job-related goals might be very short term, for example, including a certain feature into a project required for the project to be useful for their work. Once the developers are part of the community, other factors determine the level of their continued involvement (Fang and Neufeld, 2009). This would be in line with previous findings that the need for specific, idiosyncratic improvements

Table 1. Goodness-of-fit statistics and Omnibus test for Models 1–3 (Neg. Bin.)

|                | Model 1 Value | df | Value/df | Model 2 Value | df | Value/df | Model 3 Value | df | Value/df |
|----------------|---------------|----|----------|---------------|----|----------|---------------|----|----------|
| Deviance       | 109.45        | 104| 1.052    | 92.962        | 97 | 0.958    | 85.467        | 95 | 0.900    |
| Pearson chi-square | 109.45      | 104|          | 92.962        | 97 |          | 85.467        | 95 |          |
| Log Likelihood | 94.415        | 104| 0.908    | 81.552        | 97 | 0.841    | 72.743        | 95 | 0.766    |
| Akaike’s Information Criterion (AIC) | 94.415      | 104|          | 81.552        | 97 |          | 72.743        | 95 |          |
| Finite Sample Corrected AIC (AICC) | −462.035   |    |          | −453.792      |    |          | −450.044      |    |          |
| Bayesian Information Criterion (BIC) | 948.071   |    |          | 945.584       |    |          | 942.089       |    |          |
| Consistent AIC (CAIC) | 951.1       |    |          | 953.500       |    |          | 951.918       |    |          |
| Omnibus test   | 24.485        | 11 | 0.011    | 40.972        | 18 | 0.002    | 48.467        | 20 | 0.000    |

DV = Hours (weekly average contribution); Model: (Intercept), Gender, JOB, REGION, AGE.
LHR $\chi^2$ = Likelihood Ratio Chi-square.
Table 2. Negative binomial regression results for Model 1, control variables (Dependent variable: HHOURS)

| Parameter   | B       | Std. error | Lower     | Upper     | Wald | df  | Sig. | Exp(B)     | Lower | Upper |
|-------------|---------|------------|-----------|-----------|------|-----|------|------------|-------|-------|
| (Intercept) | 3.516   | 0.5381     | 2.462     | 4.571     | 42.707 | 1   | 0.000 | 33.661     | 11.725 | 96.635 |
| GENDER      | 0.319   | 0.3979     | -0.461    | 1.098     | 0.641  | 1   | 0.423 | 1.375      | 0.630  | 2.999  |
| JOBTYPEa    |         |            |           |           |       |     |      |            |       |       |
| Unemployed  | -0.317  | 0.2978     | -0.900    | 0.267     | 1.131  | 1   | 0.288 | 0.729      | 0.406  | 1.306  |
| Academic    | -1.734  | 0.2746     | -2.272    | -1.195    | 39.855 | 1   | 0.000 | 0.177      | 0.103  | 0.303  |
| Design      | 0.086   | 0.3355     | -0.572    | 0.743     | 0.065  | 1   | 0.799 | 1.089      | 0.564  | 2.102  |
| IT/Software | -0.521  | 0.2673     | -1.045    | 0.003     | 3.795  | 1   | 0.051 | 0.594      | 0.352  | 1.003  |
| Unrelated   | -0.632  | 0.2567     | -1.135    | -0.129    | 6.066  | 1   | 0.014 | 0.531      | 0.321  | 0.879  |
| AGE         | -0.015  | 0.0097     | -0.034    | 0.003     | 2.571  | 1   | 0.109 | 0.985      | 0.966  | 1.003  |
| REGIONb     |         |            |           |           |       |     |      |            |       |       |
| Turkey &    | -1.323  | 0.6293     | -2.557    | -0.090    | 4.421  | 1   | 0.036 | 0.266      | 0.078  | 0.914  |
| Arabia      |         |            |           |           |       |     |      |            |       |       |
| Asia incl.  | 0.178   | 0.3101     | -0.429    | 0.786     | 0.331  | 1   | 0.565 | 1.195      | 0.651  | 2.195  |
| Russia      |         |            |           |           |       |     |      |            |       |       |
| Latin America| 0.513  | 0.2220     | 0.078     | 0.948     | 5.541  | 1   | 0.021 | 1.670      | 1.081  | 2.580  |
| Europe (no | 0.062   | 0.2047     | -0.339    | 0.464     | 0.093  | 1   | 0.761 | 1.064      | 0.713  | 1.590  |

