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Why Do Makers Make? Examining Designer Motivations on Thingiverse.com

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Abstract

Technological advancements have made a once fictitious dream into a reality. 3D printing has become a popular manufacturing and design technique used all over the world. As this industry becomes more popular, users of these 3D printers are reaching out across the web to share designs, seek help, and build communities of users with similar interests. This study is meant to look at what motivates 3D printing users to participate in online user innovation communities such as Thingiverse.com. This study will explore motivations such as personal needs, financial gains, approval of peers, skill development, and enjoyment. Moreover, it will assess the impact of each of these motivations on the number of designs created by designers within the observation period (May 2017-May 2018) and on the market response to these designs. To study these elements, we first perused research done in previous studies on motivations in brand communities, transactional communities, and user innovation communities to create a literature review. Following the literature review, a survey was created which asked Thingiverse makers 5 sets of questions related to their specific motivations for creating and sharing designs and asked them to provide demographic data as well. The results obtained from this research indicate that the motivation to satisfy a personal need has a marginally significant, negative impact on the number of designs created by a maker while the desire to gain approval from others in the community has a significant, positive effect on market response to those designs. Additionally, it was found that a desire for financial gain has little to no effect on the number of designs created or on the market response, a result which was surprising considering that 25% of the respondents reported earning money from 3D printing. These results and their implications as well as future research directions are outlined in the concluding discussion section.

Acknowledgement

I would like to thank Dr. Matthew O'Hern for taking the time and effort to work with me in the completion of this thesis. Over the last year he has worked diligently with me through every step of the process and has allowed to gain so much knowledge, not only about the 3D printing industry but also about how to conduct and present academic research. Without Dr. O'Hern's knowledge and assistance this thesis would not have been possible.

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Market Overview and Introduction

"3D Printing can change the whole paradigm of how our children will see innovation and manufacturing in America" – Bre Pettis, MakerBot CEO

What was once just a futuristic dream on the American animated sitcom *The Jetsons* has now become a reality that is not only attainable for large corporations but for the average consumer as well. This cartoon that aired from 1962 to 1963 and again from 1985 to 1987 depicted a food replicator that created anything from asparagus to stroganoff. Fast forward to 2014 when American manufacturer 3D Systems unveiled the world's first 3D printed foods at the Consumer Electronics Show (CES) in Las Vegas. What once seemed to be the technology of the distant future has actually become reality less than 50 years later. The 3D printing industry has spread to many industries including plastics, automotive, aerospace, pharmaceuticals and medical, electronics, mechanical and plant engineering, logistics, transportation, and consumer goods. These industries are using this revolutionary technology for applications such as prototyping, proofs of concept, production, education, marketing samples, and much more. In addition, firms and hobbyists are using materials such as polymers, metals, organic materials, ceramics, sand, live cells, food and wax to produce a wide array of innovative new products.

In the automotive and aerospace industries, the added value that lightweight parts and functionally integrated components provides is rapidly elevating 3D printing from the prototyping to the serial productions stages (EY 2016). For example, GE now 3D prints functionally integrated fuel nozzles for its top selling product, the LEAP engine that generates fuel savings of up to $1.6 million per aircraft per year (EY 2018). In the medical industry, companies are gaining a competitive advantage, as patients are able to receive highly personalized products that perform better and improve their health (EY 2016). Implants, for instance, are becoming more adaptable and less risky, hearing aids are now able to be customized for each user to ensure better fit and functionality, and in dentistry, 3D printed crowns, bridges, and other orthodontic products are making dental enhancements more comfortable and less

costly (EY 2016). Prosthetics have also become more affordable and comfortable as they are able to fit each specific user and can be easier to access a replacement is needed (EY 2016). The pharmaceutical industry is also beginning to personalize drugs so that patients can now receive more precise dosages based on their biological and clinical parameters instead of using predetermined dosages (EY 2016). In the footwear industry, Nike and New Balance already use 3DP for customized sole parts for professional athletes or in limited editions (EY 2016). Adidas has taken this technology one step further, with the launch of the first widely released 3D printed shoe, the Futurecraft 4D in early 2018 (Avsec 2018). 3D printed jewelry and other customer products are also becoming popular, as they can often be customized by the end-user and printed right in the comfort of his/her own home.

3D printing is not only benefiting the industries mentioned above, it is fundamentally transforming them. According to Sculpteo's 2017 State of 3D Printing Report, more than 90% of their survey respondents consider 3D printing to provide a competitive advantage whether through improved positioning in the value chain, enhanced growth through optimized product design, or increased efficiency in supply chains and operations (Sculpteo Report 2017). Increasingly, manufacturers are able to 3D print products closer to their customers on an on-demand basis, allowing firms to more effectively and more rapidly meet the changing needs of their customers. This trend is also influencing the entire logistics and transportation industry, requiring it to adjust its business models. Many global logistics players are considering the growing influence of 3D printing and how it will affect their future strategy (EY 2016). Companies that bring these processes back in-house by developing 3D printing competencies will likely be sought out by other companies for their services. Moreover, the growing application of 3D printing technology is also bringing about increased demand for new types of employees with specific, high-tech skill sets. In particular, firms that actively utilize 3D printing needs highly skilled and creative designers who can identify novel ways to apply this new technology, engineers who possess a deep

understanding of the materials being used in the 3D printing process, and trained technicians who understand how to operate various kinds of 3D printers.

As 3D printing takes off, so do the applications and platforms that support it. These include online communities and forums where users can ask questions, share pictures and create and purchase code for 3D printing projects. Among these top online communities are Facebook and LinkedIn groups, Google+ forums, as well as websites like Instructables, 3D Warehouse and Thingiverse. This project focuses on the world's largest 3D printing community, Thingiverse.com.

