The Unexpected Sources of Innovation

De Onverwachte Bronnen van Innovatie
(met een samenvatting in het Nederlands)

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Chapter one

Introducing the unexpected sources of innovation

The past century is characterized by dramatic changes in innovation—reflected by both the rate of (technological) development and the contributing actors.

We set foot into space and recently even captured an image of a place where light cannot escape: the supermassive black hole at the center of our galaxy. We invented all means necessary for recording and consuming music, from magnetic tape to hi-fi speakers. And we developed computing and communication technologies that allow us to share across the globe all that can transpire online, to name a few examples of innovations developed in the past one hundred years (Akiyama et al., 2022; Berners-Lee et al., 1992; Engel, 1988). The rate at which innovation continues to disrupt is accelerating (Acemoglu and Restrepo, 2018), with some even concluding that we are in the Third Industrial Revolution (Greenwood, 1997; Liu and Grusky, 2013).

The impact on our daily lives is profound. Continuing with the example of communication technologies, we have entered an age in which citizens once regarded as only consumers are now active producers of content, labeled Web 3.0, and steer innovation on the web from their homes (Ritzer and Jurgenson, 2010). Extrapolating from this example, as (technological) developments continue to augment human skillsets, innovation is increasingly recognized to be done by a distributed set of actors previously thought incapable. That is, by individual citizens, end-users, and employees, sometimes in communities self-organized by these individuals. In the words of Eric von Hippel (2005): innovation is democratizing.

In this thesis, I study the implications of the democratization of innovation. I research the motivations and resource endowments permitting the development of innovations by individual citizens—both at their homes and workplaces—and when and how these innovations diffuse. Thereby, I shed light on the process of innovation brought about by actors not recognized in the traditional management and economic literature: the *unexpected sources of innovation.*

1.1. Innovation as a function of producer firms

Innovation, in this thesis, is defined as the development of goods, services, or other applications that add a distinctive function when evaluated in comparison with existing offerings in the (local) market. This definition deviates from the dominant view on innovation, which perceives the introduction to the market of such a good or service to be necessary in order for them to qualify as an innovation (Oslo Manual, 2005). The problem with such a view, however, is that it fails to account for any innovative activity that does not result in commercial sales; it focuses predominantly on innovation by "producer firms" (von Hippel, 2017, p. 80)—as very few individual citizens or employees trade their innovation for monetary compensation.

The dominant, producer-centered view on innovation is rooted in the Industrial Revolution. Rapid scientific developments introduced mechanization to production processes and, starting in Great Britain, contributed to changing social and economic arrangements (Owen, 1991). The function of production moved away from the homes of households and became confined within the boundaries of firms, with economies of scale making it impossible for citizens to compete with firms (Toffler, 1980). Intellectually, these developments were paralleled with a focus on the means used by firms to produce commodities (Marx, 1884) and innovations (Schumpeter, 1934) while solving a profit-maximization problem. Citizens were perceived to be passive consumers (Toffler, 1980).

1.2. The unfolding of a paradigm shift

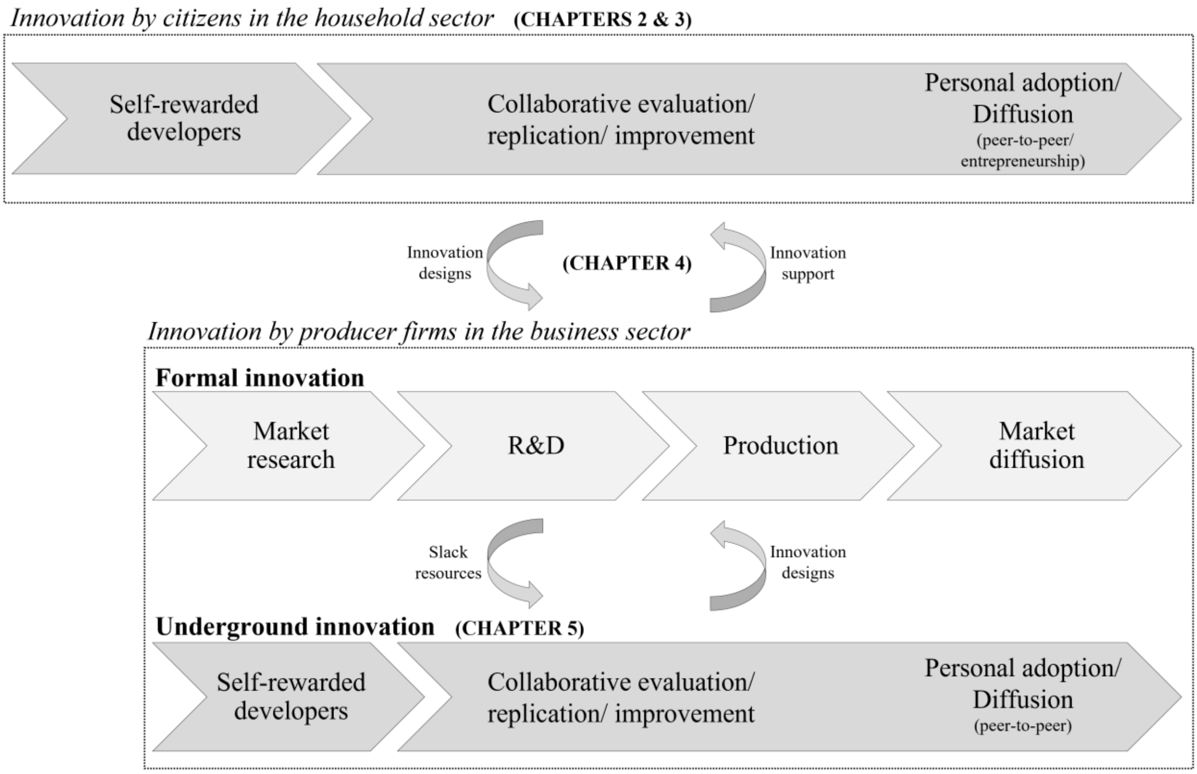
The decades following World War II, however, witnessed several intertwined trends opening new ways for individual citizens to address their needs without having to rely entirely on producer firms. Citizens became better educated and connected, facilitating their knowledge, absorptive capacity, and agency in more complex matters (von Hippel et al., 2012). The relative importance of immaterial goods characterized by zero marginal costs of production (e.g., software) increased relative to material goods—in some industries, taking away firms' benefits derived from economies of scale, which allowed them to grow competitive advantages in the preceding century (Rifkin, 2014; Ritzer et al., 2012). And new technologies assisting the production and diffusion of innovation, e.g., 3D printers or Web 3.0, became increasingly available to citizens at home (Rayna and Striukova, 2021). Together, these trends anteceded a growing capability of individual citizens to innovate and a paradigm shift in the academic literature addressing innovation (Baldwin and von Hippel, 2011).

Starting with the concept of user innovation (von Hippel, 1976; 2005), scholars recognized that, contrary to the traditionally accepted definition of innovation (Oslo Manual, 2005), innovations can be developed by individuals and make an impact without being traded on the market. These innovations are not developed for profit-maximizing purposes but because they satisfy a personal need of the innovator through their use-value (von Hippel, 2005) or the process of innovation, which may provide enjoyment or learning experiences (Raasch and von

Hippel, 2013b). By studying innovation beyond what is developed and traded on the market by firms, the academic literature unraveled that individual citizens can be active agents of change, inventing and disseminating products, services, or other applications that are functionally novel when compared to (local) market offerings—either at their private cost during their discretionary time at home (de Jong et al., 2021) or during their work time (Hartmann and Hartmann, 2023).

Many of these recent insights are summarized by von Hippel (2017), presenting a new paradigm for innovation recognizing the complementary contributions of producer firms and individual citizens. The not-for-profit innovations by citizens often precede (technological) trends explored by producer firms, as citizens do not face the uncertainty of consumer demand, which is relevant to profit maximization. Hence, citizens' innovations are more often than the innovations by producer firms at the leading edge of new markets and inspire firms' new product lines (Riggs and von Hippel, 1994). Producer firms, on the other hand, are endowed with more resources that they can employ to develop sophisticated solutions. For citizens to contribute innovations, they likely need support from producer firms (e.g., (freely) accessible tools or user-modifiable products). Hence, the complementarity between innovation by citizens and producer firms.

Figure 1.1. The new innovation paradigm



Notes: adapted from the new innovation paradigm as presented by von Hippel (2017).

1.3. Studying the new innovation paradigm

As the process and diffusion of innovations by citizens and producer firms are clearly distinct (de Jong and von Hippel, 2022), e.g., by their motivation or radicalness, the new innovation paradigm, visualized in Figure 1.1 above, opens a novel research agenda. I address this agenda, moving from the process of citizen innovation outside organizational boundaries (chapters two and three) to firms' interactions with external, innovating citizens (chapter four) to innovations developed by individual citizens at their workplaces within organizational boundaries (chapter five).

