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WHY OPEN SOURCE? EXPLORING THE MOTIVATIONS OF USING AN OPEN MODEL FOR HARDWARE DEVELOPMENT

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ABSTRACT

Following the successful adoption of the open source model in the software realm, open source is becoming a new design paradigm in hardware development. Open source models for tangible products are still in its infancy, and many studies are required to demonstrate its application to for-profit product development. It is an alluring question why entrepreneurs decide to use an open model to develop their products under risks and unknowns, such as infringement and community management. The goal of this paper is to investigate the motivations of entrepreneurs of open source hardware companies. The leaders and founders of twenty-three companies were interviewed to understand their motivation and experiences in creating a company based on open source hardware. Based on these interviews, we generated a hierarchical framework to explain these motivations, where each level of the framework has been defined, explained and illustrated with representative quotes. The motivations of open source action are framed by two categories in the paper: 1) Intrinsic Motivation, which describes the motivations of an entrepreneur as an individual, who needs personal satisfaction, enjoyment as well as altruism and reciprocity; 2) Extrinsic Motivation, which describes motivations of an entrepreneur whose identity is as a for-profit company leader.

Keywords: open design, motivation, open source

INTRODUCTION

Ever since the birth of open source hardware (OSH), it has been frequently asked whether the approach will be able to significantly influence industry practice[1–3]. Material acquisition, product testing and validation don't hardware development to iterate as fast as software[4, 5]. Thanks to the internet, it is easier for people to master relevant techniques and form communities online, based on existing products following some simple remixing and innovation[6]. The dawn of OSH has spawned an industry of "DIY" open source product development.

As the OSH industry is in its infancy, there is limited scholarly literature that has explored the state-of-art and viability of commercializing OSH. There is an increasing number of non-profit OSH products in all fields, especially for research purposes[7, 8], but the open source paradigm has only recently been attempted in commercial hardware development. Many questions and problems are waiting to be explored and solved: "How will OSH companies protect their intellectual property?", "Why do they choose to open design their products?" Without answering the questions, running an open source hardware business is like exploring uncharted territory without guidance. This paper aims to understand a headstream question of this new entrepreneurial phenomenon, that is, why do people use an open model to build a commercial hardware product?

The majority of research studies about the motivation of the open source movement focus on the motivations of free participants[9–11] rather than that of entrepreneurs who are using open model to develop their products. Understanding entrepreneurs' motivations of using open model for commercial hardware development is the first step of analyzing the large-scale utilization of open source hardware in industry use and everyday use. Meanwhile, understanding entrepreneurs' motivations can help internal and external

strategic planners to better plan business progress, milestones and business models. Government should also have a deep understanding of entrepreneurs' motivations to implement relevant policies encouraging local entrepreneurship. Further, most open hardware companies envisage similar difficulties in the early stage of company development. Understanding these motivations can help group similar companies and allow for learning from each other's experience.

By interviewing twenty-three open hardware companies from diverse areas and different countries, we attempt to understand open source hardware entrepreneurs' motivations using a qualitative research method. The paper is organized in the following way. First, the history of Open Source Software (OSS), Open Source Hardware (OSH), and Maker Movement is reviewed to understand the terminology and how OSH business comes to life. Next, the state-of-the-art OSH entrepreneurships are presented to illustrate the potentials and problems of OSH companies. In the third section, previous researches on motivations in open innovation and OSS are provided to support the framework proposed in this paper. Last, the twenty-three entrepreneurs' motivations are characterized and put into matrix according to the framework.

The History of the Open Source Software (OSS) Movement

OSS emerged from the Free Software Movement led by Richard Stallman in the 1985. Advocating for free use and distribution of software against monopolies such as Microsoft and IBM, who unbundled software from hardware, charging money for operating systems and other software, the movement was concerned with the ethical reasons of freely using, modifying and distributing software[12]. In the 1990s, Linus Torvalds, a student in Finland, released "Linux", an open source operating system, under the GNU General Public License developed by Stallman and his Free Software Foundation, allowing people to witness the community's power and potential. Since then, Linux has become remarkably popular among hobbyists, and has eventually become one of the most reliable operating systems and is broadly used in smartphones, personal computers, servers and web platforms[13]. The growing interests of commercializing OSS led to the approvals of a set of licenses managed by the Open Source Initiative, a formal organization founded in 1998 in charge of reviewing and approving open source licenses. In 2001, seeing the potential market of Linux users, IBM invested $1billion into the Linux development, embracing it as an operating system in IBM servers and software. The investment further accelerated the development of Linux and triggered development of other OSS. Android, an open source smart device operating system whose core part is Linux, has been widely used by mobile producers and other device companies. Apache, an open source web-server framework, supports about 67% of the web-servers in the world[14]. Red Hat, the leading commercial vendor of Linux, founded in 1993, provides many customizable services around Linux systems and generated over $2 billion in revenue in 2015[13].