DV = HHOURS (weekly average contribution in half hours); Model: (Intercept), Gender, JOB, REGION, AGE.
One value for each categorical variable set to zero because this parameter is redundant (not displayed).

aBaseline for JOBTYPE: professional hardware developers, engineers, or engineering students.
bBaseline for REGION: the US, the UK, Canada, New Zealand, and South Africa.
Table 3. Negative binomial regression results for Models 2 and 3 (Dependent variable: HHOURS)

| Parameter       | Model 2 |         |         | Exp(B) |         |         |         |         |         |         |
|-----------------|---------|---------|---------|--------|---------|---------|---------|---------|---------|---------|
|                 | B       | Std. Error | Wald Chi-Square | Sig. |         | B       | Std. Error | Wald Chi-Square | Sig. |
| (Intercept)     | 2.981   | 0.4970   | 35.971   | 0.000 | 19.704  | 3.168   | 0.5108   | 38.459   | 0.000 | 23.748  |
| GENDER [1 = male] | 0.421   | 0.3071   | 1.877    | 0.171 | 1.523   | 0.092   | 0.3718   | 0.061    | 0.806 | 1.096   |
| AGE             | −0.014  | 0.0088   | 2.523    | 0.112 | 0.986   | −0.016  | 0.0088   | 3.306    | 0.069 | 0.984   |
| JOBTYPE         |         |         |         |        |         |         |         |         |         |         |
| Unemployed      | 0.073   | 0.4518   | 0.026    | 0.871 | 1.076   | 0.337   | 0.4124   | 0.669    | 0.413 | 1.401   |
| Academic        | −1.042  | 0.4684   | 4.952    | 0.026 | 0.353   | −1.018  | 0.3935   | 6.689    | 0.010 | 0.361   |
| Design          | 0.212   | 0.3026   | 0.491    | 0.483 | 1.236   | 0.378   | 0.3020   | 1.570    | 0.210 | 1.460   |
| IT or Software  | −0.348  | 0.2797   | 1.544    | 0.214 | 0.706   | −0.102  | 0.2830   | 0.129    | 0.720 | 0.903   |
| Unrelated       | −0.517  | 0.2510   | 4.238    | 0.040 | 0.597   | −0.459  | 0.2347   | 3.828    | 0.050 | 0.632   |
| REGION          |         |         |         |        |         |         |         |         |         |         |
| Turkey & Arabia | −1.079  | 0.6515   | 2.745    | 0.098 | 0.304   | −0.983  | 0.6761   | 2.115    | 0.146 | 0.374   |
| Asia incl. Russia | 0.455  | 0.3718   | 1.501    | 0.221 | 1.577   | 0.260   | 0.2748   | 0.898    | 0.343 | 1.297   |
| Latin America   | 0.587   | 0.2261   | 6.738    | 0.009 | 1.798   | 0.724   | 0.2337   | 9.601    | 0.002 | 2.063   |
| Europe (w/o UK) | 0.319   | 0.1879   | 2.879    | 0.090 | 1.375   | 0.439   | 0.1796   | 5.965    | 0.015 | 1.551   |
| INTRINSIC_OBL   | −0.057  | 0.1319   | 0.186    | 0.667 | 0.945   | −0.146  | 0.1414   | 1.071    | 0.301 | 0.864   |
| INTRINSIC_JOY   | 0.492   | 0.1747   | 7.930    | 0.005 | 1.636   | 0.475   | 0.1712   | 7.708    | 0.005 | 1.609   |
| EXTRINSIC_PAY   | 0.181   | 0.1909   | 0.899    | 0.343 | 1.198   | 0.209   | 0.1805   | 1.345    | 0.246 | 1.233   |
| EXTRINSIC_USE   | 0.025   | 0.0980   | 0.067    | 0.795 | 1.026   | 0.086   | 0.0978   | 0.767    | 0.381 | 1.089   |
| OWNUSE          | −0.216  | 0.1035   | 4.353    | 0.037 | 0.806   | −0.191  | 0.1050   | 3.319    | 0.068 | 0.826   |
| SKILLS          | 0.155   | 0.0957   | 2.634    | 0.105 | 1.168   | 0.304   | 0.1049   | 8.400    | 0.004 | 1.355   |
| REPUT           | 0.144   | 0.1267   | 1.293    | 0.256 | 1.155   | 0.263   | 0.1396   | 3.553    | 0.059 | 1.301   |
| INTRINSIC_JOY × REPUT | −0.594 | 0.1755 | 11.463 | 0.001 | 0.552 | 0.288 | 0.1115 | 6.685 | 0.010 | 1.334 |
| INTRINSIC_JOY × SKILLS | 0.288 | 0.1115 | 6.685 | 0.010 | 1.334 |