Created by the firm MakerBot, the Thingiverse community encourages users to create and remix 3D printable objects regardless of their technical expertise or experience. With over 1,000,000 product designs (as of May 2018), Thingiverse is not only a repository for downloadable designs but also offers challenges, discussion groups, educational packages and lesson plans, as well as apps to facilitate product customization. Categories on Thingiverse include a wide variety of different products including but not limited to 3D printing parts, art, fashion, gadgets, replacement parts, household products, models, tools, and toys and games (Flath, Friesike & Thiesse 2017). One unique feature of Thingiverse is that designers are encouraged to license their designs under a Creative Commons license so that end-users can subsequently use or alter any of the posted designs. According to Twitter user Wayan Vota, "3D printing is putting the social back into innovation and manufacturing" (Wayan_Vota 2014). Thingiverse is turning consumers into makers, thereby helping to create an era of empowerment, where customers are more involved in the manufacturing process. This is leading to new pathways to innovation. In essence, Thingiverse is a place where anything can be made from fine jewelry, replacement parts, phone cases, tooth brush holders and even product mashups such as a Hello Kitty – Darth Vader bust.

3D Printing, also known as additive manufacturing, has grown rapidly in the last five years and shows no signs of slowing down (see Appendix A). The demand for 3D printing systems and related

services has lead to steep increases in additive manufacturing market volumes. From 2011 to 2015 these have grown at an annual rate of 28% and growth in the 3D printing market is projected to continue to grow by about 25% annually until 2020 (EY Report 2016). Not only is the industry growing, but according to Sculpteo's 2017 State of 3D Printing report, 47% of companies that have been using this technology have seen greater returns on investment than in the previous year (Sculpteo Report 2017). But it is not just the large companies that are contributing to this sustained growth. Indeed, in 2015 more than 278,000 desktop 3D printers (under $5,000) were sold to consumers and small firms worldwide.

Clearly, 3D printing is transforming the way that business is being done by bringing back manufacturing as an in-house process, localizing production, decreasing costs and time to market, and enabling a greater degree of customization and creativity, not only for the end user but also for manufacturing firms that produce highly specialized products that may not be conducive to a "one-size-fits-all" manufacturing approach. This technology is transforming industries, saving energy, time and resources, and simultaneously opening up new business opportunities for forward-thinking firms. On an even greater scale, 3D printing is directly transforming the creative problem-solving process by putting manufacturing capabilities in the hands of everyday people and empowering consumers to create a vast array of new products that commercial firms might be reluctant to produce.

The following paper will explore the phenomenon of 3D printing and will discuss the motivations that drive individuals to participate in a 3D printing community. In particular, this thesis will investigate the influence of various motivations on the number of designs that a contributor (i.e., a *maker*) creates as well as on the overall market response to the maker's designs. In short, the following research seeks to contribute new knowledge by examining the impact of various user innovator motivations on new product development activity and product adoption activity. In the following sections, I will offer a brief review of related literature on brand and user innovator communities, highlight some of the more interesting descriptive data provided by study participants, provide a detailed description of the

research design, study constructs and methods, and present the findings of this research. I will then conclude with a discussion of these findings and their managerial implications.

Literature Review

As companies explore new ways of building long-term relationships with their customers in the digital environment, online communities have become a focus of strategic marketing investments, designed to offer unique brand experiences and help retain loyal customers (Casas et al., 2016). The online environment has become not only a way to search for new information, it has also become a home to communities that foster educating, trading, purchasing and communicating between like-minded individuals. Whether searching for recommendations for a new product, finding how to make an old product better, or looking for new inspirations for solving problems, information like this can be found on many different types of forums and online communities.

Many different types of online communities exist, such as brand communities, transactive communities and user innovative communities. Brand communities are defined as a non-geographically connected groups of people based on a structured set of social relations among customers of a brand In essence, these consist of interactions between brand admirers, who are social motivated to exchange information (Muniz & O'Guinn, 2001). These communities are meant to help solve common problems, answer questions, and spur customer creativity. Brand communities also tend to be utilized as forums where users can create and contribute to discussions or threads by commenting and sharing user-generated content.

Similarly, transactional communities foster interaction between individuals but differ from brand communities, as they provide a viable trading and marketing platform that enables commercial interaction between buyers, sellers and intermediaries (Wu et al., 2010). Examples of such communities include eBay, Amazon, QWL and other online auction/ecommerce sites. These communities have many

users bidding on items and users can rate and comment on their past transactions and communicate with other buyers and sellers.

In addition, some other online communities are best classified as user innovation communities. These focus on harnessing the innovative potential of their members for new product development (Fuller et al., 2008). These are communities in which members are considered an effective means of adding value within the innovation process and for contributing to various innovative activities such as identifying needs, generating ideas, modifying concepts, developing prototypes and testing products (Fuller et al., 2008). In these communities, users can share designs and concepts as well as comment and collaborate on other users' designs as well. The resulting knowledge that is produced can be used by a company looking for new product innovations or by groups of like-minded people looking to collaborate to solve problems or share information.

MakerBot's Thingiverse is the focus of this study as well as the leading online community for 3D printing where users can go to find solutions to problems by communicating in groups, design, download and customize 3D printed objects. While Thingiverse contains elements of different types of online communities, it can best be classified as a user innovation community. Importantly, on websites like Thingiverse, users can be involved in multiple stages of the new product development process. For example, users can participate in the design and engineering stage by designing their own products according to their wants and needs. Similarly, users can be involved in the testing and launch stages by giving feedback about designs posted on the Thingiverse and sharing their own designs directly with their peers. In short, an innovation community like Thingiverse allows for rapid-response and instantaneous feedback concerning different innovative products throughout the entire innovation process (Fuller et al., 2006).