Open Source Hardware (OSH) Movement and Makers' Movement

Open Source Hardware (OSH) is a term for tangible artifacts - machines, devices, or other physical things - whose design has been released to the public in such a way that anyone can make, modify, distribute, and use those designs[1]. The design files released should include all hardware design and software code. Within the last 10 years, the OSS spirit; collaboration, knowledge sharing, openness; has spilled over to the tangible products world. The success of OSS in both personal and business markets raises question of whether OSH will follow the same trend. Holding an open spirit, several open source hardware project leaders have proved the viability of the open designing of tangible products and have revealed the potential of open source in technology innovation

A prevailing example of an OSH project is the RepRap (Replicating Rapid Prototyper) project, whose goal is to make low-cost self-replicable 3D printers. Initiated by Dr. Andrew Bowyer in England as a research project in 2005, RepRap caught the attention of students, researchers, engineers and other volunteers from all over the world and developed the biggest 3D technology community online. The blog of RepRap clearly recorded how the RepRap community actively collaborated online and offline with open-sourced files to complete the first self-replicable 3D printer[15]. Notably, the RepRap project has spun off many current open source or closed source 3D printer businesses, such as Makerbot and Ultimaker, allowing affordable 3D printing technology to mature in a very fast way. Further, the RepRap community developed other 3D technologies such as cutting and milling, spawning a pool of affordable devices. Interestingly, in the same year, an open source microcontroller board, Arduino, was born in the Interactive Design Institute as a tool to teach students to create electronic systems quickly. Arduino provides a simple schema and friendly user interface, allowing novice users to take on the technologies in a rapid manner.

Powered by affordable machine tools, easy-to-use microcontroller boards, web technology, open-sourced design files and numerous Maker communities, the Maker Movement swept the globe and revamped the notions of technology, innovation and education. The movement united an immense group of people who like making, designing, tinkering and embracing an open and collaborative spirit, resulting in global Maker communities who acquire their own culture and ethic, and a global Maker market allowing new forms of entrepreneurship and business opportunities. In industry, big companies started to reach out to their clients to seek user innovation. Open innovation platforms were built and proprietary knowledge was released to facilitate innovation exchange between the companies and clients[16,17]. In academia, a new term "open source economy" was born and researchers began to discuss about how shared knowledge and technology would contribute to the prosperity of the global economy[18,19]. The Maker Movement blurs the borderline between techies and non-techies, maximizing knowledge exchange and idea validation, bringing a "DIY" culture back to daily life and work. The Maker market also starts to play a significant role in the global economy. According to Atmel, a major backer of the Maker movement, there are

[1] https://www.oshwa.org/definition/

approximately 135 million U.S. adults who are makers, and the overall market for 3D printing products and various maker services hit $2.2 billion in 2012. That number is expected to reach $6 billion by 2017 and $8.41 billion by 2020[20]. According to *USA Today*[2], makers fuel business with some $29 billion poured into the world economy each year.

Open Hardware Entrepreneurship

OSS is widely used in industry and actively developed by individuals and companies. The free and instant acquisition, modification, validation and distribution of OSS ignited the community's passion of contributing, leading to the success of the OSS industry. In comparison to OSS, OSH has certain implementation difficulties in product testing, modifying, validating and delivering[4]. It is therefore doubtful that OSH products can be commercialized as rapidly as the OSS products.

There are several reasons that OSH companies are able to sustain themselves. First, the Maker Movement creates global maker communities who are calling for DIY-able, customizable, open-sourced products. Secondly, increasing accessibility of free and open source CAD (Computer Aided Design), and CAE (Computer Aided Engineering) tools, as well as affordable machines, microcontrollers, and free design resources, facilitates the making process, increases people's interests in making, and hence enlarges the OSH market. Thirdly, many local making spaces were formed following the Maker Movement, adding access to prototyping tools and knowledge pools. Fourthly, unlike OSS, a tangible product, even being open-sourced, can be directly sold to gain profits. This turns out the major business model in many open source electronic companies. Lastly, OSS foundations and organizations are established to promote the development of the OSH industry and to issue proper licenses to enable open source businesses. Therefore, the author believes that by carefully designing proper business models and identifying challenges and risks in advance, we can help OSH to embrace its emergence in global economy.