Chapter two: resources permitting innovation in the household sector. With the first study, I delve into the innovation process of citizens, i.e., the process of household sector (HHS) innovation (de Jong et al., 2021), and explore the role of resources. Even though citizens' resource endowments affect every facet of their lives, there have been few studies exploring how resources enter their innovation process. With a theoretical model based on Becker's (1965) seminal theory explaining citizens' allocation of time, I explain how citizens' income and discretionary time (as resources) affect their tendency to produce goods at home and the likelihood that these are innovative. I empirically test the hypotheses derived from the theoretical model using HHS innovation data from the United Arab Emirates.

Chapter three: a policy framework for household sector innovation. In the third chapter, I take a helicopter view to analyze what functions have been found to (regionally) enable HHS innovation and what policy measures have been suggested to support these functions. This analysis serves the purpose of conceptualizing a framework that can be used for more systematic policymaking. Although studies have proposed a range of measures to support innovation by citizens, these have had little impact in practice (Bengtsson and Edquist, 2022). As I show in chapter three, this can be attributed to inconsistencies and a lack of sensitivity to regional intricacies. I conducted an extensive literature review and expert interviews with scholars and policymakers knowledgeable of HHS innovation to create an ecosystem model accounting for the functions regionally enabling HHS innovation and suggested policy measures. I specifically take an ecosystem perspective, as such a perspective facilitates studying socio-economic phenomena characterized by interdependent functions requiring orchestration beyond market interactions (cf. Stam, 2015).

Chapter four: firm-hosted user innovation communities. In chapter four, I move down the framework visualized in Figure 1.1 to shed light on the interactions between innovating citizens and firms. Specifically, I focus on citizens who proactively create improvements and enhancements to firms' products. A powerful way through which a firm can benefit from citizens who innovate with the firm's products is by hosting an online user community that challenges the citizens to share their product innovations online (West and Kuk, 2016). However, little is known about the characteristics of citizens who managed to produce product innovations that are successfully adopted by the community—even though the adoption rate of product innovations in firm-hosted communities provides a valuable signal to firms about the potential customer demand for such innovations. I explore how citizens' professional experience with the product domain, motivation, and network position in the firm-hosted user community affects the adoption of the product innovations they developed and shared. To that end, I study the diffusion of citizen-developed improvements and enhancements to the Ultimaker 3D printer on Ultimaker's platform YouMagine—where users of the Ultimaker can freely share their designs.

Chapter five: underground innovation. Finally, I study how a democratized view of innovation implicates innovation within firms' boundaries. New insights into innovation by citizens also help explain their innovation processes in their roles as employees. As it appears, many employees engage in innovation activities for reasons comparable with HHS innovation. They do so during work time and under the radar of their management (Hartmann and Hartmann, 2023). I study this phenomenon by exploring underground innovation by employees at Ford Motor Company. Underground innovation describes the proactive initiation and development of innovations by employees without official company resources and that are unapproved, at least initially. Thereby, these innovations are often hidden from the organization. Various studies have reported underground innovations (Augsdörfer, 1996; 2005; Eicher, 2020) but lack an in-depth exploration of employees' motivations to innovate without their supervisors and managers knowing. These motivations, however, have serious implications for the extent to which managers observe underground innovations and can take advantage of them. In chapter five, I unravel the motivations characterizing underground innovations and link these to a broader set of project characteristics (e.g., what resources does an employee employ to produce an underground innovation) and outcomes (e.g., to what extent does the innovation diffuse throughout the organization).

Chapter two

The rich or the poor? Personal resources, do-it-yourself, and innovation in the household sector

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Abstract

Household sector innovation is significant in scale and scope. Thus far, it has been studied in isolation and with mixed evidence regarding the role of personal resources (consumers' income and discretionary time). We recognize that household sector innovation is embedded in the broader phenomenon of do-it-yourself (DIY) by consumers, as the literature reveals conceptual similarities, parallel motivations, and antecedents. The main distinction is that, whereas DIY goods may replicate existing products, household sector innovation is restricted to goods embodying a novel function. We explore if studying household sector innovation and DIY in an integrated framework helps to resolve previous inconsistent evidence on the role of personal resources. Based on a neoclassical model in which agents optimize their time allocation, we hypothesize that income and discretionary time positively relate to their DIY output, but—given that agents develop DIY goods—we hypothesize that income negatively relates to innovation. For discretionary time, we formulate a research question regarding its effect on innovation which we answer empirically. Our findings suggest that consumers with more personal resources derive more process benefits from DIY but that these benefits crowd out individuals' focus on the function of their objects, hence, the likelihood of developing innovations. Survey data from the United Arab Emirates (n = 2,728) confirm our suppositions, showing that the relationship between personal resources and household sector innovation is more refined than suggested by previous studies.

Keywords: household sector innovation; user innovation; do-it-yourself; prosumption.

1. Introduction

Household sector (HHS) innovation is the development by consumers of functionally novel products, processes, or other applications in their discretionary time without payment (von Hippel, 2017). Across a range of countries, the incidence of HHS innovation in consumer populations is generally found to be 4 to 6 percent, representing millions of consumers who spend billions of dollars developing HHS innovations (de Jong, 2016; von Hippel, 2017). Their creations, more often than the innovations by firms, enable new functions rather than incremental improvements (Hienerth et al., 2014; Riggs and von Hippel, 1994). An example of a groundbreaking technology resulting from HHS innovation is the first aircraft (Meyer, 2012). Thereby, HHS innovation is a source of venture creation at the edge of new industry emergence (Shah and Tripsas, 2007). HHS innovation is expected to rise because the production of immaterial goods (e.g., software)—which is more accessible to the public—gains importance as compared to material production (e.g., automobiles) (Ritzer et al., 2012). Furthermore, consumers increasingly have the competencies and tools to innovate for themselves (Fox, 2014). So far, researchers have explained HHS innovation by looking at antecedents such as gender or education, but this line of research is still in its infancy.

In a recent special issue in Research Policy, de Jong et al. (2021) recognized that HHS innovation is embedded in more general consumer behaviors aimed at self-production, like do-it-yourself (DIY), and recommended new research that accounts for this embeddedness. In our study, we follow up on this advice. DIY is done by individuals creating goods they think of themselves (Fox, 2014): to address personal needs, enjoy the process of design and home production, and/or express themselves (Xie et al., 2008). Like HHS innovation, DIY requires creativity, judgment, and skill as individuals are both engaged with designing and producing goods (Watson and Shove, 2008). With the availability of today's technologies, DIY activities can include traditional goods like furniture (Wolf and McQuitty, 2011) and complex products based on computer-aided design (Rajan, 2021; Rayna and Striukova, 2021). Following de Jong et al. (2021), the main difference between DIY and HHS innovation is the functional novelty of its outcomes—HHS innovations, by definition, enable novel functions (von Hippel, 2017), while DIY objects may be homebuilt versions of existing goods (e.g., Fox, 2014; Williams, 2004; Wolf and McQuitty, 2011).

Acknowledging the embeddedness of HHS innovation in DIY helps us to shed new light on the antecedents of HHS innovation. In particular, we focus on the role of personal resources (income and discretionary time) and answer the question of whether resource-rich or resource-poor people are more likely to develop DIY goods and HHS innovations. Previous evidence regarding the role of income has been mixed. Gupta (2013) and Praceus and Herstatt (2017) found qualitative evidence that poor individuals are more likely to innovate as they satisfy their personal needs in a context where alternatives are lacking. In contrast, Chen et al. (2020) found a positive correlation between income and HHS innovation. They argued that, at higher levels of income, individuals are better able to finance innovation tools and reach self-actualization by working on innovative projects. Concerning discretionary time, no previous studies about its association with HHS innovation have been done.

In this paper, we first explain that DIY and HHS innovation are truly overlapping concepts and conceptualize a framework in which HHS innovation is embedded in DIY. Next, we construct a neoclassical time allocation model to explore how personal resources impact DIY and HHS innovation in an integrated framework. Based on our model, we hypothesize that resource-rich people are more likely to develop DIY goods. An essential driver of this effect is that the rich derive more process benefits (e.g., enjoyment, self-expression) from DIY than the poor, who develop DIY goods predominantly out of economic consideration. We also anticipate that, given that people develop DIY goods, resource-poor people are more likely to develop goods with novel functions, hence, to be HHS innovators. For the poor, whose resource constraints may force them to find creative solutions for lacking market alternatives, missing functionalities are key to engaging in DIY—increasing the likelihood of coming up with truly novel solutions. We find confirmation for our hypotheses in a sample of 2,728 citizens of the United Arab Emirates.