But what exactly motivates individuals to participate in such a community? Many people engage in online communities just to participate in discussions, to gain recognition or to experience joy and

pleasure (Casas et al., 2016). These people participate for social motivational engagements and are labeled as interactive members of the community. Non-interactive members just observe and read other members' content without contributing any of their own. These members are known as "lurkers". Sometimes people participate in online communities because of rewards such as earning money or getting some sort of bonus. Sometimes they participate because they need information about a product and can get this by reading other people's comments. In the brand community literature, identification with the online community, behavioral intentions regarding the online community, brand relationship quality and brand knowledge are suggested as motivations for online community involvement (Algesheimer et al. 2005). Moreover, according to Muniz & O'Guinn (2001), users are motivated to participate in brand communities by consciousness of kind, rituals and traditions, as well as a sense of moral responsibility.

While all online community members share such things as collective consciousness (connecting), common rituals and traditions (helping, discussing, seeking assistance), and a sense of moral responsibility to the group (validation and identification) to a certain degree, user innovation community members also have a strong need for creativity and knowledge development. In most firm-sponsored innovation communities, consumer creativity, identification with the online community, and product-specific emotions and attitudes (passion and trust) as well as brand knowledge are important determinants of consumers' willingness to share their knowledge with producers (Fuller et al., 2008).

Often, online community members are willing to share their ideas free of charge, but only under certain conditions (Fuller et al., 2006). More specifically, existing research suggests that consumers do not participate in user innovation communities purely for altruistic or citizenship motives, but instead expect to attain benefits such as enhanced product knowledge, communication with other knowledgeable customers, enhanced reputation and cognitive stimulation and enjoyment (Nambisan & Baron 2009). Nambisan & Baron (2009) suggests that there are four types of benefits that customers can

derive from their participation in online communities: cognitive, social integrative, personal integrative and hedonic benefits. Cognitive benefits relate to acquiring information and strengthening of their understanding of the environment. Social integrative benefits are the strengthening of consumer ties with relevant others. Personal integrative benefits are those that strengthen the consumer's credibility, status and confidence. Hedonic benefits are those that strengthen aesthetic or pleasurable experiences. (Nambisan & Baron 2009).

Similarly, Lakhani & Wolf (2003) suggests that there are two categories that motivate individuals to participate; intrinsic motivations and extrinsic motivations. These categories can be broken down further into sub-categories. Intrinsic motivations are broken down into enjoyment based and obligation/community based types. Enjoyment based intrinsic motivations can be described as when a person is moved to participate for the fun or challenge entailed in the creative act rather than because of external prodding, pressure or rewards (Lakhani & Wolf 2003). For example, people who enjoy what they're doing tend to get into a "flow" in which their skills closely match the challenge of a task. When this occurs, it can provide user innovators with feelings of "creative discovery, a challenge overcome, and a difficulty resolved" (Lakhani & Wolf 2003). Obligation/Community based intrinsic motivations are those in which humans act on the basis of principle. These individuals are socialized into acting appropriately and in a manner consistent with the norms of a group (Lakhani & Wolf 2003). Hars and Qu (2002) adopt a similar framework and posit that intrinsic motivations also include altruism, as well as community identification.

Extrinsic motivations are outside forces that push one to participate in an online community. These motivations include the desire for financial gain, a user's need to solve a particular problem, career advancement, and skill development (human capital) (Lakhani & Wolf 2003). As long as the benefits exceed the costs, an individual is expected to contribute to the user innovation community. Monetary rewards and a user's need to solve a particular problem are also common extrinsic

motivators, as they offer substantial benefits compared to the cost involved. Although existing research has established the existence of the aforementioned motivations, much less is known about which of these motivations are most closely liked to user innovator performance. Specifically, in the following section, I will empirically rest which motivations have the greatest impact on the number of original new products that an individual produces and which motivations have the greatest impact on the market response to such products.

Research Design

Primary research to look at user motivations on Thingiverse.com was conducted through a short online survey. The survey was designed to assess the intrinsic and extrinsic factors that motivate users to create new products. Participants were asked five short sets of questions pertaining to the specific motivations being measured in the study. Each question set asked the respondent to indicate the extent to which he/she agreed or disagreed with the focal statements. The scales employed were seven-point scales including strongly disagree, disagree, neither agree nor disagree, somewhat agree, agree, and strongly agree. Respondents were also asked to provide demographic data such as age, years of experience, whether they use 3D printing in their full-time job and the country in which they reside. As this research focuses on the motivation of makers, a link to the survey was posted on several prominent user groups on Thingiverse.com. These groups tend to attract makers rather than passive consumers of 3D printable products. In addition, participants were instructed to only complete the survey if they had created a 3D printable design in the past year. After collecting the survey responses, a search of posted products on Thingiverse.com was conducted to verify that this was the case.

At the end of the study, respondents were directed to a separate survey and asked to give their Thingiverse username to enter a raffle for a $500 Amazon gift card. These usernames were then searched to ensure that each participant met the requirements for taking part in the study. In addition, this data was used to obtain information about the number of designs produced by each maker both

before and during the observation period as well as the number of downloads of the maker's products during the observation period. To be clear, the observation window comprised a twelve-month period from May 2017 to May 2018. Moreover, this data about maker motivations acquired via the online survey was used to generate the independent variables and the data on the number of products produced and the number of downloads associated with those products was comprised the dependent variables in this study. More specifically, this data was fed into two separate regression equations in order to examine which motivations are most closely associated with the number of products produced and which are most closely associated with public acceptance of these products by Thingiverse users.

Individual Difference Measures (Motivations)

Personal Enjoyment

As noted above, the short survey contained a number of questions that were designed to identify relevant individual difference measures that might affect maker performance. The first set of questions, measuring personal enjoyment, is based on research by Hars and Qu (2002) and Lakhani and Wolf (2003). Someone who is motivated for personal enjoyment participates for the fun or challenge entailed rather than because of external prodding, pressure or rewards (Lakhani & Wolf 2003). The scale for personal enjoyment in this paper consists of four statements in which respondents were prompted to select their level of agreement. These statements included measuring their level of intellectual stimulation, enjoyment, and creativity. A list of these items appears in Appendix C – Scale 1.