One value for each categorical variable set to zero because this parameter is redundant (not displayed).

*Baseline for JOBTYPE: professional hardware developers, engineers, or engineering students.

*Baseline for REGION: the US, the UK, Canada, New Zealand, and South Africa.
or developments motivates only initial contribution with many developers leaving when their goal is reached (Shah, 2006).

Our data confirm the effects of all three aspects of internalized extrinsic motivation. While in case of own-use motivation (H4a) and gaining reputation (H4c) the significance levels are borderline with $P$-values of 0.068 and 0.059, respectively, the $P$-value for the effect of learning new skills is significant at the 1% level (0.004). Given our relatively small sample size, the statistical power is such that we risk finding only very strong effects, which makes our conclusions very conservative. While enjoyment-based intrinsic motivation increased contribution levels by about 60%, according to our results, seeing a personal use value in the OSH project’s object reduces contribution levels only by about 17%. A one-point increase of the expectation to learn and improve the own skills (H4b) increases the odds of contributing another half an hour by 35%. In line with previous research in OSS communities, expected learning effect stimulated higher commitment in OSH development. Contributors to open source hardware communities hence are very similar to pendants in software development in this regard. Finally, the effect size we found for expected reputation gains (H4c) was comparable to that of learning. However, the significance level is not as high. Nonetheless, it appears that also regarding the effect of reputation, the OSH developers behave a lot similar to OSS developers.

Finally, we could also confirm our hypotheses regarding the interaction effects of enjoyment-based intrinsic motivation with reputation (H5a) and learning (H5b). The interaction with reputation is much more significant ($P$-value 0.001) than that with learning ($P$-value 0.01). However, in both the cases, the effect signs are as expected. In order to allow a better interpretation of the interaction, we visualized the interactions based on the predicted mean responses and the high and low groups for the variables involved in the interaction.

First, as Figure 2 shows, the effect of enjoyment-based intrinsic motivation almost disappears...
for high levels of motivation through expected reputation gains. However, as predicted, this is not because high levels of enjoyment do not motivate, but because reputation compensates for low levels of enjoyment, while expected gains in reputation apparently cannot increase the motivational effect of high enjoyment any further. These two factors do not work well together, as expected. Second, Figure 3 illustrates our prediction for the second interaction effect. The expectation to learn new skills can add to high enjoyment-based motivation, while it results ineffective for unpleasant tasks. This increases the slope of the enjoyment-based motivation as expected.