Our contribution to the existing literature is threefold. First, the parallels we find between HHS innovation and DIY bridge two previously disconnected strands of literature. Integrating these strands of literature is paramount to a better understanding of HHS innovation in future work. Second, we find an empirical explanation for conflicting evidence about the role of personal resources in HHS innovation emergence, as reported in previous studies. We find that income and discretionary time are positively associated with DIY, but—given that DIY is observed—people with less income and discretionary time are more likely to develop functionally novel goods. Third, we connect HHS innovation to economic theory by applying a modified version of Becker's (1965) time allocation model. This provides a more in-depth account of the underlying mechanisms driving the effects of personal resources on DIY and HHS innovation than previous work (e.g., Chen et al., 2020) has attempted. We show that process benefits may be a key mechanism in this respect and can provide an (economic) rationale for people's decision to increase their DIY engagement when their income increases—even when this means an increase in their opportunity costs of not working.

2. Literature review

2.1. Household sector innovation

HHS innovations are important for economic and societal welfare. As HHS innovators are more likely than producers to innovate at the leading edge of markets—where demand is still too uncertain for established firms—they have a pioneering role in steering technological change (Baldwin et al., 2006; Hienerth et al., 2014). Societal welfare increases when HHS innovations diffuse. This can happen either through new venture creation (Shah and Tripsas, 2007) or when incumbent producers adopt the innovations by consumers. The latter occurred, e.g., in kitesurfing (von Hippel and Kaulartz, 2021). HHS innovation can give rise to competition, such as in the case of Linux versus Windows, but it can also give rise to goods that complement existing commercial offerings.

Consequently, both consumers and producers can benefit from HHS innovation. An example where this is observed is the gaming industry (Gambardella et al., 2017). Incumbent producers are, therefore, encouraged to facilitate and leverage knowledge developed by innovating householders (Gambardella et al., 2017; von Hippel, 2017).

Its high societal relevance has inspired scholars to study the antecedents of HHS innovation. So far, scholars have identified demographic factors such as gender (Fursov et al., 2017; Kim, 2015), competence-related variables such as education and technical work experience (see, e.g., von Hippel et al. 2012), lead-user characteristics (Franke et al., 2006), and personality traits such as openness and conscientiousness (Stock et al., 2016) as predictors of HHS innovation.

2.2. Who innovates: the resource-rich or the poor?

Researchers have also investigated the role of personal resources—in particular, the role of income. But the empirical evidence on its relationship with HHS innovation is mixed.

Chen et al. (2020) surveyed Chinese citizens and found a positive association between citizens' level of income and innovation. They suggested two explanations. First, based on Maslow's (1943) hierarchy of needs, Chen et al. (2020) argued that income positively affects people's pursuit of higher-order life goals (e.g., self-actualization) and that developing innovations can be part of such goals. Second, based on planned behavior theory (Ajzen, 1991), the authors argued that income might increase one's perceived behavioral control—i.e., how one perceives one's ability to execute the actions required to deal with prospective situations (Ajzen, 1991; Bandura, 1977; 1982)—which has been shown to enhance consumers' innovation activities (Hau and Kang, 2016). Income helps to secure access to innovation resources like design tools and (paid) assistance to support the innovation process, potentially increasing one's perceived ability.

However, these theoretical explanations do not seem compatible with related studies on HHS innovations developed by those who are deprived of personal resources (Gupta, 2006; 2013; Praceus and Herstatt, 2017; Rajan, 2021). Having documented thousands of innovations developed in India, Gupta (2006) recognized high innovation potential in lower-income groups. By strengthening ties between local villagers and the scientific community, Gupta (2006) witnessed an immense amount of local knowledge that, when diffused, led to numerous patents filed in India as well as in the US. Praceus and Herstatt (2017) even found that individuals at the bottom of the pyramid in India were more likely to create new solutions as compared to UK consumers, who focused more on incremental solutions. The mechanism that drives these resource-deprived people to be more innovative seems to be that, in order to benefit from innovation, they need to focus on the distinct function their creations fulfill and not on incremental changes or added luxury—as has also been advocated in the bottom-of-the-pyramid innovation literature (Prahalad and Hart, 2000).

These findings suggest a different interpretation of Maslow's (1943) hierarchy of needs in the context of HHS innovation than the interpretation by Chen et al. (2020). Observations at the bottom of the pyramid in India suggest that people's push for basic needs—innovating for necessity—results in the development of goods that add a novel function (i.e., HHS innovations) rather than the pursuit of self-actualization goals, observed more frequently under people living in high-income areas (Williams, 2008). Furthermore, evaluating the role of planned behavior theory, behavior is not only affected by perceived behavioral control (which might indeed be higher for people with more income) but also by intention—i.e., the motivation to engage in a particular behavior (Ajzen, 1991). Based on the hierarchy of needs (Maslow, 1943), the intention for behavior necessary for securing basic needs is higher than the intention for behavior in pursuit of higher-order needs. As innovating for necessity is more prominent at the bottom of the pyramid (Rajan, 2021), this creates ambiguity in whether income actually leads to a higher likelihood of HHS innovation when considering both perceived ability and intention as elements of planned behavior theory.

So far, we have only discussed the role of income. In surveys of HHS innovation, citizens' discretionary time has not yet been investigated as an explanatory variable. By definition, HHS innovation requires at least some discretionary time. However, whether and how increases in discretionary time affect innovation is unclear. Agrawal et al. (2018) studied the innovative activities on Kickstarter by a consumer sample (primarily students) in relation to their slack time. They found that the number of projects increased with consumers' slack time but also more dispersion in the quality of the innovative projects. Agrawal et al. (2018), however, did not investigate the dimension of functional novelty when evaluating the projects. Hence, it is unclear what the effect of discretionary time would be in the context of HHS innovation.

In summary, the literature is inconclusive about the association between personal resources and HHS innovation. As we explain hereafter, recognizing that HHS innovation is embedded in the broader concept of DIY helps to explain past incompatible research findings.

2.3. Do-it-yourself

We define DIY as the active design and production by consumers of products, processes, or other applications in their discretionary time without payment. In contrast to HHS innovation, DIY may result in functionally novel goods (Fox, 2014; Mauroner, 2017; Wolf et al., 2020), but not necessarily so (e.g., Williams, 2008; Wolf and McQuitty, 2011). Therefore, HHS innovations can be regarded as a subset of DIY, reflecting goods that enable a novel function.

The nature and scope of DIY have evolved quickly in the past few decades, accelerated by technological progress (Ritzer and Jurgenson, 2010). In essence, DIY is rooted in prosumption (Kotler, 1986; Toffler, 1980)—formally defined by Xie et al. (2008, p. 110) as "value creation activities undertaken by the consumer that result in the production of products they eventually consume and that become their consumption experiences". Futurist Toffler (1980) was early to identify three eras of societal progress (i.e., the agricultural, industrial, and information society) marked by subsequent 'waves' of prosumption: subsistence, industrial, and information-based. Fox (2014) summarized their main characteristics as in Table 2.1.

Table 2.1. Definition of subsistence, industrial, and information-based prosumption

	Subsistence prosumption	*Industrial prosumption*	*Information-based prosumption*
Definition	People grow what they eat and make what they personally need without regularly making purchases in a marketplace	People buy made-to-forecast kits of goods	People draw upon the read and write functionality of the Internet and digitally-driven design/manufacture to invent, design, and make goods that they think of themselves
Example	People building their own houses with local resources	IKEA furniture kits	Self-designed 3D printed objects

Source: Fox (2014).

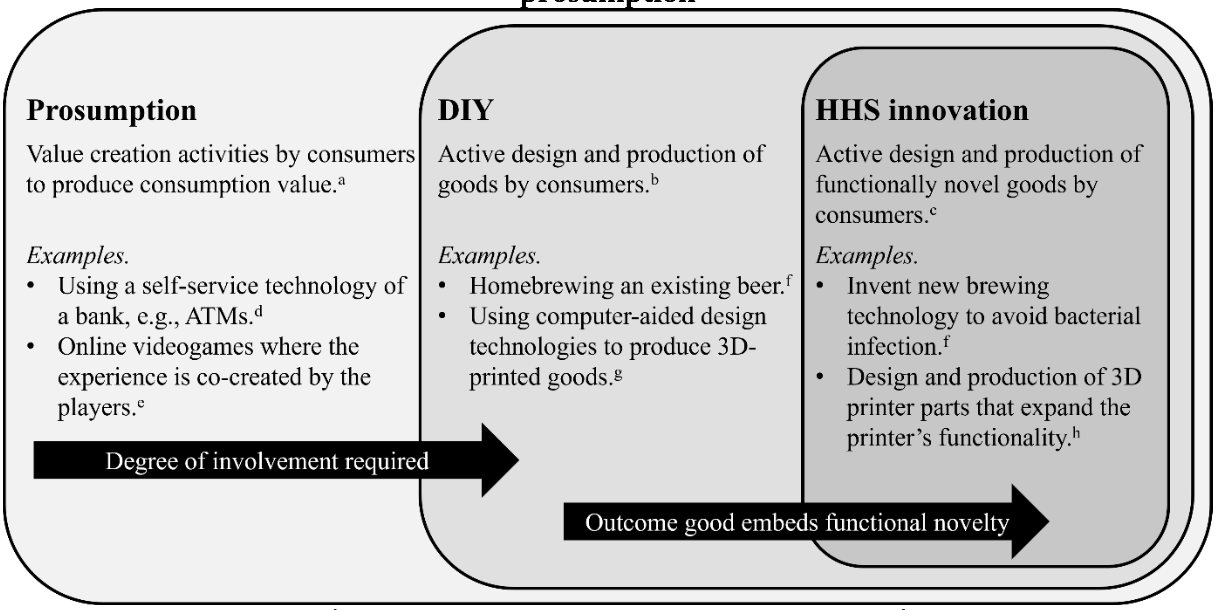
The industrial revolution introduced mechanization to manufacturing processes, implying that means of production became more concentrated (Toffler, 1980). Big firms increasingly engaged in production and shaped and satisfied the needs of passive consumers—whose production function was marginalized to rather minimal efforts such as cooking meals or putting together made-to-forecast kits of goods (Fox, 2014; Rayna and Striukova, 2021; Ritzer and Jurgenson, 2010). Thanks to the information revolution, individuals re-gained the possibility to take greater care of their own individualized needs (Dusi, 2018; Toffler and Toffler, 2006). Enabling technologies (such as Web 2.0 and additive manufacturing) have propelled a 'Third Wave' of prosumption (Fox, 2014), in which individuals generate and share digital content online (Ritzer and Jurgenson, 2010) and use these to produce physical goods at home (Belk, 2014; Rayna and Striukova, 2021). The re-emergence of the prosumer can be observed in a plurality of forms, including co-creation (in which consumers have an active role in the consumption/usage of goods, e.g., online videogames where the experience is co-created by the players (Prahalad and Ramaswamy, 2004)), co-production (in which consumers take over parts of the production process from producer firms, e.g., putting together Ikea furniture (Etgar, 2008)), and DIY.