Personal Need

Satisfying personal needs is the second motivational element that was examined. This scale is also derived from Hars and Qu (2002) and Lakhani and Wolf (2003). Prior research indicates that users often need to create solutions to their problems, because there is not already a commonly available solution that satisfies their needs. The scale for satisfying personal needs in this paper consists of four statements that are based on whether the user is participating for a personal need for the product, a

need to make an existing product better, or satisfying personal unique needs. A list of these items appears in Appendix C – Scale 2.

Skill Development

Skill development is the third motivation we examined. This sale was derived from Hars and Qu (2002). The underlying assumption of this scale is that users may participate in user innovation communities to expand their skills, capabilities, and knowledge. Prior research suggests that this may be an important motivation, as increasing one's human capital by means of education, training learning, and practicing can lead to better job opportunities, higher salaries, and enhanced job fulfillment (Hars and Qu 2002). The scale for skill development in this paper consists of three statements based on the development of new skills, the development of first-hand knowledge, and the enhancement of personal design expertise. A list of these items appears in Appendix C – Scale 3.

Approval

Approval from others is the fourth motivational element that was explored. This scale is derived from research by Casas et al., (2016) and Nambisan & Baron (2009). This motivation relates to the validation (Casas et al., 2016) and the gains in reputation or status and the achievement of a sense of self-efficacy (Nambisan & Baron 2009) that is achieved through participation in online communities. This scale consists of four statements that reflect the extent to which people participate in Thingiverse in order to create value for others, the gratification they experience, when they make designs for others, the joy of receiving positive feedback from others, and the satisfaction of having others download their designs. A list of these items appears in Appendix C – Scale 4.

Financial Rewards

Financial rewards is the fifth motivational element that was considered. This scale is derived from Hars and Qu (2002) but is also mentioned within this paper as well by Casas et al., (2016), and Lakhani & Wolf (2003). Financial rewards consist of monetary rewards or payments for participation.

The scale for financial rewards in this paper consists of five statements that are based on whether or not users are paid for the digital designs they create, are paid to produce physical designs and whether or not the free designs that they have shown online lead to other users purchasing files later from either Thingiverse or their personal websites. A list of these items appears in Appendix C – Scale 5.

Methods

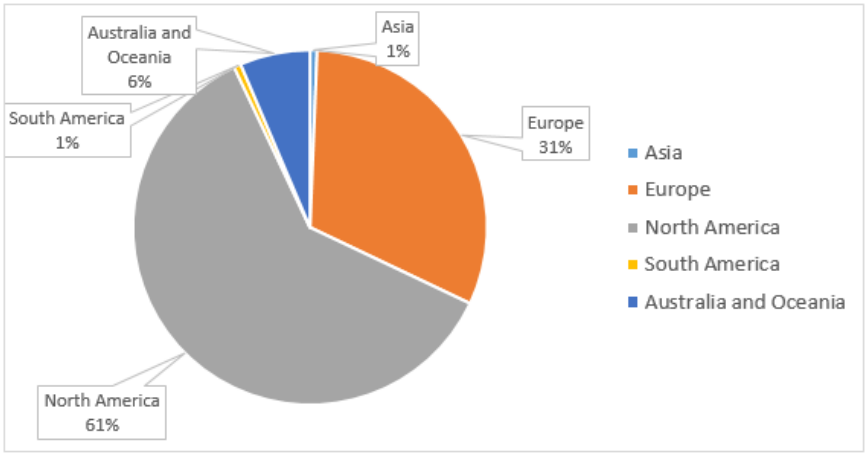
Survey Procedure and Participants

A link to the focal survey was posted on multiple Thingiverse group discussions. Thingiverse makers were instructed to click the link which would lead them to an online Qualtrics survey. As described above, the survey continued with several sets of questions where respondents were asked to respond to various statements on a seven-point agree – disagree scale. At the end of the survey, respondents were asked demographic questions such as age, resident country, years of experience with 3D printing and if they used 3D printing in their full-time jobs. Thingiverse user names were obtained in a separate survey to maintain confidentiality and to ensure that these usernames were not stored with the participants' survey responses. These usernames were then searched on Thingiverse.com to ensure that the participants met the study requirements and to collect the publicly available data on the number of creations and downloads for the maker within the observation period from May 2017 to May 2018. This data was also used to determine the number of product designs each maker created before the observation period. The resulting data was used to create two separate regression equations to understand which motivations led to higher new product creation activity within the community and to greater market acceptance of these product creations.

208 users responded to the online survey. Of these, 195 respondents completed the second survey in which they registered for the prize drawing and provided their usernames for the drawing. This number was again narrowed down to only those who had actually created a new product on Thingiverse in the past year, yielding a total of 155 respondents. These respondents came from 29 countries and 5

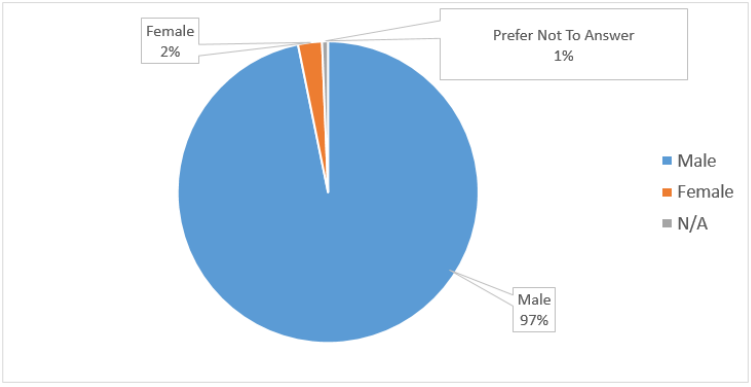
different regions. 61% of these respondents were from the United States, 31% from Europe, 6% from Australia/Oceania, 1% from South America, and 1% from Asia. These results are not entirely surprising, as Thingiverse is an American company and makers from English speaking countries should be well represented. Figure 1 provides a visual representation of the country of origin for the survey respondents.