RESEARCH METHODS AND DATA COLLECTION

In this research, we adopted a qualitative approach to perform an empirical study on motivations of OSH entrepreneurs. First, we searched OSH companies in Kickstarter [3] and Indiegogo [4] (leading crowdfunding companies), TechCrunch [5] (leading online publisher on technology startups), and Wevolver [6] (award-wining open collaboration platforms). Eighty-seven companies are identified as OSH companies with the criteria that one of its products satisfied the definition of openness defined by Balka & Raach[21], that is, transparency, accessibility and replicability. Requests for an interview were sent to the company founders or CEOs, with twenty-three accepting interview requests.

TABLE 1 INTERVIEWED COMPANIES' INFORMATION

Company	Year Established	Location	Product
Seeed Studio	2003	China	Electronics platform
Lemarker	2014	China	Electronics platform
M5Stack	2016	China	Microprocessor Module
AI.Frame	2014	China	Humanoid Robot
Ufactory	2013	China	Robotic Arm
Faraday Motion	2016	Denmark	Electronic Skateboard
OpenDesk	2014	England	Furniture
RepRap	2005	England	3D printer
Sunzilla	2016	Germany	Portable Solar Energy
OSA	2012	England	Telescope
Arduino	2005	Italy	Electronics platform
PLEN	2014	Japan	Humanoid Robot
ExIII	2014	Japan	Bionic hand
OSvehicle	2013	Italy	Electric Vehicle
Ultimaker	2011	Netherlands	3D printer
3dr/ Ardupilot	2012	US	Drone
OpenMV	2016	US	Computer Vision Module
OpenROV	2012	US	Underwater Drone
Re3D	2013	US	3D printer
OpenBCI	2013	US	Neuroscience Device
Sparkfun	2003	US	Electronics platform
Ford/OpenXC	2012	US	Smart car platform
Intel/01org	N/A	US	I.o.T. platform

The interview questions were semi-structured with seven questions asked (shown below) to identify the motivations.

- What is your professional background?
- What is the product of your company?
- In which situation did you decide to build up a company?
- Why did you decide to open source your product?
- When did you decide to open source your product?
- Have you ever participated in open source product development?
- Have you ever regretted open sourced your product?

Interviewees were encouraged to speak freely about what they believed to be relevant to the questions. The interviews lasted on average 68 minutes via Skype or in person and were audibly recorded with the subjects' permission. The records were then translated into written materials and used to perform the qualitative analysis presented in this paper. Secondary resources were collected for all companies from company homepages, the business and specialist press, and video channels.

From lessons on research studies about motivations for free participation in OSS and co-creation in open innovations, a framework is proposed. The framework presents a systematic approach to understanding emerging phenomenon and also provides a general structure for comparison of different companies.

[2] https://www.usatoday.com/story/money/business/2013/10/14/martha-stewart-column-meet-the-makers/2980701/

[3] https://www.kickstarter.com/

[4] https://www.indiegogo.com/

[5] https://www.techcrunch.com/

[6] https://www.wevolver.com/

A PROPOSED MOTIVATION FRAMEWORK

Literature Review of Frameworks of Motivations for Free Participation in OSS Development

Previous qualitative research studies characterized the motivations of free participation according to different frameworks. The frameworks have two main branches: one classifies motivations using Intrinsic/Extrinsic factors; the other describes the motivations of the contributors as those either of an individual developer or of a firm.

Intrinsic/Extrinsic Framework The Intrinsic/Extrinsic framework inherits features from Cognitive Evaluation Theory (CET), a psychological theory originally explaining the effects of external consequences on internal motivations[22]. Due to the analogous structure, it has also been heavily used in organization management in identifying employees' incentives of working[23, 24]. Similarity between the autonomous participation of the open source community and a loosely structured organization with a goal of developing a product leads to many research studies borrowing the same framework to analyze the motivations of OSS development[25, 26].

Ryan and Deci[22] defined intrinsic motivation as "doing of an activity for its inherent satisfactions rather than for some separable consequence. When intrinsically motivated, a person is moved to act for the fun or challenge entailed rather than because of external prods, pressures, or rewards." Lindenberg[27] explained that people will be intrinsically motivated when the activity is "interesting, satisfying, enjoyable, fulfilling, and absorbing." Lindenberg further classified the intrinsic motivation as "enjoyment based intrinsic motivation" and "obligation/community based intrinsic motivations". Having fun or enjoying oneself is the core idea of the enjoyment-based intrinsic motivation. People pursue some activities for the enjoyment of doing them without considering the outcome, such as "creative discovery, a challenge to overcome and a difficulty resolved"[28]. In OSS development, such pursuit can be justified when developers are freely choosing the projects that interest them and fit their skill level. Action based on the principles or sense of obligation is another form of intrinsic motivation. "Hacker" turns out to be an honored title in the community of software developers. It shows one's intelligence in solving difficult problems and possession of a sharing spirit. In OSS development, these are essential.