What sets DIY apart is that it requires high, proactive involvement from consumers (Wolf and McQuitty, 2011; Wolf et al., 2020). DIYers apply their skills, knowledge, and judgment to produce goods they design and build themselves (Campbell, 2005; Watson and Shove, 2008). Partly because DIYers now have access to means of production that were formerly restricted to firms, DIY outcomes can compete with (and sometimes even outcompete) commercial offerings (Dellaert, 2019; Rayna and Striukova, 2021) and be a breeding ground for innovation (Wolf et al., 2020).

DIY encompasses a range of creative activities in which consumers develop products, processes, or other applications in their discretionary time. Modern examples are hackers—who reappropriate and redesign objects for other than their original purposes (Williams et al., 2012), and makers—who passionately engage in the production of new objects (Dougherty, 2012). What hacker- and maker-DIYers have in common is that they are both concerned with unique applications of complex technologies (Mauroner, 2017), for example, in 3D printing (Browder et al., 2019). This makes the connection between DIY and innovation more clearly visible (Fox, 2014, Hahn et al., 2016). Yet, 'classical' DIY activities such as home remodeling and furniture design (Collier and Wayment, 2018; Williams, 2004, 2008; Wolf and McQuitty, 2011) also fit our definition of DIY. Hence, we consider both classical and modern appearances of DIY, recognizing that both these different forms can result in functionally novel goods (Fox, 2014; Wolf et al, 2020), which would qualify DIYers as innovators.

Our conceptualization of HHS innovation as embedded in DIY and prosumption is visualized in Figure 2.1 below. To summarize, we consider HHS innovations a subset of DIY goods. HHS innovations are distinct from DIY goods by enabling a novel function (de Jong et al., 2021). Subsequently, we consider DIY a specific form of prosumption. Compared to other forms of prosumption (e.g., co-creation or co-production) (cf. Ritzer and Jurgenson, 2010), DIY requires a higher degree of involvement from the consumer (Wolf and McQuitty, 2011; Wolf et al., 2020)—the consumer both actively designs and produces the good (Campbell, 2005; Watson and Shove, 2008).

Figure 2.1. Conceptual framework of HHS innovation embedded in DIY and prosumption



Sources: [a]Xie et al. (2008), [b]Watson and Shove (2008), [c]von Hippel (2017), [d]Dusi (2018), [e]Prahalad and Ramaswamy (2004), [f]Wolf et al. (2020), [g]Browder et al. (2019), [h]Mulhuijzen and de Jong (2022).

2.4. Other similarities between DIY and HHS innovation

Beyond their relatedness, as visualized in Figure 2.1, the literature on DIY and HHS innovation identified similar trends explaining why the scale and scope of the phenomena have increased. DIY has grown with the emergence of the Internet, the availability of low-cost design tools (Fox, 2014; Rayna and Striukova, 2021; Ritzer and Jurgenson, 2010), and the shift from material to immaterial production (Ritzer et al., 2012). In these circumstances, an increasing number of people around the globe engage in DIY (Anderson, 2012; Hatch, 2013). Innovation scholars identified similar trends for HHS innovation: its importance increased during the past twenty years with the Internet, low-cost design tools, improved education, and improved connectedness of individuals (e.g., Chen et al., 2020; Stock et al., 2016; von Hippel, 2017; von Hippel et al., 2012).

Next, the reported motives for individuals to develop DIY goods and HHS innovations are highly similar. People generally develop HHS innovations for personal use-value (von Hippel, 2005) and/or for process benefits such as fun, self-expression, and learning (Raasch and von Hippel, 2013b). Similar motives apply to DIY (Xie et al., 2008), as seen in Table 2.2. Both strands of the literature rarely encountered commercial benefits as an essential motivator.

Table 2.2. Motives for do-it-yourself and household sector innovation

Motive	*Do-it-yourself*	*Household sector innovation*
Use/consumption benefits	Use-value of design[a,b,c,d]	Solution to a personal need[e,f]
	Lack of (good) alternatives[a,b,c,d]	
	To tailor a design to personal needs[a,b,c]	
Process benefits	To learn[b,h]	To learn or develop skills[e,f]
	For fun and enjoyment[a,b,c]	For fun and enjoyment[e,f]
	To help others[c]	To help others[e,f]
	To connect with a community[c,g,h]	
	Self-fulfillment[c]	
	Sense of control[c]	
Commercial benefits	For employment opportunities[h]	To earn money[e,f]

Sources: [a]Williams (2004), [b]Williams (2008), [c]Wolf and McQuitty (2011), [d]Wolf and McQuitty (2013), [e]de Jong et al. (2015), [f]Chen et al. (2020), [g]Collier and Wayment (2018), and [h]Kuznetsov and Paulos (2010).

The DIY literature has elaborated on motives in more detail. Yet, in studies of narrower forms of HHS innovation, we can also identify accounts of community interest and self-fulfillment motivations—for example, in studies of open-source software (Lakhani and Wolf, 2005) and online knowledge-sharing platforms (de Jong and Lindsen, 2021).

Acknowledging their high resemblance and the embeddedness of HHS innovation in DIY, we study the role of personal resources through a theoretical model that integrates the concepts of DIY and HHS innovation.

3. Hypotheses

To develop an in-depth rationale for the relationships between personal resources, DIY, and HHS innovation, we developed a theoretical model in which agents maximize utility over their time invested in working on the labor market, producing DIY goods, and leisure, and—given that they produce DIY goods—develop HHS innovations.

3.1. Theoretical model

We draw on Becker's (1965) neoclassical model developed to explain the time allocation of households over labor market participation, leisure time consumption, and home production. The premise of this model is that "households are producers as well as consumers" (Becker, 1965, p. 516). We adopt the fundamentals of Becker's model to explain the trade-off between agents' labor market participation and leisure time consumption but add engagement in DIY. Modern-day DIY goes beyond the home production activities described by Becker (1965) (e.g., cleaning) and has become a source of utility by itself because of its embodied process benefits (Xie et al., 2008). As we explained in our literature review, DIY can be self-rewarding; it has become a "morally uplifting way of utilizing spare time" (Atkinson, 2006, p. 1).

Our model proposes that agents maximize utility over four factors: consumption of goods bought on the market c_m, consumption of goods produced through DIY c_{DIY}, time spent on the labor market h_m, and time spent on DIY h_{DIY}. In doing so, agents are constrained by their total income I and discretionary time T, their ability to produce DIY goods $g(.)$, and the assumptions that consumption (c_m; c_{DIY}) and time spent (h_m; h_{DIY}) cannot be negative. Thereby, the maximization problem becomes as follows:

$$\max U(c_m, c_{DIY}, h_m, h_{DIY})$$

Subject to:

$$c_m \leq I$$

$$h_m + h_{DIY} \leq T$$

$$c_{DIY} \leq g(.)$$

$$c_j \geq 0$$

$$h_j \geq 0$$

To further specify the maximization problem, we use insights into the functional form of the utility function by Benhabib et al. (1990; 1991). That is, the agent's preferences are defined by equation (1) below:

(1) $$U = \ln(c_m + c_{DIY}) + A\ln(T - h_m - h_{DIY}) + b(w, \theta) \cdot h_{DIY}$$

In which $A \geq 0$ and measures the agent's preference for leisure, and $b(.) \geq 0$. We expand earlier economic work on time allocation by including the agent's preference for process benefits derived from DIY $b(w, \theta)$. Findings by Williams (2004; 2008) show that people's preferences for process benefits are not only determined by exogenous factors θ but also correlate with their level of income —such that $b'(w) > 0$ (in other words: $b(.)$ increases with wage w). Whereas people with low incomes more often develop DIY goods out of necessity (Rajan, 2021) for their consumption value c_{DIY}, people with high incomes are more often driven by self-actualization and enjoyment (Williams, 2004). Finally, in line with Benhabib et al. (1990; 1991), we assume that utility is marginally decreasing in these factors by taking the log over consumption and leisure time.