Figure 1: Survey Respondents' Country of Origin



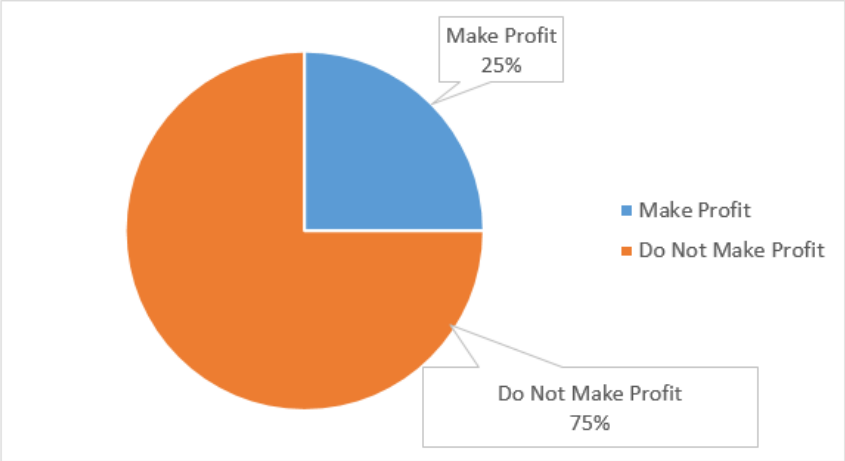
In terms of gender breakdown, the overwhelming majority of these 156 respondents were male. 151 respondents identified as male, 4 identified as female and 1 responded preferred not to be identified.

Figure 2: Survey Respondents' Gender



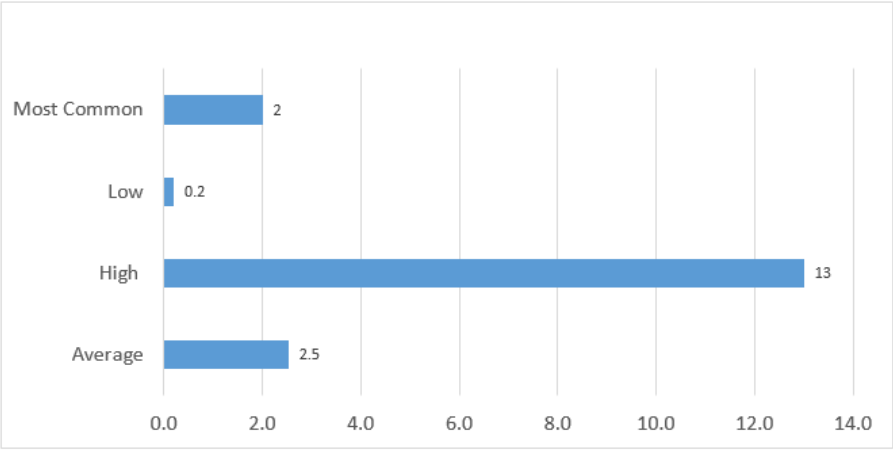
Interestingly, about 25% of the survey respondents indicated that they earn money from their 3D printing work, either by selling their designs to others or by manufacturing physical products for others using their 3D printers.

Figure 3: Profits Made By Survey Respondents



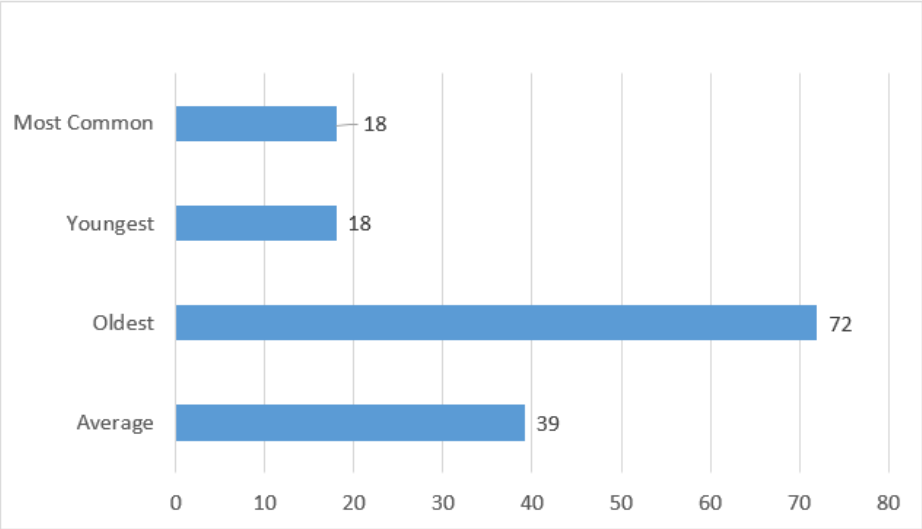
Data on the years of experience with 3D printing technology was also collected from the respondents. The average years of experience for the respondents was 2.5 years, the most was 13 years, the least was 0.2 years, and the modal number was 2 years of experience. Hence, it appears that because 3D printing technology itself is relatively new, the average level of experience that respondents have with this technology is also relatively low.

Figure 4: Survey Respondents' Experience With 3D Printing In Years



The age of respondents, however seems to be relatively mixed. The average age was 39 years, the oldest maker was 72, the youngest was 18 and the modal age of the respondents was 18 years of age.