7. Conclusion

We investigated the motives behind the contributions to OSH communities based on the self-determination theory. Given our particular context of 3D printing communities, we could observe the potential influence that the higher need for physical proximity and face-to-face interactions in the maker communities has. This different nature of individual interactions and local communities could lead to different motivations driving developers’ contribution compared to the already extensively researched OSS development communities. We therefore can claim to make some important and timely contributions to the research on the open source phenomenon. We showed that some of the classical motivations behind OSS development contribution are the major factors also in the case of OSH development, but we also show some interesting interaction effects and thus contribute to theory development of the self-determination theory as well as to a better understanding of the OSH development.

Firstly, we show the individual effects of the three internalized intrinsic motivational factors: own-use, reputation and learning as well as enjoyment-based intrinsic motivation. We find support for our hypothesis of a negative effect of personal own-use value
on contribution extent. This is in line with Roberts et al. (2006) but contrasts with some other findings. From the data, we cannot tell whether members with a high personal use value quickly drop out or whether high-commitment contributors cease to perceive a high personal use value over time. The time component is an intriguing issue, which needs to be resolved by future research.

Secondly, we unveil two interesting interaction effects. On the one hand, learning increases the positive effect of enjoyment. On the other hand, expected reputational benefits compensate for the lack of enjoyment-based intrinsic motivation. These findings are particularly interesting for the self-determination theory, not only in the context of the open source phenomenon, but because both the factors, expected private benefits through learning new skills and gaining reputation in the peer group, are internalized extrinsic motivations. These findings suggest that internalization and self-regulation follow potentially different mechanisms for different factors and may lead to compensation as well as a supplementation of pure intrinsic motivation.

Some unexpected differences between the findings from previous studies on OSS and our OSH communities emerged. Obligation-based intrinsic motivation did not exhibit a significant positive effect as we expected and as previous literature suggests. (Stewart and Gosain, 2006; Wu et al., 2007; von Krogh et al., 2012). Also, being an unpaid hobbyist and a paid-for-work contributor did not make a statistically significant difference in terms of contribution efforts. Our sample consisted to 78% of unpaid contributors; only time can tell if that figure will dwindle over time, similar to what we see in the OSS communities, as commercial involvement increases.

The cross-sectional nature of our data makes it difficult to claim causal relationships. This relates also to another limitation, which is potential endogeneity. It could be argued, for example, that more extensive contributions to OSH development improves skills and flow, and not vice versa. We attempt to counter this with the way our items are formulated. In fact, we do not measure skills but ask for the expected gains in skills (i.e. learning) from contributing to the OSH development. It is much harder to imagine how a higher commitment in OSH development could increase much the expected gains in skills. Also, the sample size is rather limited. This is particularly important when estimating the effects of the origin of the respondents. If several respondents come from the same highly active OSH community and are the majority of the representatives of their region, this can introduce a certain bias to the estimate of the region’s effects.

Returning to our starting point about turning consumers into creating prosumers, applying outside-in and coupled open innovation models (Enkel et al., 2009; West and Bogers, 2014), organization designers and community managers may struggle to provide the right incentives. Allowing to benefit through reputational gains and providing “right-sized” learning tasks to participants rather than focusing on a lifestyle as hacker, or catering to a contributor’s ideology might be one way to design OSH communities. Designing and managing online communities that create value for a focal company is a daunting task (Spaeth et al., 2015).

For management and innovation practice, this will become increasingly important with the acceleration that we currently witness in the development of 3D printing technologies for the end consumer market. As resolutions increase and prices drop, manufacturing industries have to face entirely new challenges and traditional business models have to be replaced by innovative ones. Our contributions provide a first glance at the motivations of the people that are at the basis of these dynamics which need to be involved in future user innovation and crowdsourcing processes.

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Notes

1. https://opensource.org/osd.
2. https://www.oshwa.org/definition/.

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Appendix A

Figure A1. Histogram of average hours per week (HOURS).

