Barriers to Widespread Adoption of Fab City Products

13

A User (Innovator) Perspective

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13.1 Introduction

Just as one swallow does not make a summer, one Fab Lab (fabrication laboratory) does not make a “Fab City”. To really earn this status, the maker movement needs to reach not just a small group of tech-savvy individuals but many citizens.

The concept of Fab City stems from the Fab Lab movement – a global network of open workshops initiated by Prof. Neil Gershenfeld at Massachusetts Institute of Technology (MIT) in the early 2000s. Fab Labs provide access to manufacturing technologies (e.g., 3-D printers, laser cutters, CNC mills) as well as the necessary skills and materials. A city becomes a Fab City if it joins the global initiative and ensures that access to these Fab Labs is as low-threshold as possible for citizens. The vision is that products of the future will be designed globally but manufactured locally. This method of production is called digital manufacturing as it utilizes, inter alia, computer-aided designs (CAD). As every citizen has the possibility to become a user innovator by developing product designs, finally, not only production but also innovation shall be more decentralized.

Depending on the country, between 1.5% and 9.6% of the population are user innovators (for an overview: Jin et al., 2018). Fortunately, most of these have no problem with making their ideas open-source (von Hippel, 2006). However, recent studies indicate that innovators often have no real incentive to bear the costs of active diffusion efforts (de Jong et al., 2015), such as easy-to-understand documentation or marketing. Social welfare losses result from this so-called diffusion shortfall (von Hippel, 2017; Franke & Lüthje, 2020). Further reasons user innovators hesitate to share their ideas in the first place are

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legal concerns, for instance, about their intellectual property (IP) rights or liability issues. However, sometimes producers are responsible for this diffusion shortfall as they frequently underestimate the potential of user innovations and, thus, do not adopt them (von Hippel, 2017; Bradonjic et al., 2019).

The diffusion of user-generated designs is both complex and exciting for innovation research. Unlike for most innovations, not only potential adoption barriers on the end user's side must be overcome but also those hindering user innovators from sharing their ideas. Therefore, in this conceptual paper, we provide an overview of factors that may prevent a diffusion of products designed for production in Fab Labs. We focus on factors that apply both, on the level of the product designers as well as on the level of potential adopters of products generated in Fab Labs. Thus, our contribution is threefold. In Sect. 13.2, we present voluntary payment methods that might incentivize user innovators to take on diffusion efforts. Next, in Sect. 13.3, we discuss how Fab Cities can help overcome legal concerns user innovators potentially deal with. In Sect. 13.4, we take a closer look at consumers and introduce methods that may be used to overcome potential adoption barriers. Finally, our contribution concludes in Sect. 13.5.

13.2 Monetary Incentives in Open Source

Users of products and services constitute an important source of innovation (von Hippel, 2006). There is a high number of documented examples showing that major first-of-type innovations originated from users (e.g., windsurfing, airplanes, the world wide web). In addition, there is a large body of studies showing that user innovation is not a rare but a rather frequent phenomenon in many different industries (von Hippel et al., 2012; Franke et al., 2016). User innovation is not limited to firms and technological professionals. Also, private households and citizens are in a good position to develop improved or completely new products (von Hippel, 2017). Cost-effective design and prototyping tools make it feasible for many household innovators to design and build new product solutions. These tools are now affordable and, even more importantly, easily accessible via Fab Labs (Wolf & McQuitty, 2013; Weller et al., 2015; Whitson et al., 2018). In addition, the internet facilitates the interaction between creative users in communities and dedicated development projects (Franke & Lüthje, 2020). Hence, households and citizens have the potential to become the backbone of the invention, design, prototyping, and manufacturing activities unfolding by and in Fab Labs.

Several research studies demonstrate that user innovation activities are triggered by other motives and expectations than innovation work carried out by firms. The main reason why users innovate is to find solutions for themselves that best fit their individual needs (von Hippel et al., 2011, 2012; de Jong & von Hippel, 2013; de Jong et al., 2015; Stock et al., 2015). Besides the expectation to benefit personally from the innovation, users are often motivated by several intrinsic and process-related benefits such as fun, altruism, or getting positive feedback from peers (Füller et al., 2008, 2009; Nambisan & Baron, 2009; Brabham, 2010; Füller, 2010). Users that are primarily driven by these self-rewarding aspects put less or even no attention to compensation or economic returns for their innovation effort. This is why most private innovators are willing to give up their intellectual property rights and to freely reveal their inventions to everyone (de Jong et al., 2015; von Hippel, 2017).