Figure 5: Survey Respondents' Age In Years



Model Specification

The empirical model that we developed is depicted in the following 2 equations:

$$(1)\quad Products\ Created = \beta_0 + \beta_1 Enjoyment + \beta_2 Personal + \beta_3 Skill + \beta_4 Approval + \beta_5 Financial + \beta_6 Age + \beta_7 Gender + \beta_8 Experience + \beta_9 3DPJob + \beta_{10} PriorProducts + \varepsilon_{it}$$

$$(2)\quad Product\ Adoption = \beta_0 + \beta_1 Enjoyment + \beta_2 Personal + \beta_3 Skill + \beta_4 Approval + \beta_5 Financial + \beta_6 Age + \beta_7 Gender + \beta_8 Experience + \beta_9 3DPJob + \beta_{10} PriorProducts + \varepsilon_{it}$$

where *Enjoyment* denotes the motivational factors for enjoyment, *Personal* denotes the motivational factors for personal needs, *Skill* denotes the motivational factors for skill development, *Approval* denotes the motivational factors for approval of others, *Financial* denotes the motivational factors for financial gains, *Age* denotes the age of the user in years, *Gender* denotes gender, *Experience* denotes the years of experience the user has with 3D printing, *3DPJob* denotes a binary response to whether or not the respondent uses 3D printing in their full-time job, and *PriorProducts* denotes the number of

products each maker produced prior to the start of the observation period. A list of these variables can be found in Appendix D.

Cronbach's alpha was used as a measure of scale reliability. The alpha statistics for each of the 5 scales that were employed appear in Appendix E – Table 2. As one can see, all of the alpha values except one, exceeded the value of .69, indicating acceptable levels of reliability. In one case (i.e., the Personal Need scale), the alpha value was significantly lower than in the other scales. This indicates that there may be some reliability concerns with this measurement scale; however, we ultimately opted to include this measure in the final analysis.

Results

The data from the experiment was analyzed in STATA, a popular software package for statistical analysis. Reliability for each of the independent variables was assessed through the use of Cronbach's alpha. The alphas for the independent variables were as follows; *Enjoyment* ~.6967, *Personal* ~.488, *Approval* ~.7699, *Skill* ~.8343, *Financial* ~.7420, these alphas can also be seen in Appendix E – Table 2. This shows that all of the measures except for the Personal Need scale demonstrate acceptable levels of reliability.

Two separate regressions were calculated to gain a better understanding of which motivation had a larger impact on the number of designs created within the observation period (May 2017-May 2018) and on the market response to these designs (i.e., average number of downloads per design) for each maker.

Results for regression equation 1 can be found in Table 3 of Appendix F. This regression focused on finding the variables that had the largest impact on the number of designs created within the observation period. The significant / marginally significant variables that were returned in this analysis consisted of *3DPJob*, *PriorProducts* and *Personal*. *PriorProducts,* a control variable, had a positive, significant effect on the dependent variable (coeff .2304583, $p>0.001$). This suggests that makers who

created many designs before the observation period began, tended to continue to produce many designs during the observation period. This provides evidence that users who have actively contributed in the past are likely to continue making new products in the future. Another control variable, *3DPJob,* has a negative, marginally significant effect on the number of designs that a maker creates (coeff: -5.263727, p>0.053). This shows that those who use 3D printing in their full-time job tended to create fewer designs during the observation period. This result is somewhat surprising, but could be attributed to the need to protect intellectual property or time constraints from the responsibilities of a full-time job.

In terms of the motivational variables, *Personal* appears to have a negative, significant effect on the number of designs produced (coeff: -2.891397, p>0.046). This could be attributed to the fact that when personal need is a strong motivating factor to product designs and a designer's need is satisfied, he/she no longer has a strong interest in contributing other designs on Thingiverse. Given the problems with the reliability of this scale, however, perhaps we should not read too much into this result.

Results for regression equation 2 appear in Table 4 of Appendix F. This regression focused on selecting the variables that had the largest impact on the market response to the maker's designs, which was expressed as the average number of downloads for the maker's designs within the observation period. In this regression, the variables *3DPJob* and *Approval* were significant / marginally significant. Again, *3DPJob,* a control variable exerted a negative, marginally significant effect on the dependent variable (coeff: -56.0336, p>0.092). This suggests that those who utilize 3D printing as part of their full-time jobs tend to create products that are downloaded less by other community members. This could be the case, because these designs are quite user or job specific and not necessarily something that an average user would be interested in. The analysis also reveals that another control variable, *PriorProducts,* has a marginally significant, positive effect on market response to a maker's posted designs (coeff: 1.339235, p>0.093). This indicates that makers, who have previously created other

products may be better recognized by members of the Thingiverse community and may be capable of drawing greater attention to their designs versus makers who have been less active contributors in the past.

In addition, one of the motivational measures, *Approval,* has a positive and significant influence on market response (coeff: 51.19987, p>0.032). This finding suggests that makers who are motivated to create designs in order to garner approval / praise from others in the community tend to achieve a greater level of market response versus those who create designs because of intrinsic motivations. This may be the case, because such makers tend to pay greater attention to the needs of their peers and realize that in order to satisfy their need for approval and validation from the Thingiverse community, they must product designs that are innovative and attractive to other community members.

General Discussion

The results that were obtained in this study have several implications for online user innovation communities such as Thingiverse. Recall that this study was conducted in order to gain a better understanding of the motivations of makers who participate in user innovation communities like Thingiverse. Through the online survey that we employed, we were able to garner some initial insights relating to the relative importance of various maker motivations.

One common theme that ran through these results was the potential importance of the variable *3DPJob*. These results showed that makers who participated in these communities and used 3D printing in their full-time jobs tend to produce fewer designs as well as designs that are less widely accepted by their peers. This could be related to the purpose of these designs. For example, if designs are created solely for the use in a full-time job, there could be licensing and intellectual property issues which could reduce the number of designs that the maker chooses to share with the community. Moreover, if the resulting designs are too specific to the maker's job context, they may not be broadly appealing to other more users on Thingiverse.

Interestingly, one motivational variable that was never significant in the equations was *Financial.* This suggests that despite the fact that about 25% of makers report receiving money for their 3D printing efforts, financial gain is not an important variable in predicting the number of designs created or the popularity of the designs that makers produce on Thingiverse. In contrast, *Personal,* was the only significant (negative) motivational factor in the first regression equation. This indicates that those that participate primarily for personal need tended to produce fewer designs than their peers. However, given that there are concerns about the reliability of this measure, it is important not to draw too many conclusions from this finding.