Extrinsic motivation, on the other hand, is defined and used mostly by economists, which describes motivations driven by external factors. "People change their actions because they are induced to do so by an external intervention. Economic theory thus takes extrinsic motivation to be relevant for behavior."[15, 16] Many researchers believe that taking advantage of Extrinsic motivations will motivate developers to contribute. Extrinsic motivations include learning, personal use, field reputation and pay[18]. Krogh argued about the transpose phase between Intrinsic and Extrinsic motivations and proposed Internalized Extrinsic Motivations[9].

Social-Technological-Economical Framework (STE) The Intrinsic/Extrinsic model is effective in explaining the individual's motivations in OSS participation, but according to Lakhani's[25] study, the majority of contributors are firms, where the Intrinsic/Extrinsic model is weak in characterizing the motivations of a profit-oriented firm's "non-profit" behavior. Feller and Fitzgerald[31] proposed another framework containing three subcategories of motivations: Technological, Economical and Social motivations. This framework can be used to explain both individual's and firm's motivations. However, according to Bonaccorsi and Rossi's[32] study, significant differences are found between the set of motivations of individuals and those of firms: "In particular, firms emphasize economic and technological reasons for entering and contributing to open source and do not subscribe to many social motivations that are, by contrast, typical of individual programmers." The Social aspect in this framework is similar to the Intrinsic part in CET, while Technology and Economic aspects resemble the Extrinsic part.

TABLE 2 FRAMEWORK FROM KARIM LAKHANI

Intrinsic	**Enjoyment-based** - "creativity discovered, a challenge overcome and a difficulty solved", - "a challenge who matches their skills that cannot be found in their regular job", - "sense of creativity in a task accomplishment" **Obligation-based:** - "sense of community identification and adherence to the norm of behavior", - "hacker is an honor…"
Extrinsic	**Immediate pays-off** (*CET: "rewards, reputation, pays"*) - Get paid - Own use **Long-term pays-off:** - Career development - Skill enhancement - Peer review for fast development

TABLE 3 FRAMEWORK FROM KROGH & WALLIN

Intrinsic	ideology, altruism, kinship, and fun
Internalized Extrinsic	reputation, reciprocity, learning, and own-use
Extrinsic	career, pay

Other framework Some researches are particularly interested in understanding the motivations of firms' participation. Anderson and Gott[33, 34] case studied three OSS companies and proposed a framework represented by a triangle graph whose angles are sales of Complimentary Services, Innovation and Cost Reduction. This framework focuses only on companies' motivations resembling the Extrinsic aspect in CET, or Technology and Economic in STE.

Framework Proposed in This Paper

From the interview data, we realized that the interviewees have two identities when they make the decision of open-sourcing their products. Many of them have rich experience in OSS development and they have deep understanding of and appreciation for open spirit. Meanwhile, they are also company leaders, whose duty is to assure the sustainability of the company, increase profits and decrease risks. The action of open-sourcing their products would bring in more risks.

Considering the above, we propose the hierarchical framework shown in Figure 1. The top layer of the framework adopts the Intrinsic/Extrinsic structure because of the dual facets of the interviewees as individuals possessing personal dreams and open spirit (hence Intrinsic Motivations) and as

firm leaders who are responsible for the growth of the company (hence Extrinsic Motivations).

Hacker's spirit, Personal Satisfaction, Reciprocity and Altruism have been identified as sub-levels under Intrinsic Motivations. Personal Satisfaction and Altruism are aligned with the enjoyment based Intrinsic motivations, while Hacker Ethic and Reciprocity refer to obligation/community based intrinsic motivation.

The Technological-Economical-Social framework, an effective structure for explaining a firms' motivation for participating in OSS development, was implemented as the sub-level of Extrinsic Motivations. According to Bonaccorsi and Rossi[35], companies demonstrate less social motivations than individuals in OSS development. Additionally, a company's Social motivations are represented in Intrinsic Motivations in the framework. Taking these into consideration, the social aspect was removed from Extrinsic motivations. During the interviews, many interviewees mentioned their product-based motivation - a motivation that is related to their customers' need and distribution permission. Because of this, the product-based motivation aspect was added as a new aspect within the Extrinsic domain. Details of each aspect of motivations are given in the following sections.