Before we can derive the effects of personal resources on DIY, we need to integrate the agent's constraints for the consumption of market goods c_m and DIY goods c_{DIY} into the utility function above. We simply propose that the agent's income I is determined by the product of the agent's wage w and labor hours h_m and that a share of the wage is spent on market goods δ $(0 \leq \delta \leq 1)$. Hence, the budget constraint for market consumption becomes: $c_m \leq \delta w h_m$. For DIY, "it could be argued that when consumers take part in production processes, they either contribute time or money (or a mix of both)" (Rayna and Striukova, 2021, p. 223), complemented by their competencies (Xie et al., 2008). Accordingly, the other share of the agent's wage $(1-\delta)w$ is used to buy raw materials for DIY. Along with hours spent on DIY h_{DIY}, this enters a Cobb-Douglas production function defining the agent's ability to produce DIY goods: $c_{DIY} \leq \varphi((1-\delta)w)^{\alpha} h_{DIY}^{\beta}$. Parameter φ reflects the agent's (technical) DIY competencies, while parameters α and β represent the marginal returns to monetary and time inputs, respectively. We can assume diminishing returns to both of these input factors ($0 < \alpha < 1$ and $0 < \beta < 1$) as studies on the broader phenomenon of home production (see, e.g., Gronau, 1977) and more closely related studies on HHS innovation (see, e.g., Baldwin et al., 2006) find diminishing returns to (time) investments in these activities. As Baldwin et al. (2006) explained, the probability that a particular design improves diminishes with resources spent as the design space surrounding a new opportunity matures. Thereby, the function over which the agent maximizes utility becomes:

$$(2) \qquad \max U = \ln(\delta w h_m + \varphi((1-\delta)w)^{\alpha} h_{DIY}^{\beta}) + A \ln(T - h_m - h_{DIY}) + b(w, \theta) \cdot h_{DIY}$$

Before we conducted a comparative statics analysis to evaluate the impact of personal resources on DIY, we concluded that an optimum exists. For relevant derivations, we refer to Appendix A1.

3.2. Personal resources and DIY

As a first indicator of how personal resources affect DIY, we study the effect of income. In our model, this implies evaluating the effect of a wage increase on the hours spent on DIY:

$\frac{\partial h^*_{DIY}}{\partial w}$. In Appendix A2, we find that the effect of income on hours spent on DIY is positive ($\frac{\partial h^*_{DIY}}{\partial w} > 0$) if and only if:

(3) $$(\alpha - 1)c_m + B_w X > (1 - \alpha)c_{DIY}$$

In which B_w is the first derivative of process benefits with respect to wage (i.e., $\frac{\partial b(w,\theta)}{\partial w}$), which we can assume to be positive—research has shown that the process benefits of DIY (enjoyment, self-expression, etc.) increase with income (Williams, 2004; 2008). X is a term simplifying the product of the agent's wage w and total consumption squared $(c_m + c_{DIY})^2$ divided by the first derivative of the agent's DIY Cobb-Douglas production function with respect to hours spent on DIY $\frac{\partial g(.)}{\partial h_{DIY}}\left(= G_{h_{DIY}}\right)$ (see Appendix A2). By definition of the model, X is positive, so the overall term $B_w X$ can be assumed to be positive as well.

Expression (3) shows that the higher the agent's process benefits obtained from DIY when income increases, the more likely a wage increase results in increased DIY production. Recall that $0 < \alpha < 1$, indicating diminishing returns to the share of the agent's wage invested in DIY. This implies that the term $(\alpha - 1)c_m$ is negative, while—on the right-hand side of expression (3)—the term $(1 - \alpha)c_{DIY}$ is positive. Effectively, $B_w X$ may compensate for the negative term $(\alpha - 1)c_m$, and this is increasingly likely the higher the agent's income.

In other words, though a wage increase might be better spent on market consumption when evaluating the consumption value of DIY goods versus market alternatives, the process benefits attached to developing DIY goods can outweigh this deficit and make DIY a favorable activity. The possibility of such a scenario is substantiated by literature on the so-called 'IKEA effect' (Marsh et al., 2018; Mochon et al., 2012; Norton et al., 2012). The 'IKEA effect' shows that people's valuation of DIY goods is often higher than their valuation of market goods, even when self-created products are amateurish compared to those made by experts (Norton et al., 2012).

Due to obtained process benefits, our model predicts that when income increases, the development of DIY goods becomes increasingly likely—even when agents face increasing opportunity costs of not working. Ceteris paribus, the positive effect of income on DIY hinges on the observation that process benefits B_w derived from DIY increase with income, as DIY becomes more of an uplifting way to spend time when not being driven by economic necessity. We hypothesize:

H1a: Individuals' development of DIY goods increases with their level of income.

As a second indicator of personal resources, we study the effect of discretionary time—being the agent's time free from obligations (von Hippel, 2017). In our model, an increase in discretionary time implies an upward shift in the budget constraint in $h_m + h_{DIY} \leq T$. One can think of different scenarios in which this would occur. For example, when children move out of their parental home and need fewer hours of care. Evaluating the effect of discretionary time T on the hours spent on DIY (i.e., $\frac{\partial h^*_{DIY}}{\partial T}$, see Appendix A3), we find that T has a positive effect on h^*_{DIY} if and only if:

$$\frac{\delta w}{\big((1-\delta)w\big)^{\alpha}} > \beta \varphi h_{DIY}^{\beta - 1} \tag{4}$$

Recall that we can assume $0 < \beta < 1$—so the term on the right-hand side is most likely smaller than one. Only in the case of an extremely competent creator, where $\varphi > 1$ (meaning that the agent can create more consumption value at home than by working on the market, disregarding process benefits from DIY), the right-hand side can be higher than one. A study by Watson and Shove (2008) on the role of competencies in DIY shows that such a scenario is unlikely when disentangling the assistance of tools and human competencies. Likewise, HHS innovation studies have shown that only a minority of consumers developing innovations are technically trained and/or have work experience in a technical setting, suggesting that for a representative agent $\varphi \leq 1$ (von Hippel, 2017).

The left-hand side equals one if the agent would face constant marginal returns to investments in DIY ($\alpha = 1$) and if the agent would spend as much income on raw materials for DIY as the agent would spend on market goods to consume directly. Empirical evidence on DIY shows that expenditures on raw materials used for DIY are generally significantly less than consumers' expenditures on market goods (cf. Mintel, 2006). Furthermore, we assumed $0 < \alpha < 1$. This means that the left-hand side is higher than one. Hence, we hypothesize discretionary time to have a positive effect on the development of DIY goods:

H1b: Individuals' development of DIY goods increases with their discretionary time.

3.3. Personal resources and HHS innovation

As discussed above, functional novelty determines whether DIY goods are also innovative. Combining expressions (3) and (4) with empirical evidence on HHS innovation, we formulate a hypothesis and a research question.

Concerning income, we hypothesize that—given that the agent develops DIY goods—income negatively relates to the likelihood that the agent develops a HHS innovation. To illustrate our argument, we consider the cases of people with very low incomes (the poor) and very high incomes (the rich). At very low incomes, process benefits can approach zero ($b(w, \theta) \to 0$): poor agents develop DIY goods (mainly) out of necessity (Williams, 2008). Then, the effect of income on DIY can be rewritten such that its direction is defined by $\frac{\alpha-1}{1-\beta}$ (see Appendix A2). The decision to increase or decrease DIY production is based entirely on the agent's marginal return to money α and time β invested in DIY. This implies that poor agents carefully assess where their resources are spent most productively when maximizing their utility—on DIY or by directly acquiring goods on the market. For the poor, it is use-value that matters, not process benefits.

For agents with high incomes, for whom process benefits do matter, the effect of income on DIY can be rewritten such that its direction is defined by $\frac{\alpha-1}{1-\beta} + \frac{B_w w(c_m + c_{DIY})}{(1-\beta)G_{h_{DIY}}}$ (see Appendix A2). The effect of income on DIY is likely to be positive in this case, as the latter term increases substantially with income (echoing our hypothesis H1a). Necessary for our hypothesis on HHS innovation, however, is that rich agents' decision to develop more DIY goods is driven by their anticipated process benefits—the use benefits only play a marginal role in their decision-making. In summary, our model implies that poor people carefully assess the consumption value of DIY versus market goods, while, for the rich, process benefits are more influential. Hence, we theorize a crowding-out effect: income can crowd out people's focus on the actual use-value of their DIY goods.