The self-rewarding character of user innovation work is both a curse and a blessing. It promotes the free revealing of ideas and product designs, but it also implies that user innovators have little incentive to drive a wide adoption of their innovations. After all, most benefits that motivate users to engage in innovation can be achieved without a broad diffusion. Furthermore, reaching a wider adoption is costly for the originators as it requires a dedicated effort to document the product designs so appropriately that others could rebuild them. Users would also need to invest resources to actively promote their inventions effectively and on a large scale. Consequently, self-rewarded innovators have been found to rarely engage in diffusion activities involving these physical costs (de Jong et al., 2015, 2018). This implies that user innovations may often fail to reach those potential adopters that may significantly benefit from them. This phenomenon that limits the potential impact of user innovation is often referred to as "diffusion shortfall" (von Hippel, 2017; von Hippel et al., 2017).

The question arises how the empirically documented problem of low levels of diffusion of user-generated product designs could be eliminated. One self-evident way to address this issue is to offer financial benefits to user firms and household innovators. Even though most users do not start to innovate because of financial considerations, the outlook of possible revenues might nonetheless motivate them to actively promote their ideas to others and to engage in practices that make it easier for others to adopt, build and use the innovations. If supporting a wider diffusion creates costs, innovating users may require financial returns to compensate for the costs that they personally incur.

Monetary returns for innovating users can be generated by adding a commercial path to the free and open-source model of Fab Labs. Like other online maker spaces for digital and physical goods, individual Fab Labs or networks of Fab Labs may seek to establish marketplaces where user innovators' property rights for their designs lie and through which a license price may be charged. These online platforms open easily accessible and low-cost paths to commercialization and ensure that users are directly compensated for taking the effort. However, establishing market models bear the risk of crowding-out the self-reward-oriented and intrinsically motivated innovation activities of user firms and households. It may have negative effects on Fab Lab communities in which open licenses, free revealing and mutual support constitute a very supportive context for the generation of innovative designs (West & Gallagher, 2006).

This is why other forms of financial compensation with a lower risk of losing the idea of an open-source community in which all ideas can be easily accessed, adapted, or even improved by others should be considered for user innovators. Systems based on voluntary payments are one interesting alternative to proprietary commercial models. Donations have been a very common practice in several areas, and tips given to service employees accumulate to substantial volumes (Azar, 2011). Voluntary payments to the originators of digital products are frequently used in open-source software and might transfer well to a Fab Lab context of open product designs (Natter & Kaufmann, 2015).

When thinking about voluntary payments, it is of particular interest to understand under which conditions models involving voluntary payment elements are more or less likely to generate significant and fair monetary compensation for the originators of product designs. Future research needs to investigate to what extent these drivers and inhibitors are relevant in the specific context of maker spaces and Fab Labs. The following factors seem to be of particular relevance:

Anchoring Kim et al. (2009) demonstrated in three field studies that the amount of voluntarily paid money in pay-what-you-want (PWYW) models depends on internal reference prices that customers use as an anchor. In the case of products manufactured in Fab Labs, customers could use the price of the next best commercial alternative as their internal anchor to determine the appropriateness of which voluntary payment. In this case, the average price of a similar product in stores would influence the paid price. However, it is also likely that customers of Fab Lab products would use the next-best free product designs that are offered for a prize of zero as their mental anchor. Obviously enough, this may significantly reduce the willingness to make considerable voluntary payments for product designs. We propose that future research should investigate how Fab Lab customers build internal price anchors and how the development of reference prices can be influenced by deliberately providing external reference prices. For example, one could investigate whether priming customers by simply asking them to think about how much the product would cost in the store leads to a higher voluntary payment.

Product Costs Different to the distribution of software, re-producing products is associated with variable costs. Therefore, product customers need to cover the costs of material and product manufacturing in the Fab Lab – even if the product design itself is offered for free. In this respect, the situation in most Fab Labs will differ from pure PWYW models commonly known in software. It would be very helpful to know how this mandatory cost-based price influences the willingness to pay the originator of a product design an extra tip. It might make a significant difference whether customers need to decide to pay voluntarily on top of a fixed price or rather decide whether to pay anything at all. On the one hand, paying voluntarily in pure PWYW models constitutes a more significantly perceived psychological effort than tipping the product designer in addition to a mandatory payment for production. This would imply higher voluntary payments in the context of Fab Labs. On the other hand, a fixed price reduces the customer rent and can therefore be expected to result in lower voluntary payments to the originator of the product designs. Research scholars should explore the magnitude of these opposite effects. Studies on the success of voluntary payment models in Fab Labs could contribute interesting differences to the studies that have been conducted on donation-based systems in free software.