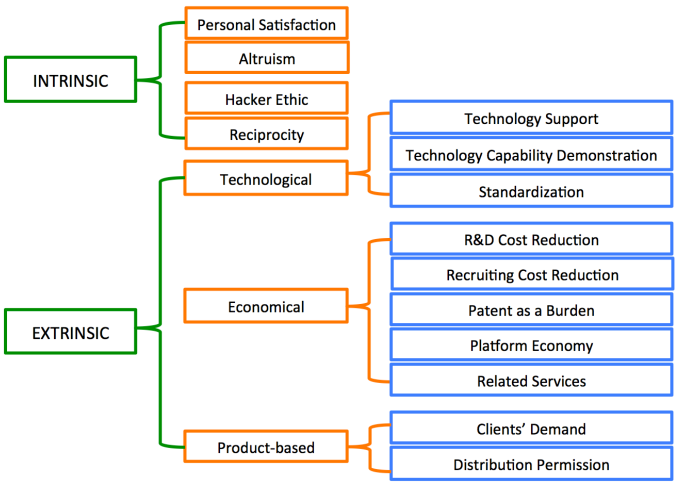

FIGURE 1 HIERARCHICAL FRAMEWORKS OF OPEN SOURCE MOTIVATIONS

Intrinsic Motivations

The intrinsic motivations focus on interviewees as individuals who have a need for enjoyment, achievement, and recognition and who have personal dreams to be fulfilled. The definition of Intrinsic motivation here is quite similar to those in the research studies of exploring individual developers motivation in OSS development[36]. Within the scope of Intrinsic motivations, four sub-levels have been observed from the interviews; Personal Satisfactions, Altruism, Reciprocity, and Hacker Ethic.

Personal satisfaction Personal satisfaction is defined as the state in which one feels recognized or honored, or realizes one's dream when one shares his/her design with the public. This occurs when the subject is an experienced maker who possesses superior knowledge or skills in the product domain. They are confident in their own abilities and believe that even if competitors copy the design, they are still likely to further innovate and exceed the competitors. They may already have a group of followers and the followers are loyal to the design.

"… I am a Gun Dam fan from a very young age. It is great to share your dream with so many people who like you… It is quite cool to see so many people from all over the world posting pictures of their DIY Gun Dam using our open-sourced files. They even make off-line groups to battle with each other. That's incredible and exciting! …"

- Co-founder of AI-Frame

AI.Frame is a startup company, founded by two Chinese electronic engineers who both have solid backgrounds in robotics. The product of AI.Frame, Apollo I, is a humanoid robot inspired by a Japanese animation image, Gun Dam Robot.

Altruism Altruism reflects the motivation of generating social benefits, usually out of empathy. Some interviewees had special life experience, so they invented and open-designed product with an affordable price to help people overcome similar difficulties. Some interviewees felt responsible for the fair accessibility of certain technologies.

Recovered from a bad accident, the founder of FaradayMotion started to design an open source 3D-printable electric skateboard for people who lack normal mobility.

"… A couple of years ago, I got an accident and was told that I might lose my mobility. During the recovery… I decided to make a smart skateboard and share its design with everyone, so people who don't have normal mobility can make it with cheap materials, move fast and look cool."

- Founder of FaradayMotion

Another example comes from the RepRap project, creating the world's first open source 3D printer using collective intelligence. The project founder was dedicated to reducing the cost of 3D printers and producing open source self-replicable 3D printers.

"… I realized that I can make a machine that can make itself, so it will be made a lot cheaper than those expensive machines. I was excited about this powerful idea and I wanted to make 3D printers available to everyone in the world. There was nothing more exciting and meaningful than this idea…"

- Founder of RepRap Project

Hacker Ethic Hacker Ethic was first proposed by Steven Levy in his book *Hackers*. The general principles of hacker ethic are sharing, free information, hands-on imperative and community[37]. According to Hacker Ethic, design should be shared and free-accessed. Interviewees who demonstrated Hacker Ethic are more familiar with OSS development and believed open source will become a trend of hardware design.

"… We are from RepRap, so we should keep it open as it is. That's makers' spirit and nobody should violate it …".

- Founder and Senior Developer of Ultimaker

Ultimaker is a Dutch company, spin-off from RepRap project, producing open source 3D printers.

Reciprocity Reciprocity, a will to give back to the open source community, is often found as a trait of some company leaders. This occurs when leaders do not have much experience initially but make significant progress on their products by using open source materials and by consulting the open source community.

"… Neither of the founders are professional in underwater device design. The community helped us a lot to design and test OpenROV prototype, and give us many insightful advices. Without them, it is impossible for us to make this happen. We feel bad if we don't share "their" design with them …"

- Project manager of OpenROV

OpenROV is an underwater robotics company manufacturing both open source and closed source products. Before the establishment of the company, the two co-founders were working as manufacturing engineer and technology editor respectively.