In addition, our analysis provides evidence that the desire to receive a positive response from one's peers, or *Approval,* plays a role in predicting the popularity of the designs that a maker creates as seen in the second regression analysis. This result suggests that product adoption may be linked to a maker's desire to create products that their peers will enjoy and value. Interestingly this seems to indicate that products that are born out of a desire to satisfy others' needs generate a greater market response than those that are born from an attempt to satisfy one's own need. In essence, this finding suggests that *Approval* (an extrinsic motivation) is a better predictor of market response than intrinsic motivations such as *Enjoyment or Skill.*

Overall, although these analyses are preliminary, they do enrich our understanding of the role that different motivations play in predicting maker performance within online user innovative communities like Thingiverse.com. These findings broadly suggest that makers may be better able to create popular products when they are looking for feedback and validation from the user community, and not necessarily seeking financial gain, seeking enjoyment, or trying to satisfy personal needs. Although additional research needs to be done to better understand these relationships and to validate these findings, we hope that this study will help to spur interest in this topic and lead to additional scholarly examinations of this intriguing topic.

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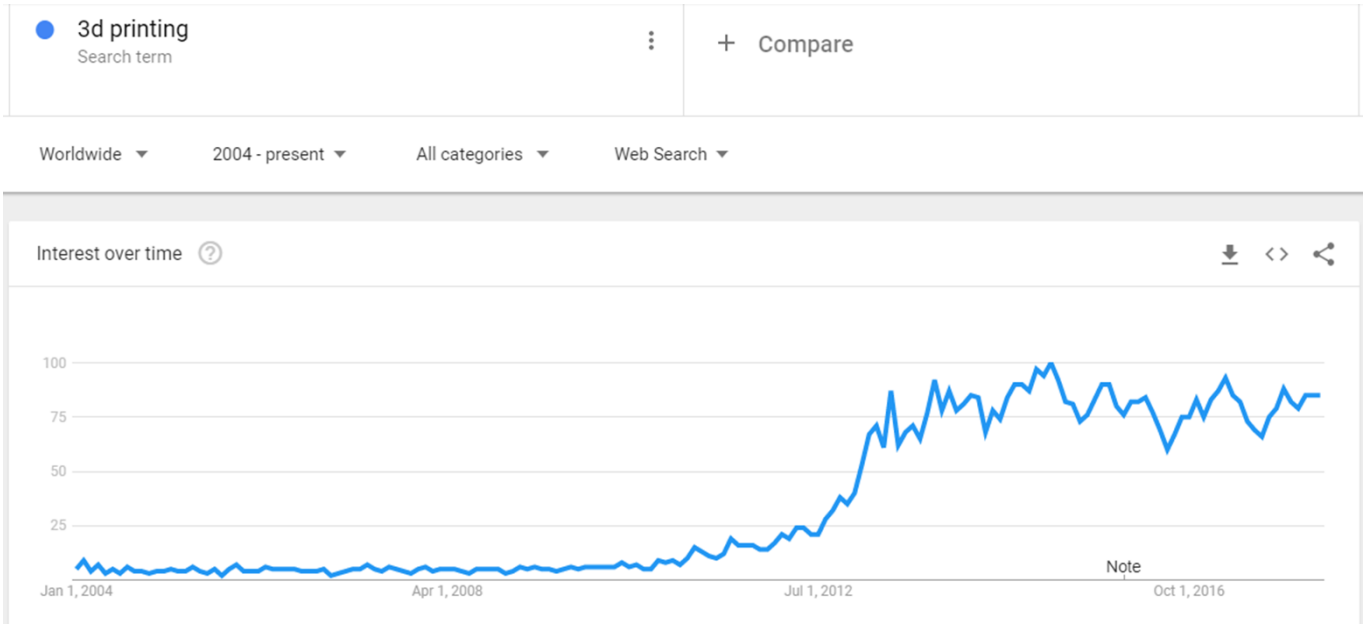
Appendix A: Growth of the Search Term "3D Printing" (2004-2018)



Source: https://trends.google.com/trends/explore?date=all&q=3d%20printing

Appendix B: Correlation Matrix for Variables

Correlation Matrix

	Variable	1	2	3	4	5	6	7	8	9	10
1	Skill	1.0000									
2	Enjoyment	0.4165	1.0000								
3	Personal	0.1184	0.0407	1.0000							
4	Approval	0.1723	0.2312	0.0736	1.0000						
5	Financial	***0.0302***	0.0807	***-0.0081***	0.1631	1.0000					
6	Age	-0.1470	-0.1675	0.0599	-0.1198	-0.1120	1.0000				
7	Gender	-0.1076	-0.1556	***0.0243***	-0.0869	0.0064	0.1180	1.0000			
8	Experience	-0.1007	***-0.0429***	-0.1601	-0.0898	-0.0540	0.1755	0.1175	1.0000		
9	3DPJob	0.0643	0.1242	-0.1537	-0.0935	***0.0110***	***0.0152***	0.0944	0.3022	1.0000	
10	Sell	-0.0104	0.0783	-0.1315	***-0.0200***	0.2108	***0.0161***	0.0960	0.1486	0.0658	1.0000

Note: All correlations except the ones in bold, italics are significant at .05 level

Appendix C: Motivation Scales Used In Survey

Scale 1: Hedonic / Personal Enjoyment (*Enjoyment)*

Scale 1: Hedonic / Personal Enjoyment (*Enjoyment*) *α*=.6967	Strongly Agree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
Creating digital designs is intellectually stimulating	⬭	⬭	⬭	⬭	⬭	⬭	⬭
I derive a lot of enjoyment from creating digital designs	⬭	⬭	⬭	⬭	⬭	⬭	⬭
I find creating digital designs as or more creative than any other task I engage in	⬭	⬭	⬭	⬭	⬭	⬭	⬭
If I had an extra hour in the day, I would probably spend it creaint digital designs	⬭	⬭	⬭	⬭	⬭	⬭	⬭