Interestingly, the fixed price for covering a Fab Lab's production costs may also influence the internal reference price that customers develop in their heads. Customers may take the fixed price as an anchor when deciding the voluntary payment of the product design. In this respect, the two aspects of anchoring and non-voluntary product costs are partly interrelated.

Relationship to Fab Cities It has been repeatedly shown that the relationship between the payer and the provider of a product or service heavily influences the willingness to donate or tip. Consequently, a higher closeness usually leads to higher voluntary payments (Andreoni & Bernheim, 2009).

Fab Labs would need to enable customers who decide to make a product design a convenient online access to the facilities and machines. Ideally, the entire process of design scanning, product ordering and payment would happen via digital channels. While this online process is efficient, it constitutes a rather anonymous setting that could lead to a high psychological distance between customers and Fab Labs and, in turn, to rather low payments (Kim et al., 2014).

However, many customers of products generated and produced in Fab Labs may feel a strong connection to the basic objectives of a Fab Lab enriched economy. Fab Labs provide access to materials and production technologies to everybody allowing them to digitally design and produce solutions to their own needs. Therefore, the democratization of innovation is one of the key missions in most existing Fab Lab networks (Diez Ladera, 2016). Additionally, there are nuclei of maker communities of diverse inventors, designers, artists, and engineers which facilitates education, learning and innovation across domains. Fab Cities as well as several Fab Labs promote the idea of local production and a circular economy. All this indicates that customers should often develop a closer relationship to a Fab Lab than they usually do to a conventional retailer or online shop.

13.3 Legal Matters

In this chapter we discuss two exemplary legal matters that might hinder user innovators to share their ideas, namely, product piracy and liability concerns. These two are certainly not the only relevant legal matters, however, we picked them as we feel that they occur most frequently.

Product Piracy Concerns Free revealing of product designs is in contradiction to economic theory. Classic theory proposes that an innovator can hope to reap the profits associated with an innovation only if they manage to protect it by intellectual property rights (Teece, 1986). This is particularly important in markets for technologies or markets for designs in which licensing fees are the main source of revenue. The risk of uncompensated knowledge spillovers and uncontrolled generation of copies is very high for digital products (Peitz & Waelbroeck, 2006). Most notably, the insanely high product piracy and sharing of illegal copies of all kinds of media and software resulted in high financial losses for the software programmers, artists, and content creators. The risk of uncontrolled copying and sharing is also high for product designs in digital format (e.g., CAD files) which can be recreated by production technology accessible in Fab Labs.

Fortunately enough for user firms, independent designers, and household innovators, many product designs cannot be easily built by production technology that is commonly available, such as low-cost 3-D printers and other simple tools. More complex designs require more sophisticated equipment and support that is exclusively accessible in Fab Labs. Here, to avoid fraud, Fab Labs could, for instance, make sure that no pirated designs can be produced with their machines.

However, maybe the problem for user innovators is not the few end users copying their ideas secretly but the fear that a commercial company makes profit off it while they, being only a small fish in a shark tank, could do nothing about it. For this reason, the reliable and uncomplicated possibility to protect IP rights could not only lower the concerns of user innovators but also create a business model for Fab Labs. User innovators that could hire Fab Labs to protect the idea IP, while, in return, the Fab Lab – or Fab City as a brand – officially registers the rights, guarantees that plagiarisms cannot be illegally produced in any Fab Lab worldwide or assists with legal matters, such as when a large company is trying to steal the idea. Further research should, therefore, investigate whether such a service would lead to more user innovations being diffused and how much user innovators would be willing to pay for it.