Figure A2. Scatter plots for visual inspection for heteroskedasticity.
Figure A3. Deviance residuals for Models 2 and 3.
Table A1. Continuous variables

| CODE         | Item (Likert scale: 1 ‘strongly disagree’ to 7 ‘strongly agree’)                                                                 | Min | Max | Mean  | SD    |
|--------------|-------------------------------------------------------------------------------------------------------------------------------|-----|-----|-------|-------|
| HHOURS (DV)  | How many hours do you usually spend each week working on all your current open source hardware projects for 3D printing? (measured in half hours) | 0   | 100 | 21.45 | 22.556|
| AGE          | Please indicate your age:                                                                                                       | 16  | 75  | 35.08 | 10.74 |
| INTRINSIC_OBL| I feel a personal obligation to contribute to the community because I also use open source digital models for 3D printing. (INTOBL1) | 1   | 7   | 5.37  | 1     |
|              | I like the idea that my work helps others and/or society. (INTOBL2)                                                            | 1   | 7   | 6.33  | 1     |
|              | I believe that hardware for 3D printing should be open source. (INTOBL3)                                                        | 1   | 7   | 5.87  | 1     |
|              | I dislike proprietary hardware for 3D printing or the companies that produce it and want to help the open source community to overcome them. (INTOBL4) | 1   | 7   | 5.27  | 1     |
| INTRINSIC_JOY| Developing hardware for 3D printing is intellectually stimulating. (INTJOY1)                                                    | 2   | 7   | 6.18  | 2     |
|              | I am fascinated by the 3D printing technology and therefore engage in open source hardware development. (INTJOY2)             | 1   | 7   | 5.75  | 1     |
|              | I like working with hardware developers from the open source 3D printing community. (INTJOY3)                                 | 2   | 7   | 5.66  | 2     |
|              | The open source 3D printing community is an essential part of my life. (INTJOY4)                                                | 1   | 7   | 4.78  | 1     |
|              | How likely is it for you to lose track of time when you are developing hardware for 3D printing? (INTJOY5)                    | 1   | 5   | 3.76  | 1     |
|              | If you had an extra hour in the day: would you devote it to developing hardware for 3D printing? (INTJOY6)                     | 1   | 5   | 3.11  | 1     |
| EXTRINSIC_USE| I need the open source hardware for my work. (JOBUSE)                                                                            | 1   | 7   | 4.59  | 1     |
| SKILLS       | My activity on a project improves my hardware development skills. (SKILLS)                                                      | 1   | 7   | 6.3   | 1     |
| PERSUSE      | I need the open source hardware for my personal use / non-work life. (PERSUSE)                                                   | 2   | 7   | 5.56  | 2     |
| REPUTATION   | My contributions to open source hardware development will enhance my professional status. (REPUT1)                          | 1   | 7   | 4.91  | 1     |
|              | My contributions will enhance my reputation in the open source 3D printing community. (REPUT2)                              | 1   | 7   | 5.04  | 1     |
|              | I found ways to earn money with open source hardware development. (REPUT3)                                                      | 1   | 7   | 3.93  | 1     |
### Table A2. Categorical variables

| Name        | Item                                                                 | % of cases |
|-------------|----------------------------------------------------------------------|------------|
| **JOBTYPE** | How does your daily job relate to hardware development and/or 3D design? |            |
|             | 1 = Not related to neither                                           | 19.1       |
|             | 2 = IT or Software development                                       | 24.3       |
|             | 3 = Engineering, hardware development or R&D                         | 27.0       |
|             | 4 = Design                                                           | 7.8        |
|             | 5 = Academic research                                                | 5.2        |
|             | 6 = unemployed                                                        | 7.0        |
|             | Missing values                                                       | 9.6        |
| **GENDER**  |                                                                     |            |
|             | 1 = Male                                                             | 85.2       |
|             | 0 = Female                                                           | 6.1        |
|             | Missing values                                                       | 8.7        |
| **EXTRINSIC_PAY** | Do you receive and/or have you received direct financial compensation for your participation in open source projects for 3D printing? |            |
|             | 1 = Yes                                                              | 21.7       |
|             | 0 = No                                                               | 78.3       |
| **REGION**  | Please indicate your country of residence.                           |            |
|             | 1 = Continental Europe                                               | 48.7       |
|             | 2 = US, UK, Canada, New Zealand, Australia, South Africa             | 31.3       |
|             | 3 = Latin America                                                     | 11.3       |
|             | 4 = Asia including Russia                                             | 6.1        |
|             | 5 = Turkey and Arabia                                                 | 2.6        |
Table A3. Bivariate Pearson correlations of likert-scaled items