Especially for DIY goods with functional novelty (i.e., HHS innovations), use benefits will be high. HHS innovations enable their developers to perform functions that were not possible before, and that cannot be found in existing products sold on the (local) market (de Jong et al., 2015; von Hippel, 2017). As low-income DIYers more carefully assess the use-value of their self-provisioned good, while high-income DIYers focus on process benefits, we can expect that low-income DIYers are more likely to develop DIY goods that are innovative:

H2: Given that individuals develop DIY goods, the likelihood that their DIY goods are innovative decreases with their income.

This hypothesis is in line with the observation by Praceus and Herstatt (2017) that people in low-income areas are more likely to innovate because their resource constraints force them to find creative solutions to a lack of market alternatives. Our hypothesis is also consistent with observations that some people in affluent environments keep tinkering with personal designs or software without any consumption need in mind (cf. Hann et al., 2013; Lakhani and

Wolf, 2005) and that, for some consumers, process benefits alone are sufficient to compensate for their development efforts (Raasch and von Hippel, 2013b).

Next, concerning discretionary time, intuitively, we would expect a similar, negative effect on developing HHS innovations. However, previous research findings and our theoretical model leave room for miscellaneous interpretations, and for this study, we formulate a research question about the relationship between discretionary time and HHS innovation.

Recall that the effect of discretionary time on DIY is positive if: $\frac{\delta w}{((1-\delta)w)^{\alpha}} > \beta\varphi h_{DIY}^{\beta-1}$ (expression (4)). We hypothesized this expression to hold since people's expenditure on market goods δ is generally much higher than their expenditure on raw materials used for DIY $(1-\delta)$, and their technical competencies are generally not such that they produce more consumption value at home as compared to what can be acquired on the market ($\varphi \leq 1$).

Studying expression (4) in light of HHS innovation, we know that HHS innovation connects with the expression through the agent's (technical) competencies φ. HHS innovators do not resemble the general population of citizens but are a subsample that is better educated and has more technical work experience (see, e.g., von Hippel, 2017; von Hippel et al., 2012;). Hence, our intuition is that the competencies of HHS innovators are significantly higher than those of an agent representative of the general population—i.e., $\varphi_{HHS} > \varphi$—implying that, for HHS innovators, the right-hand side of expression (4) is higher. This can result in a situation where the right-hand side of expression (4) exceeds the left-hand side. Then, an increase in discretionary time, for HHS innovators specifically, would be associated with less time invested in the development of innovations. However, neither from our theoretical model nor from empirical studies can we unambiguously hypothesize such a negative effect.

Empirical studies, to date, provide no clear guidance on the difference in φ when comparing HHS innovators to the general population. Therefore, with the other parameters on the left-hand side (δ; α) and right-hand side (β) of expression (4), we cannot exclude the scenario that, also for HHS innovators, the left-hand side exceeds the right-hand side. Furthermore, as we explained in section 2.2, there have been no studies that directly study the relationship between discretionary time and HHS innovation, and even the related study by Agrawal et al. (2018, p. 1056) shows that the effect of "slack time on innovative outcomes is ambiguous". Two opposing mechanisms drive their ambiguous results: slack time (1) can cause innovators to be less selective when screening out ideas—decreasing the quality of ideas—but (2) allow innovators to spend more time on improving ideas—facilitating the quality of ideas (Agrawal et al., 2018).

Altogether, our theoretical model and past studies do not allow for the formulation of an unambiguous hypothesis regarding the effect of discretionary time on HHS innovation. We feel that this is a matter to further explore empirically and, instead, formulate the research question:

RQ: Given that individuals develop DIY goods, how is the innovativeness of their DIY goods related to their discretionary time?

4. Data

4.1. Sample

We tested our hypotheses on a sample of consumers in the United Arab Emirates (UAE). Since the discovery of oil and follow-up investments by local and foreign investors, the country has had a booming economy and a rapidly growing population. With an estimated population of nearly 10 million citizens in 2020, the population sky-rocketed if we compare this number to the total of 2.3 million people inhabiting the UAE in 1989.

UAE's citizens vary in their levels of income and discretionary time, providing us with a suitable context for our research. Only an estimated 10% of today's population consists of locals (Emirati), while around 90% comes from abroad. These include a minority of prosperous laborers (e.g., engineers, managers, researchers, and advisors) from Western countries (e.g., Europe, Russia, North America), a middle class of workers from the Middle East (e.g., Jordan, Egypt, Oman) and India and Pakistan, and a substantial group of contract workers from Asian countries including Sri Lanka, Philippines, and (again) India and Pakistan. In our discussion section, we reflect on the advantages and disadvantages of our research context.

Our data collection was sponsored by the UAE's Prime Minister's office as part of a scientific study to measure HHS innovation and identify policy implications. The data were collected by NR Research, a local marketing research company in Dubai, by means of computer-assisted telephone interviewing. NR obtained our initial sample with a random number generator covering cell phones and landlines. This method ensures that each citizen has an equal chance of ending up in the sample (Malhotra and Birks, 2017). We recognized that contract workers have scant leisure time, so most telephone interviews were attempted in the later evenings and during the weekends.

In advance, we trained NR's workforce by introducing them to the fundamental concepts of our study (i.e., DIY, HHS innovation) and gave feedback on a series of test interviews. In the introduction to each survey, the interviewer indicated that the research was done on behalf of the Prime Minister's office. The interviewer then checked if the respondent was at least 18 years old. In particular, the interviewer asked to speak to the person aged 18+ in the household whose birthday would come up first—allowing us to naturally randomize the sample.

Over four months, contact attempts were made with 18,005 UAE citizens. In total, 6,902 citizens remained out of reach—meaning no answer after five attempts, no reply, or voicemail—or were less than 18 years old. Another 8,102 citizens were unwilling to take the survey. Ergo, we obtained responses from 3,001 UAE citizens. Concerning our variables of interest, however, we faced missing values, especially for income. After the listwise deletion of such cases, we ended up with a dataset of 2,728 citizens—making the response rate 15.2% (or 24.6% of those we had reached).

4.2. Identifying DIY goods and HHS innovations

We applied screening questions described by de Jong (2016) that collectively determine whether consumers developed a DIY good, and, if yes, whether their DIY good is innovative. The same questions have been used in surveys in over ten countries (von Hippel, 2017).

Individual householders tend to associate innovation with high-tech and are usually ignorant about what innovation entails. Accordingly, the survey script did not ask for 'innovations' but offered a range of specific cues proof-tested in previous studies (de Jong, 2016; Kuusisto et al., 2013): computer software; household items; transportation and vehicle-related; tools and equipment; sports, hobby, and entertainment; children and education; healthcare and medical; and other.

Our interviewers introduced the survey as follows: *"My next questions are about what you do in your free time. During this time, you may engage in various creative behaviors, I will give some examples."* Then they read out the first cue, "*computer software by programming original code*", and asked, *"In your free time, did you ever create this in the past three years?"*. Next, the other cues (household items, etc.) were offered one by one (cf. de Jong, 2016). If respondents said 'yes' to any cue, they had potentially developed a DIY good. In case they could mention several examples, we asked them to focus on their most recently developed case to obtain a random sample of creations that were still on top of the respondents' minds (Malhotra and Birks, 2017). Next, to avoid false positives, we added a screening question: we explicitly checked if the respondent had created the good for their job or because their employer had asked for it. This excluded any creations that belonged to the business sector.

Next, we asked two screening questions to check whether a reported DIY good is also innovative. First, respondents themselves indicated if they could have bought a product with similar functions on the market. If yes, their creation was considered a DIY good but not a HHS innovation with an embodied novel function. Second, respondents described the developed good and explained what was new about it (open-ended question). Two coders independently reviewed the answers to rate the (lack of) functional novelty. Specifically, they assessed whether the DIY good was 'new' given that the product and its functionality did not clearly exist already. The DIY good was considered to be no HHS innovation when at least one of both coders indicated that some novel function was lacking. In case of doubt, for example, when the open-ended description was insufficiently detailed, we followed the respondent's assessment of whether the DIY good was innovative. The kappa statistic was 0.83, indicating good inter-rater agreement (Landis and Koch, 1977).

Respondents were considered to have produced DIY output in case they developed at least one good outside their work hours in the past three years; this applied to 239 respondents (8.8%). Examples of reported DIY goods were *"I built my own device to irrigate gardens. There's nothing new except the way it looks."* (tools and equipment; DIY good but not coded as innovative because a similar product was available on the market), and "*A decorative bedside lamp. I wanted to do one myself since the materials were available. It was my own style, you cannot find it on the market."* (household item; coded as DIY but not as innovative because the coders did not see a novel function enabled by the bedside lamp).