Moreover, the provision of digital twins (Tao et al., 2018) for each product (thus guaranteeing the origin of design) could be beneficial and its implementation another business model for Fab Labs. Such a digital twin might play a key role for the offering or reselling of already produced designs on other platforms. Digital twins would also allow the user innovators to see what happened with their idea, meaning that it is possible to track the number of replicas made and where (e.g., a Fab Lab in Barcelona). Future research could, thus, investigate whether these statistics could work as an intrinsic motivation for user innovators. Moreover, if the digital twin is stored on a distributed ledger, it should be easily possible to pay the designer via micropayments over the ledger in the near future (Klein et al., 2022).

Liability Risk Digital twins cannot only guarantee a design's originality but also play an important role in terms of its warranty or liability issues. Liability in general is a big concern in terms of new products. In this context, user innovators might be afraid to share their designs as they do not want to be held responsible for damages. This might either be the case for designs that have not been tested several times already but also for designs that are technically solid but need a professional rework after laser cutting or 3-D printing it.

This, once again, offers a business opportunity for Fab Labs. They could, for example, offer user innovators to stress test their innovations. If approved by official experts, the product in return gets a Fab Lab seal, similar to the German "TÜV" certifications, handing of potential liability issues to Fab Labs. If a user innovation is not yet mature enough, they can give recommendations on product improvements so that, after some trial and error, a seal could be granted. The demand of such a service by user innovators and the potential importance of such a branding for end consumers should be examined in further research. With choice-based conjoint analysis, for example, not only the importance of such a branding but also the willingness to pay could be examined with potential consumers. A Fab City seal might have the potential to become a strong brand if it signals sustainability, local production, and assures users that no big companies, only user innovators profit from it. Analyzing the potential of this signaling effect is another interesting direction for further research.

13.4 Customer Adoption Barriers

Innovation diffusion, as defined by Rogers (2003), is the "(…) process by which an innovation is communicated through certain channels over time among the members of a social system." Diffusion in the context of Fab Labs refers to the aggregated adoption of digital product designs and their reproduction with the (open-source) production equipment available in the facilities.

Fast and wide diffusion processes require that innovations are useful to customers and represent a better alternative compared to existing products (Ram, 1987; Rogers, 2003). This creates a pro-change bias, meaning that consumers are open to change and have an interest in evaluating new products (Sheth, 1981). However, if consumers reject the innovation before really evaluating it, they will never fully realize its potential (Talke & Heidenreich, 2014). An innovation may have obvious advantages for its developers, yet potential customers initially tend to be less enthusiastic because the adoption of new products involves uncertainties (e.g., quality, reliability, safety) and often requires the customers to change their behavior. High perceived risks and adaptation costs are particularly prevalent in the case of high-tech novelties (Heidenreich & Handrich, 2015; Ram & Sheth, 1989). For example, the diffusion of green innovations is often sluggish. Products with a more favorable environmental impact often struggle to penetrate mainstream markets because their climate neutrality is often accompanied by deficits in performance which, in turn, forces the early adopters to change their usage behavior. For example, early models of electric vehicles involved a high cost in changed behavior as the maximum driving range with one battery load was very limited (Klein et al., 2020).

Ram und Sheth (1989) categorize the adoption barriers into two groups: functional (usage, value, risk) and psychological barriers (tradition, image), which are presented in Table 13.1.

Table 13.1 Overview of adoption barriers

Usage barrier:	• Not in line with current habits, routines, processes, or procedures
Value barrier:	• No significant added value, poor quality-to-price value
Risk barrier:	• Physical risk – Safety issues • Economic risk – Too little value for money, too high implementation costs, unclear value loss of product • Functional risk – Low reliability, performance, quality • Social risk – Negative feedback from peers, negative reputational effects
Tradition barrier:	• Innovation requires a cultural change • Incompatible with existing standards and norms
Image barrier:	• Simplistic negative perceptions of new technologies • Stereotypic views of innovators

In the following, we discuss potential functional barriers which are likely to be most relevant in the Fab City context.

High Perceived Functional Risk The perceived risk regarding the safety, reliability, and performance of products that are manufactured in Fab Labs is a key adoption barrier. Usually products are designed by firms, often established brand owners, that have built up a reliable reputation of generating high-quality solutions. If products are designed outside firms by individual professionals, hobbyists and amateurs, to be then produced in a rather unknown fabrication space, it is likely that potential adopters perceive a higher functional and economic risk. User innovations might be considered as amateurish and not tested extensively. In addition, potential customers can hardly evaluate the quality of the production process and quality control within Fab Labs. Some consumers might have more safety concerns about the statics of a chair they sit on than for a small play figure. Others, in contrast, are specifically afraid of the material of these small play figures as they have kids who might put them in their own mouths. As outlined in Sect. 13.3, these fears could be overcome with a trusted Fab Lab seal for risk-sensitive products in order to forestall potential consumer fears on safety, quality or performance.