|      | HHOURS | INTOB  | INTJOY | REPUT | PERSUSE | SKILL |
|------|---------|--------|--------|-------|---------|-------|
|      | 1       | 2      | 3      | 4     | 5       | 6     | 1    | 2    | 3    |
| INTOB1 | 0.028   |         |        |       |         |       |      |      |      |
|        | 0.765   |         |        |       |         |       |      |      |      |
| INTOB2 | 0.068   | 0.382** |        |       |         |       |      |      |      |
|        | 0.469   | 0.000   |        |       |         |       |      |      |      |
| INTOB3 | −0.057  | 0.294** | 0.240**|       |         |       |      |      |      |
|        | 0.544   | 0.001   | 0.010  |       |         |       |      |      |      |
| INTOB4 | 0.108   | 0.272** | 0.181  | 0.492**|         |       |      |      |      |
|        | 0.247   | 0.003   | 0.052  | 0.000 |         |       |      |      |      |
| INTJOY1 | 0.174   | 0.140   | 0.202* | 0.144 | 0.098   |       |      |      |      |
|        | 0.061   | 0.134   | 0.030  | 0.123 | 0.295   |       |      |      |      |
| INTJOY2 | 0.144   | 0.245** | 0.215* | 0.189*| 0.116   | 0.286**|      |      |      |
|        | 0.124   | 0.008   | 0.020  | 0.042 | 0.215   | 0.002 |      |      |      |
| INTJOY3 | 0.130   | 0.199*  | 0.259**| 0.245**| 0.167   | 0.263**| 0.245**|      |      |
|        | 0.165   | 0.033   | 0.005  | 0.008 | 0.074   | 0.004 | 0.008 |      |      |
| INTJOY4 | 0.246** | 0.411** | 0.396**| 0.217* | 0.183*  | 0.128  | 0.263**| 0.192*|      |
|        | 0.008   | 0.000   | 0.000  | 0.019 | 0.049   | 0.171  | 0.004 | 0.039 |      |
| INTJOY5 | 0.133   | 0.242** | 0.171  | 0.125 | 0.168   | 0.353**| 0.262**| 0.172 | 0.329**|
|        | 0.154   | 0.009   | 0.066  | 0.181 | 0.071   | 0.000  | 0.004 | 0.064 | 0.000 |
| INTJOY6 | 0.268** | 0.208*  | 0.112  | 0.179 | 0.226*  | 0.430**| 0.469**| 0.204*| 0.357**| 0.481**|
|        | 0.004   | 0.025   | 0.233  | 0.055 | 0.015   | 0.000  | 0.000 | 0.028 | 0.000 | 0.000 |
| REPUT1 | 0.111   | 0.283** | 0.352**| 0.035 | 0.080   | 0.186* | −0.009 | 0.240**| 0.167 | 0.031 | −0.026|
|        | 0.237   | 0.002   | 0.000  | 0.711 | 0.392   | 0.045  | 0.920  | 0.010 | 0.073 | 0.745 | 0.786 |
| REPUT2 | 0.215*  | 0.345** | 0.387**| 0.111 | 0.097   | 0.248**| 0.283**| 0.202* | 0.397**| 0.279**| 0.271**| 0.521**|
|        | 0.020   | 0.000   | 0.000  | 0.233 | 0.301   | 0.007  | 0.002  | 0.030 | 0.000 | 0.002 | 0.003 | 0.000 |
| REPUT3 | 0.201*  | 0.148   | 0.172  | −0.013| 0.005   | 0.095  | 0.024  | 0.133 | 0.272**| 0.183* | 0.163 | 0.444**| 0.538**|
|        | 0.031   | 0.112   | 0.065  | 0.890 | 0.955   | 0.310  | 0.800  | 0.154 | 0.003 | 0.050 | 0.081 | 0.000 | 0.000 |
| PERSUSE | −0.045  | 0.501** | 0.175  | 0.150 | 0.196*  | 0.165  | 0.186* | 0.227* | 0.320**| 0.248**| 0.125 | 0.157 | 0.264**| 0.109 |
|        | 0.631   | 0.000   | 0.060  | 0.107 | 0.035   | 0.076  | 0.046  | 0.014 | 0.000 | 0.007 | 0.180 | 0.091 | 0.004 | 0.245 |
| SKILL  | 0.215*  | 0.184*  | 0.231* | 0.169 | 0.164   | 0.333**| 0.479**| 0.226**| 0.192* | 0.200* | 0.232* | 0.181 | 0.282**| 0.075 | 0.096 |
|        | 0.021   | 0.048   | 0.013  | 0.069 | 0.078   | 0.000  | 0.000  | 0.015 | 0.039 | 0.032 | 0.012 | 0.052 | 0.002 | 0.426 | 0.303 |
| JOBUSE | 0.202*  | 0.095   | 0.215* | 0.063 | 0.079   | 0.006  | −0.052 | 0.116 | 0.351**| −0.106 | 0.022 | 0.423**| 0.294**| 0.397**| 0.171 | 0.038 |
|        | 0.029   | 0.312   | 0.021  | 0.501 | 0.402   | 0.950  | 0.579  | 0.217 | 0.000 | 0.258 | 0.819 | 0.000 | 0.001 | 0.000 | 0.067 | 0.683 |