Respondents were considered to be also HHS innovators when they had developed at least one good that was not yet available on the market, and their description indicated functional novelty; this applied to 123 respondents (4.5%). Examples of reported HHS innovations were *"I hold camels and created a medicine for drying inflammation in the pores of my camels' heads. It cleans the pores, and it is made of natural products."* (health and medical) and *"A car engine with a design different from all current engine systems. Fuel efficient and easy to repair, and the number of engine parts is much lower than regular engine parts."* (transport and vehicle-related).

In the rest of the survey, we collected data about the respondents' income, time spent at work (to proxy their discretionary time), and a range of control variables discussed hereafter. Our approach to distinguishing HHS innovations within a broader category of DIY goods deviates from past studies, which ignored reported cases without functional novelty. Past studies considered DIY a nuisance (e.g., Chen et al., 2020; Kim, 2015; von Hippel et al., 2012) but here we regarded lack-of-functional novelty as an interesting source of variance, enabling us to analyze differences in factors associated with DIY goods versus HHS innovations.

4.3. Variables

Table 2.3 shows the variables we used in our analyses. Effectively, 8.8% of our sample had created a DIY good, and 4.5% had created a DIY good that included a novel functionality—a HHS innovation. A frequency of 4.5% is in line with the frequencies encountered in other national surveys (von Hippel, 2017).

Table 2.3. Variables

Variable	*Description*	*Mean*	*SD*
DIY output	In the past three years, respondent created a good in the respondent's discretionary time (0 = no, 1 = yes)	.088	.283
HHS innovation	In the past three years, respondent created a good with functional novelty in the respondent's discretionary time (0 = no, 1 = yes)	.045	.208
Income	Respondent's monthly income in 1,000 Dirham (AED)	9.398	10.439
Discretionary time	Respondent's estimated discretionary time per week, in hours (computed as 168 -/- 56 (assumed sleeping time) -/- reported time for work	71.622	23.931
Gender	Respondent was (0) male or (1) female	.247	.432
Age	Respondent was (1) 18-24 years, (2) 25-34 years, (3) 35-44 years, (4) 45-54 years, (5) 55 years or more	2.547	1.068
Collective household	Respondent lived in a collective household (0 = no, 1 = yes)	.247	.432
Technical education	Respondent had a technical or science degree, or accreditation in a technical skilled trade (0 = no, 1 = yes)	.305	.460
Technical work experience	Respondent had work experience in a technical job or profession (0 = no, 1 = yes)	.321	.467
Education level	Respondent's best educational attainment was (1) none, (2) primary school, (3) secondary or tertiary school, (4) bachelor degree, (5) master degree or higher	3.517	.899

Notes: n = 2,728. SD = Standard Deviation.

Income was measured in thousands of dirhams (AED), the UAE's local currency. Discretionary time available was estimated in hours per week. We calculated the respondents' discretionary time by subtracting from 168-week hours: self-reported work hours (time spent weekly on a job or business) and an assumed 56 sleep hours.

Other variables in Table 2.3 are control variables. We included demographic factors (gender, age) as well as technical education and experience, and education level, as these are relevant antecedents of HHS innovation (de Jong and von Hippel, 2022; von Hippel, 2017) and DIY (e.g., Williams, 2008; Wolf and McQuitty, 2011). Notice that only 25% of the respondents were female. This reflects the dominant presence of temporary contract workers in the country, who are generally males. We also added a variable if the respondent lived in a collective household, which is common in the UAE. Individuals living in collective households may be constrained in physical space to engage in DIY and innovation.

5. Findings

The correlations between our variables are shown in Table 2.4. Concerning our variables of interest, DIY output and HHS innovation are positively related (r = .701) as an artifact of how we collected our data. Also, our independent variables, income and discretionary time, are modestly and negatively related (r = -.163), which justifies estimating their association with DIY output and HHS innovation separately (income and discretionary time cannot be considered reflective indicators of a single personal resource construct).

The correlation coefficients raise no concerns for multicollinearity. In the regression models presented hereafter, variance inflation factors (VIFs) are within acceptable limits, as the highest VIF in our models is 1.84. In general, when VIFs < 10, multicollinearity is not considered problematic, and when VIFs < 2.5, multicollinearity is not regarded to play any role (Malhotra and Birks, 2017).

Table 2.4. Correlation matrix

	1	2	3	4	5	6	7	8	9
1 DIY output									
2 HHS innovation	.701**								
3 Income	.147**	.093**							
4 Discretionary time	.063**	.009	-.163**						
5 Female	.036	-.006	-.118**	.389**					
6 Age	.065**	.041*	.448**	-.041*	-.043*				
7 Collective household	-.091**	-.055**	-.299**	-.136**	-.091**	-.202**			
8 Technical education	.113**	.090**	-.271**	.016	-.044*	.169**	-.108**		
9 Technical work experience	.126**	.097**	.252**	-.076**	-.090**	.127**	-.083**	.642**	
10 Education level	.139**	.099**	.419**	.062**	.126**	.256**	-.278**	.311**	.249**

Notes: n = 2,728. Pearson correlations are shown. **p < .01; *p < .05.

5.1. Regression results

To test our hypotheses, we estimated a sequential logit model. Sequential logit models allow for studying the effects of explanatory variables on the probabilities of passing a set of transitions (Buis, 2013). In our study, the first transition is the probability that individuals developed a DIY good. The second transition is the probability that someone with a developed DIY good also developed an innovation. We included income, discretionary time, and all control variables in our model estimation: see Table 2.5.

The overall model fit is good (Wald-χ^2 = 124.24 with df = 8, p < .01). As indicated by the first transition, our regression shows a significant positive effect of income and discretionary time on developing a DIY good (p < .01)—confirming hypotheses H1a and H1b.

Table 2.5. Sequential logit regression of DIY output and HHS innovation

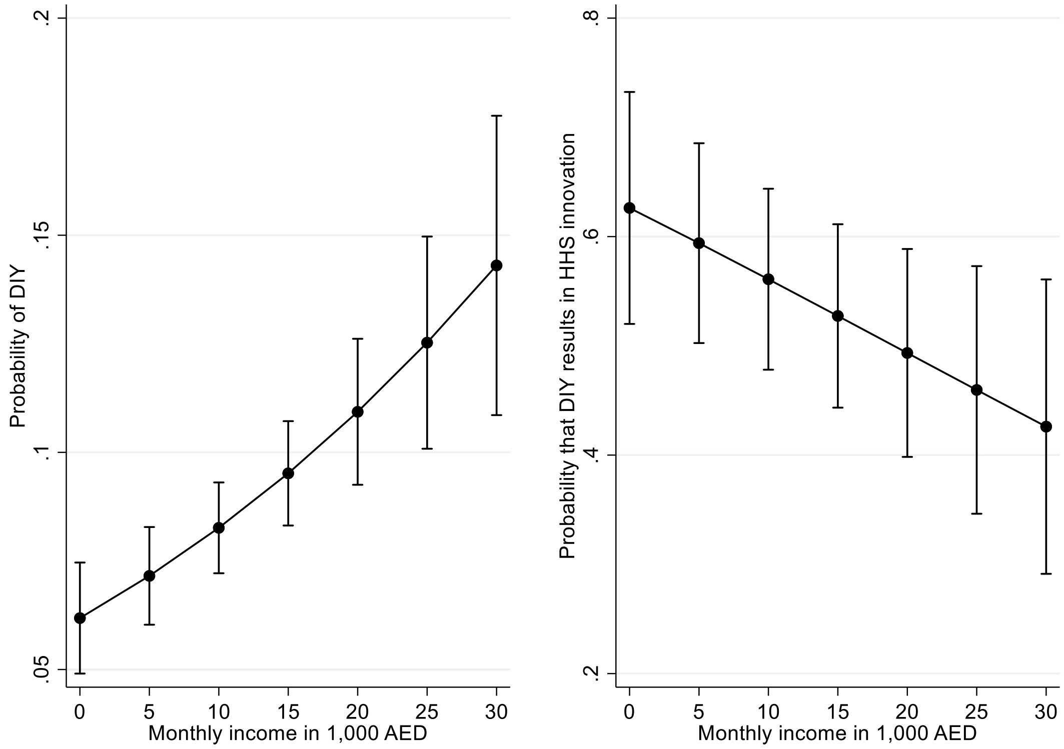
Step 1. dependent variable: DIY output		
Baseline value:	.0876**	
Marginal effects:	*dy/dx*	*SE*
Income	.0024**	(.0006)
Discretionary time	.0011**	(.0003)
Female	.0098	(.0130)
Age	-.0037	(.0053)
Collective household	-.0236	(.0139)
Technical education	.0057	(.0149)
Technical work experience	.0484**	(.0162)
Education level	.0248**	(.0074)
Step 2. dependent variable: HHS innovation		
Baseline value:	.5636**	
Marginal effects:	*dy/dx*	*SE*
Income	-.0067*	(.0031)
Discretionary time	-.0041*	(.0017)
Female	-.0976	(.0854)
Age	.0014	(.0310)
Collective household	-.0381	(.1135)
Technical education	.0281	(.0820)
Technical work experience	-.0334	(.0822)
Education level	.0140	(.0460)
Model fit:		
Wald-χ^2 (df)	124.24 (8)**	
Observations	2,728	

Notes: Average marginal effects (dy/dx) are shown. Robust standard errors (SE) in parentheses. Two-tailed significance: **p < .01, *p < .05.