Extrinsic Motivations

The extrinsic aspect of motivation explains the motivations of interviewees as company leaders in seeking to increase profit and decrease risks. The sub-levels of extrinsic motivations contain Technological aspects, Economical aspects, and Product-based aspects.

Technological A company is considered to possess technological motivations when it decides to open-design a product based on a consideration of technological needs. This includes three sub-categories: 1) Gain extra idea-based and knowledge-based technology resources for fast and low-cost product development; 2) Demonstrate technological capabilities for potential investment, partnership or selling complementary services. 3) Set technology standards allowing for market domination.

I) Technological support: Startup companies may use an open model to gain external technology resources in order to accelerate product development and innovation. Having access to the source files, users can easily develop mutual interests in modifying and innovating the product, forming a community. At the same time, community members closely and actively collaborate with the company to share ideas, fix bugs, enhance innovations, and thus become "full-time" technology consultants and prototypers for the development of the product.

"… Our clients gave us much feedback, urging us to make our product better. Sometimes, it is actually not only feedback, also new ideas with solutions… When we are stuck by some technology issues, we simply have a meet-up with our clients and listen to their solutions ,, "

- Founder of Re3D

Re3D is a large-scale 3D printer manufacturer and social enterprise located in Texas.

Large companies are often said to have a lack of innovation capability due to their cumbersome planning and budgeting systems. Launching open source projects can help them quickly gather innovative ideas, test prototypes and evaluate technical feasibility. OpenXC is an open innovation platform for smart vehicles application operated by Ford.

"… The traditional R&D is way much more expensive than open projects. When people have privileges of choosing their favored projects, they are more motivated to develop. The community voluntarily does research and collects information. Most importantly, we understand quickly the technical feasibility and community experiences with the project product. We have also found many interesting projects done by the community and some of them can be imbedded into Ford's systems pretty well …"

- Manager of Research Innovation, Ford

II) Technology capability demonstration: The goal of developing an OSH product is not only to increase sales, but also to showcase technological capability. Trillion Technology is a London-based design company for space products. Their 3D-printable telescope is the winner of NASA's Asteroid Grand Challenge. In order to seek further collaboration with NASA and other space agencies, the CEO of Trillion Technology founded Open Space Agency (OSA), open-sourcing the design of the 3D-printable telescope as the featured project, as a way to attract more clients.

"..,You have to show something real to make the world know what you can do… we hope to show our capability and get more clients by open sourcing some designs "

- Founder, Open Space Agency and Trillian Technology

III) Standardization: Setting standards in an immature market can quickly spread the company's reputation, allowing them to take control of the market technology structure. , This helps the market players adopt the technologies or standards initiated by the company, hence providing potential revenue streams such as consultancy, incubation and trademarks. OSVehicle is an Italian open source modular electric vehicle framework. Their technological solutions allow customers to focus on industrial design and user experiences design instead of investing a good amount of time in structural or mechanical design for electric vehicles.

"… Automotive is such a conservative industry. We pilot the open source movement in this industry, and our chassis just provides the platform and standards for this change…(Why do you want to set the standards of this industry?)… The standards will help more and more people participating into this movement, and potentially become our customers. We hope that one day when people wants to do an startup on electronic vehicles, their first and best choice is OSVehicle… "

- Chief Marketing Office, OSVehicle

Economical Economical motivations simply refer to reducing costs and increasing profits. Five sub-levels were observed under economic motivation: 1) reduce R&D cost, 2) reduce recruiting cost, 3) eliminate cost of patenting (reduce technology investment), 4) build platform, and 5) provide related service. The first three sub-levels target cost reduction, while the last two target revenue increase.

I) R&D cost reduction: Using an open model to harvest external knowledge has been proven to be effective in reducing R&D cost. Evidence for this was found within the data collected for this paper.

"Our community creates great attachments of the ROV, and they open sourced the design file and agreed that we could manufacturing the attachments and sell them on our online store, so other users can use them too. That saves us a lot R&D investment. "

- Project Manager, OpenROV

II) Recruiting cost reduction: OSH companies can recruit engineers directly from its community, which greatly

reduces recruiting cost compared to the conventional recruiting procedure, mainly for two reasons. First, the community narrows the talent acquisition scope to a group of people who have already had the ability to design or engineer part of the product. Secondly, the skills and contribution of each community member is clearly logged, so the company could match people with more confidence to the available positions. OpenXC is Ford's open source platform providing a solution to access your vehicle data. The main purpose of Ford sponsoring this platform is to discover innovations based on vehicle data and potential talents.