Scale 2: Personal Need (*Personal)*

Scale 2: Personal Need (*Personal*) *α*=.488	Strongly Agree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
I create digital designs because I usually have a personal need for these products	⬭	⬭	⬭	⬭	⬭	⬭	⬭
I create digital designs because I can produce products better that satisfy my needs than existing commercial products can.	⬭	⬭	⬭	⬭	⬭	⬭	⬭
When I create a digital design I am mainly focused on creating something that will satisfy my own unique needs.	⬭	⬭	⬭	⬭	⬭	⬭	⬭
When I create a digital design I rarely print the product and use it myself.	⬭	⬭	⬭	⬭	⬭	⬭	⬭

Scale 3: Skill Development (*Skill)*

Scale 3: Skill Development (*Skill*) *α=.8343*	Strongly Agree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
Creating digital designs enables me to develop valuable new skills	◯	◯	◯	◯	◯	◯	◯
Creating digital designs helps me develop the first-hand knowledge I need to become a better designer	◯	◯	◯	◯	◯	◯	◯
Creating digital designs is an excellent way for me to learn new things and enhance my design expertise	◯	◯	◯	◯	◯	◯	◯

Scale 4: Popularity (*Approval)*

Scale 4: Others' Approval/Popularity (*Approval*) *α=.7699*	Strongly Agree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
When I create a digital design, I try to make something that I think other users will value	◯	◯	◯	◯	◯	◯	◯
I really enjoy getting positive feedback from other users about my digital designs	◯	◯	◯	◯	◯	◯	◯
When I see that a lot of users have downloaded my digital designs, I feel very satisfied	◯	◯	◯	◯	◯	◯	◯

Scale 5: Financial Gain (*Financial)*

Scale 5: Financial Gain (*Financial*) *α*=.7420	Strongly Agree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
Other users sometimes pay me for the digital designs I create	◯	◯	◯	◯	◯	◯	◯
Other users sometimes pay me to produce physical products from the digitial designs I create	◯	◯	◯	◯	◯	◯	◯
Other users sometimes find my free digital designs on Thingiverse and then later comeback and purchase original files / physical products I have created	◯	◯	◯	◯	◯	◯	◯
Having a presence on Thingiverse is an effective way to draw attention to the digital designs that I sell online	◯	◯	◯	◯	◯	◯	◯
Having a presence on Thingiverse benefits me financially	◯	◯	◯	◯	◯	◯	◯

Appendix D: Variable Operationalizations

Table 1: Variable Operationalizations

Category	Variables	Operationalizations
Dependent Variables	Number of designs created by user	The cumulative number of designs created by designer *i* during the observation period from May 2017-May 2018
	Number of downloads for user	The cumulative number of downloads for designer *i* during the obsercation period from May 2017-May 2018
Independent Variables	Enjoyment	Four item scale assessing the importance of hedonics / enjoyment as a motivational factor
	Skill	Three item scale assessing the importance of skill development as a motivational factor
	Personal	Four item scale assessing the importance of satisfying own personal needs as a motivational factor
	Approval	Three item scale assessing the importance of satisfying others' needs / gaining feedback and approval from others as a motivational factor
	Financial	Five item scale assessing the importance of financial gains as a motivational factor
Control Variables	Age	The age of survey respondents
	Gender	The gender of survey respondents
	Experience	The number of years of experience with 3D printing that survey respondents had
	3DPJob	The binary variable that indicates whether or not the survey respondent used 3D printing in their full-time job
	PriorProducts	The cumulative number of designs created by designer *i* before the observation period from May 2017-May 2018

Appendix E: Scale Reliability Using Cronbach's Alpha)

Table 2: Scale Reliability (Cronbach's Alphas)

Variable	Cronbach's Alpha
Experience	0.6967
Skill	0.8343
Personal	0.488
Approval	0.7699
Financial	0.742

Appendix F: Regression Tables

Table 3: The Effect of Maker Motivations on Designs Created In Observation Period

Variables	D.V.:ThingsInObs		
	Coefficient	P>|t|	Standard Error
Main Effects			
Skill	1.801116	0.262	1.599311
Enjoyment	-0.6214912	0.698	1.59833
Personal	-2.891397	0.046 **	1.438751
Approval	1.975928	0.313	1.951116
Financial	-0.4649475	0.728	1.333925
Controls			
Age	0.0928764	0.258	0.081719
Gender	6.730625	0.341	7.04819
Experience	-0.7983899	0.299	0.7654212
3DPJob	-5.263727	0.053 *	2.702604
PriorProducts	0.2304583	0.001 **	0.0657364
Constant	-1.535381	0.935	18.732
Model Fit			
R-squared overall	0.1562		

Note:
*indicate a significance level of .10
**indicate a significance level of .05

Table 4: The Effect of Maker Motivations On Designs Downloaded In Observation Period

Variables	D.V.:dwnIdsPerThingInObs		
	Coefficient	P>|t|	Standard Error
Main Effects			
Skill	-17.99139	0.35	19.20146
Enjoyment	6.097558	0.752	19.26358
Personal	-22.9328	0.187	17.30626
Approval	51.19987	0.032 **	23.58418
Financial	12.18962	0.461	16.47008
Controls			
Age	0.5226412	0.599	0.9913606
Gender	105.898	0.208	83.7302
Experience	-4.537438	0.629	9.371156
3DPJob	-56.0336	0.092 *	33.01892
Prior Products	1.339235	0.093 *	0.7915862
Constant	-161.149	0.476	225.6258
Model Fit			
R-squared overall	0.1111		

Note:
*indicate a significance level of .10
**indicate a significance level of .05