* p < 0.05, ** p < 0.01
Table A4. Principal component analysis for Harman’s single-factor test

| Component | Initial eigenvalues | Extraction sums of squared loadings | Varimax rotation sums of squared loadings |
|-----------|---------------------|-------------------------------------|------------------------------------------|
|           | Total % of Variance | Cumulative %                         | Total % of Variance | Cumulative % | Total % of Variance | Cumulative % |
| 1         | 4.571               | 24.057                              | 4.571                     | 24.057       | 4.571               | 24.057       |
| 2         | 1.983               | 10.439                              | 1.983                     | 10.439       | 1.983               | 10.439       |
| 3         | 1.636               | 8.609                               | 1.636                     | 8.609        | 1.636               | 8.609        |
| 4         | 1.327               | 6.982                               | 1.327                     | 6.982        | 1.327               | 6.982        |
| 5         | 1.183               | 6.227                               | 1.183                     | 6.227        | 1.183               | 6.227        |
| 6         | 1.046               | 5.504                               | 1.046                     | 5.504        | 1.046               | 5.504        |
| 7         | 0.933               | 4.912                               | 71.305                    |              |                      |              |
| 8         | 0.869               | 4.575                               | 71.305                    |              |                      |              |
| 9         | 0.770               | 4.053                               | 71.305                    |              |                      |              |
| 10        | 0.740               | 3.895                               | 71.305                    |              |                      |              |
| 11        | 0.649               | 3.415                               | 71.305                    |              |                      |              |
| 12        | 0.585               | 3.076                               | 71.305                    |              |                      |              |
| 13        | 0.535               | 2.813                               | 71.305                    |              |                      |              |
| 14        | 0.473               | 2.489                               | 71.305                    |              |                      |              |
| 15        | 0.399               | 2.100                               | 71.305                    |              |                      |              |
| 16        | 0.383               | 2.014                               | 71.305                    |              |                      |              |
| 17        | 0.341               | 1.793                               | 71.305                    |              |                      |              |
| 18        | 0.305               | 1.606                               | 71.305                    |              |                      |              |
| 19        | 0.274               | 1.441                               | 71.305                    |              |                      |              |