"…It is quite easy to notice who is more capable of coding and who is more capable of making. If we find someone matches our positions, we will invite him for an interview…"

- Manager of Innovation Research, OpenXC

III) Patent as a burden: If a company doesn't have a technological edge over its competitors, patenting will not provide them much protection, but act as a heavy load instead. Many companies in the robotics entertainment industry exemplify this fact. PLEN is a Japanese robotics company, producing humanoid toy robots.

"*Honestly, we are not unique and our technology is not the most advanced. There are so many similar robot companies in Japan… For now, patent is too expensive for us to afford and I don't think it will make us more valuable if we are acquired one day. We'd rather use our money to make our products more functional."*

- Chief Marketing Officer, PLEN

***IV) Platform economy*:** Platform economy refers to increasing revenue streams by gathering products, community, marketplace, forums, documentations, tutorials, galleries, design/manufacturing resources, and business resources and services on a platform to form a self-sustained product development ecosystem. Such a mode could be seen in SeeedStudio, a Chinese electronics company that manufactures microcontroller boards and other electronics as well as providing a marketplace for people to sell their own makings and an incubator for hardware startups.

"*…Our goal is to build an open ecosystem for product development… Everything is open and accessible and we provides all services around electronics and products. We believe the platform economy will make people trust our brand, and buy our products and services …"*

- Founder and CEO, SeeedStudio

V) Related service: Related service includes coaching, training, outsourcing, incubating, customization, and consulting services around the open source product.

"… We also teach robotic classes for high school students and providing workshops for high school teachers…"

- Chief Marketing Officer, PLEN

Product-based

I) Clients' demand: Businesses, with makers as targeted clients, tend to open-source their product for the sake of makers' need of being open. OpenMV is a US startup company, producing a Python-powered open source machine vision module. Born in Hackaday.io (a leading web-magazine for best hardware hacks), OpenMV targets the Maker community as their primary customers.

"…Our clients are makers and they will refuse anything that are not open..."

- Founder and CEO, OpenMV

Similarly, businesses whose target clients are researchers may choose an open model. OpenBCI is a US open source company specializing in brain-computer interfaces. It was crowdfunded in 2013. Its community consists of many researchers and engineers in the field of neuron and cognitive science.

"…We decided to keep it open because it is a research-based product. We must make it hackable so that researchers can customize it to their own purpose …"

- Founder, OpenBCI

II) Distribution permission: Due to the distribution policies for certain kinds of products, such as medical devices, companies may not have effective distribution channels for their products. As a result, companies choose to open-source the design in order to gain other benefits. EXIII, a Japanese medical device design company, designs 3D-printable bionic hands and has such concerns.

"…We can't make it to the market without applying for medical device licenses like FDA, and we know it will take a long time and a lot of money. By open sourcing the design, we want to help people by letting them 3D print their customized bionic hand. We are also expecting feedbacks from them, so we can further improve our design…"

- Founder and CEO, EXIII

RESULT ANALYSIS

Analysis of Intrinsic Motivations

All of the six interviewees who possessed Personal Satisfaction as an Intrinsic motivation are experienced makers. This aligns with the description of the personal satisfaction motivation outlined in the previous section. Three of the six were students who majored in a product related field when they started their open hardware companies and the other three were professionals in design. Presumably, it is difficult for the students or entry-level employees to get recognition from their work, and they are limited in their ability to choose what they work on. However, open sourcing their design to the community can provide these individuals a sense of satisfaction and recognition. The leader of M5Stack and EXIII used to work in a less innovative environment, which forced them to seek fun after work, and eventually led them to start their entrepreneurship activities. Fourteen interviewees possess Altruism as Intrinsic motivation. Their products are mostly consumer electronics. The original idea of building an open hardware startup is based on their personal dreams. Six entrepreneurs have motivation of Reciprocity, while none of them is experienced enough to create a complete product on their own. They all received enormous help from the open source community and they feel obliged to give back. The majority of interviewees demonstrated Hacker Ethic in the conversation. The characterization and accumulative result of interviewees' Intrinsic Motivations are shown in Table 4 and Figure 2.

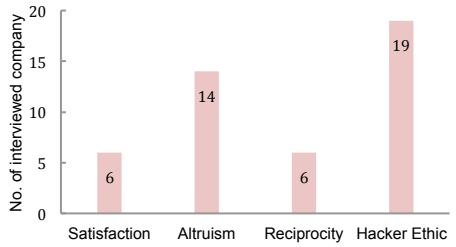

FIGURE 2 DEMOGRAPHY OF INTRINSIC MOTIVATIONS

TABLE 4 INTRINSIC MOTIVATIONS OF INTERVIEWEES

Company	Satisfaction	Altruism	Reciprocity	Hacker Ethic
EXIII	✓	✓		✓
M5Stack	✓	✓		✓
OpenDesk	✓	✓		✓
AI.Frame	✓			✓
SparkFun	✓			✓
Ufactory	✓			✓
3DR/ Ardupilot		✓	✓	✓
FaradayMotion		✓	✓	✓
OpenBCI		✓	✓	✓
OpenROV		✓	✓	✓
OSVehicle		✓	✓	✓
Sunzilla		✓	✓	
Arduino		✓		✓
PLEN		✓		✓
RE3D		✓		✓
RepRapPro		✓		✓
Ultimaker		✓		✓
Lemarker				✓
OpenMV				✓
SeeedStudio				✓
Intel 01org				
Ford OpenXC				
OSA				