Low Relative Advantage As most Fab Lab products will not be radical innovations, it is very likely that producers already offer a standardized alternative (e.g., drones). Therefore, a key mission for the Fab City Initiative is to highlight the unique selling points (USP) of locally manufactured products (e.g., customization, climate friendliness, “support your locals”, etc.) and to target potential barriers that hinder consumers to adopt this specific product in a Fab Lab. Furthermore, research activities should focus on investigating which products would win the most from individual customization, as these are more likely to be products consumers would prefer to adopt in a Fab Lab.

Misalignment with Current Usage Behavior Although the exemplary outlined USPs can be classified as relative advantages compared to traditional products, they might trigger usage barriers. Consumers are used to buying their products online and in stores that are close by or in the city center. Buying products now in Fab Labs is, therefore, not in line with their current habits. A consumer might have never been in a Fab Lab before, might not know how to find one or, worst, might never have heard of the Fab Lab concept at all. For this reason, it is important to create general awareness about Fab Labs and how to find them. Thus, it is crucial to overcome potential inhibitions to visit these (subjectively) unfamiliar Fab Labs. This could be done by, for instance, making events that address a wide target group. Here, the first contact with a Fab Lab in order to build trust is more of interest and less that every participant goes home with a Fab Lab product. Moreover, city planners should examine the best locations for these Labs. It could, for instance, be beneficial to build them next to supermarkets as a visit would not change customers' daily routines too much.

Another usage barrier might be the as of yet rather complex software needed to operate machines or to customize the product. Although, end users might already be familiar with the concept of mass customization (Piller, 2004), the number of potential options could lead to an information overload; also both UI and UX are, currently, unsuitable for the masses. Therefore, building easy to use (standardized) software and toolkits is a major task for the Fab City initiative. Furthermore, showcasing typical Fab Lab products in Fab Labs could be beneficial to consumers for a better understanding of the outcome. In time, the offer of services like production and rework on request should be considered, so that less tech-savvy consumers only must come in to pick up the product or get it delivered to their homes. This service could be an interesting business model for Fab Cities.

13.5 Conclusion

For a significant impact on the environment, Fab Cities must get a critical mass of citizens on board. On the one hand, enough user innovators need to be convinced to share their replicable designs with the community and, on the other hand, enough end users need to adopt them.

Obviously, the first incentive that comes to mind is monetary compensation for designers to overcome the current diffusion shortfall. We find that voluntary payments for open-source hardware is a very promising field of research since, unlike with open-source software, (micro-)payments for materials as well as wear and tear take place anyway. This open-source-hardware phenomenon might lead to more frequent and higher tips for designers and could, therefore, be the decisive point for some user innovators to share their ideas or enhance diffusion efforts. At the same time, all ideas remain open-source while there should be no increased economic risk for end-users, as there is no obligation to tip anything with the mentioned participative pricing mechanisms.

Furthermore, we suggest that Fab Cities, as independent authorities, should consider establishing a seal of quality and anchor of trust that bundles legal rights. For instance, by supporting user innovators with legal matters, such as IP protection or liability. This could constitute a new business model for Fab Cities to generate revenue streams and, finally, become self-sufficient. Although consumers will have to pay some extra fees for these services, they might be necessary to overcome adoption barriers and, consequently, support the diffusion of user innovations. In this context, future research should investigate if these commercial and open models could work in parallel and if they could even benefit from each other. Consumers might wonder why some products have a Fab City seal, while others have not.

Finally, giving general advice on how to address potential value barriers is difficult, as it is mostly very product-specific. However, communicating the fundamental USPs of local production can be supportive (e.g., customization, climate friendliness, "support your locals", etc.). Maybe some direct comparisons of popular Fab Lab products to their commercial siblings in terms of cost, quality, carbon footprint, etc. could be promising marketing activities. For some products, the time factor could be another USP. Imagine needing a specific spare part for your dishwashing machine where delivery takes 10 days vs. just going to a Fab Lab and printing it there. Further research should investigate how frequent such cases are and may utilize this example for an influence on/of marketing.

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