Analysis of Extrinsic Motivations

Extrinsic motivations depend on the company leaders' understanding of the benefits and risks that an open source model may bring to the development. Meanwhile Extrinsic motivations vary significantly on the functional purpose and technological maturity of the product. For example, pharmaceutical firms may have a motivation (Distribution Permission) to open-source their products, as their product distribution notably depends on licensing or certification from the local drug administration. This could be seen from the examples of OpenBCI and EXIII. Overall, Gaining External Technology Support, Platform Economy, Reducing R&D cost and Providing other services are the motivations most often observed. The characterization and accumulative result of interviewees' Extrinsic Motivations are shown in Table 5 and Figure 3.

THE APPLICATION OF THE FRAMEWORK AND FUTURE RESEARCH

This framework could be significant in the following three aspects. First, the OSH motivation framework provides an explicit language for evaluating motivations. For government, this framework can be adopted to understand the influence of open design on entrepreneurship innovation and local technology innovation. For education, this framework can be used to guide students in pursuing open source entrepreneurship. Secondly, this framework can be used to evaluate the open hardware companies' development and financial status to understand how motivation can influence a company's success and thus provide an assessment tool of open hardware startups for investment companies. It is a common problem for investment companies to evaluate an open design company, as the open hardware companies don't possess any intellectual property so that there is no hardcopy reference to be used. With very few cases of open entrepreneurship investment, statistical inference is nearly impossible as well. Thirdly, the extrinsic part of the framework provides a guideline on how to leverage open design community resources. By utilizing the open design motivation framework, startup leaders can better harness information gathered through interacting with the community; thus, this framework can be referred to as a community management tool.

Further quantitative research, such as surveys, can be designed based on the proposed framework to validate the motivation explorations. With further validation, this framework can be applied to government policy making, open design entrepreneurship education or investment evaluation.

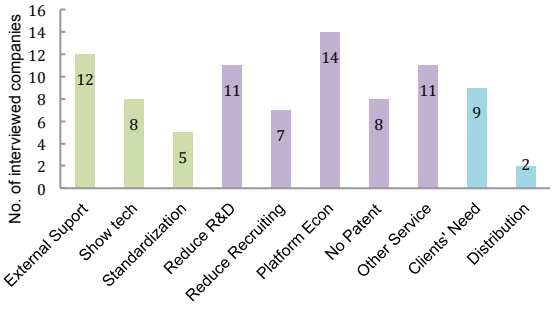

FIGURE 3 DEMOGRAPHY OF EXTRINSIC MOTIVATIONS

TABLE 5 EXTRINSIC MOTIVATIONS OF INTERVIEWEES

	Technological			Economical					Spc. Prod.	
Companies	Ext. spt.	Tech. cap.	Std.	Rdc. R&D cost	Red. Hir. cost	Plf. Econ	No nd. Ptt.	Svc.	Clt's nd.	Lcs
Sunzilla	✓			✓						
Re3D	✓				✓				✓	
OSVehicle	✓	✓	✓	✓		✓		✓	✓	
OSA	✓	✓		✓			✓			
RepRap	✓		✓	✓				✓		
OpenBCI	✓		✓	✓		✓				✓
OpenROV	✓			✓	✓	✓		✓		
3DR/ Ardupilot	✓			✓	✓	✓		✓	✓	
PLEN		✓		✓		✓	✓	✓		
FaradayMotion	✓			✓	✓	✓				
SeeedStudio						✓	✓	✓	✓	
OpenMV							✓		✓	
Ultimaker									✓	
OpenDesk	✓	✓			✓	✓	✓	✓		
EXIII		✓				✓		✓		✓
Ufactory		✓								
AI.Frame		✓								
Ford OpenXC	✓		✓	✓	✓	✓				
Intel 01org	✓		✓	✓	✓	✓				
M5Stack		✓					✓			
Arduino						✓		✓	✓	
SparkFun						✓	✓	✓	✓	
Lemarker						✓	✓	✓	✓	

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