Focusing on the second transition, estimating the likelihood that someone with a DIY good created an innovation, we observe that this is negatively affected by income and discretionary time ($p < .05$). Hence, the results confirm hypothesis H2, while the answer to our research question is that, when more discretionary time becomes available, the likelihood of a DIY good being innovative diminishes. Figures 2.2 and 2.3 show the effects we found in more detail.

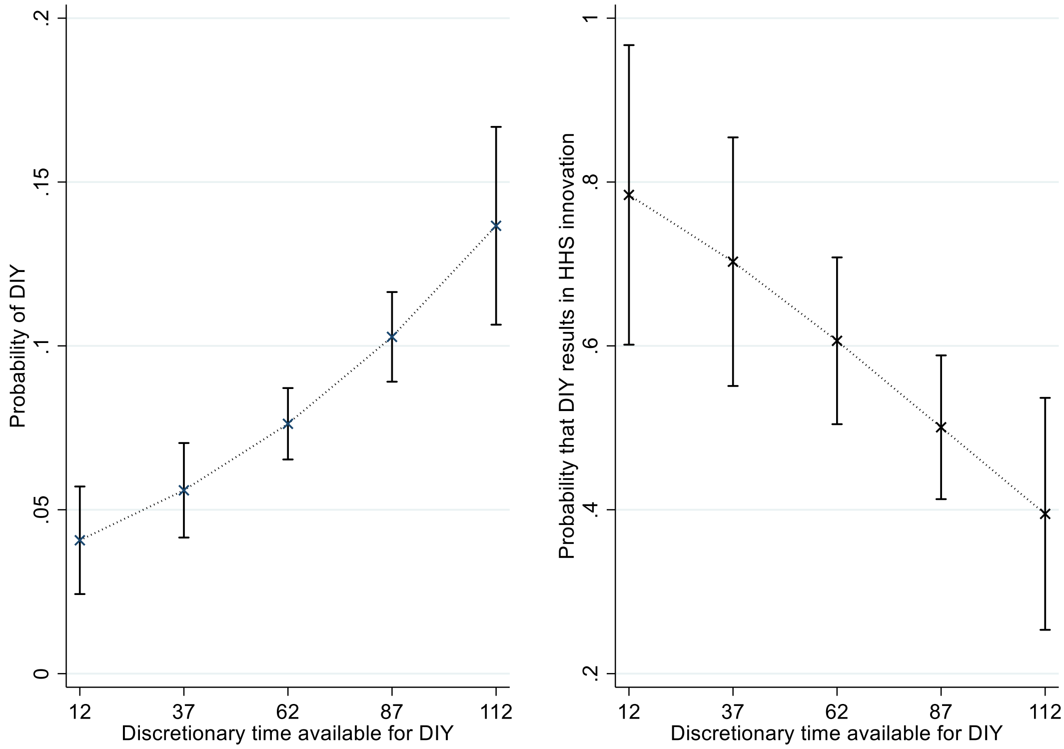
Figure 2.2 visualizes the positive effect of income on DIY output, with the probability of DIY output being around 6% for the lowest incomes to almost 15% for the highest incomes in our data. Given that a DIY good has been developed, the effect of income shows the opposite for HHS innovation. We see that a DIYer's probability of developing a HHS innovation is over 60% for those with low incomes but around 42% for those earning the highest income.

Figure 2.2. The probability of DIY output and HHS innovation for different levels of income



Notes: Predicted probabilities are shown with 95% confidence levels.

Figure 2.3. The probability of DIY output and HHS innovation for different levels of discretionary time



Notes: Predicted probabilities are shown with 95% confidence levels.

A similar pattern prevails for the effects of discretionary time (see Figure 2.3). The probability of DIY output is just below 5% for severely time-constrained people—having 12 hours of available discretionary time per week—while it is around 14% for people having 112 hours of available discretionary time per week. The probability that a DIYer develops an innovation is just below 80% when the DIYer only has 12 hours available per week, while this probability drops to 40% for individuals with the most discretionary time. As an artifact of how the data were collected, we speculate that respondents with a lot of discretionary time have less work experience. Accordingly, we suspect these respondents to have fewer (technical) competencies learned on the job that can be employed to self-provision goods, decreasing the probability of HHS innovation. Evidence of this potential mechanism is also provided in Table 2.4, which shows a significant negative correlation between discretionary time and technical work experience. With our theoretical model, such a mechanism could not have been hypothesized as we did not endogenize the agent's (technical) competencies.

Next, since our approach deviates from previous studies of HHS innovation, we explore the association between income, discretionary time, and HHS innovation when we would ignore its embeddedness in DIY. We estimated a simple probit model (see Table 2.6), as has been done in previous studies.

Table 2.6. Probit regression of HHS innovation

	Dependent variable: HHS innovation	
Baseline value:	.0451	
Marginal effects:	*dy/dx*	*SE*
Income	.0009*	(.0004)
Discretionary time	.0002	(.0002)
Female	-.0037	(.0093)
Age	-.0025	(.0041)
Collective household	-.0109	(.0100)
Technical education	.0074	(.0107)
Technical work experience	.0246*	(.0115)
Education level	.0151**	(.0056)
Model fit:		
Wald-χ^2 (df)	57.7 (8)**	
Observations	2,728	
Pseudo R^2	.051	

Notes: Average marginal effects are shown. Robust standard errors in parentheses. Two-tailed significance: **p < .01, *p < .05.

Table 2.6 is well in line with earlier HHS innovation studies. Chen et al. (2020) found similar results in their study of Chinese citizens—i.e., a positive association between income and HHS innovation. Discretionary time has not been investigated before, but Tables 2.5 and 2.6 suggest that no relationship with innovation would be found unless the embeddedness of HHS innovation in DIY is considered.

5.2. Robustness checks

As a robustness check, we ran the sequential logit model reported in Table 2.5 with an additional set of control variables. This set of controls, first, included the respondents' access to the Internet. Fox (2014) argued that individuals' ability to engage in DIY is likely to be limited when they have poor internet access. Similarly, HHS innovation scholars have also stressed the importance of the Internet (von Hippel, 2017). Second, we controlled for the respondents' nationality to account for the fact that many of the UAE's citizens come from abroad. We added dummy variables indicating whether respondents were expats from a Western country, an Arabian country, India, Pakistan, the Philippines, Sri Lanka, another Asian country, or another non-Asian country to control for the main immigrant groups within the country. None of the conclusions drawn from our results in Table 2.5 was affected.

Next, we estimated an alternative Heckman probit model with selection instead of a sequential logit model. We specified DIY output as the dependent variable in the selection equation and HHS innovation as the dependent variable in the main equation, then included income, discretionary time, and all control variables as predictors. The model was identified because technical work experience and education level were related to DIY output but not to HHS innovation. Our estimates were very similar, with a significant positive effect of income and discretionary time on the likelihood that one develops DIY output ($p < .01$) and a negative effect of income and discretionary time on the likelihood that one develops an innovation ($p < .05$).

Finally, we recognized that the responses to our survey could have been selective. Although we did not have an up-to-date sampling frame with national coverage, the UAE's Prime Minister's office did provide us with their best estimates of population statistics that enabled us to compute weight variables. We re-estimated our sequential logit model with two weight variables that make the sample more representative of the population according to these best estimates. The first weight variable we constructed using statistics on gender, age, and emirate of residence (Abu Dhabi, Dubai, Sharjah, or the Northern Emirates). The second weight variable we constructed based on nationality (UAE, Arabian, Western, India, Pakistan, Philippines, Bangladesh, other Asian, other non-Asian). Our weighting scheme and the results of the weighted sequential regression analyses can be found in Appendix B of this thesis.

6. Discussion

The contribution of this paper is threefold. First, we expand the HHS innovation literature by connecting the concept to the literature on DIY. Following de Jong et al.'s (2021) call, we recognized important parallels: HHS innovation and DIY describe the active production of goods, where individuals design and create goods by themselves. Both are increasingly observed due to similar trends (e.g., availability of low-cost tools), and continued growth is expected. Also, both concepts are driven by similar motives that can be aggregated to use benefits/consumption value (e.g., to satisfy personal needs) and process benefits (derived from engaging in DIY/innovation regardless of the outcome; such as enjoyment, learning, self-actualization) (Chen et al., 2020; de Jong et al., 2015; Kuznetsov and Paulos, 2010; Williams, 2004; 2008; Wolf and McQuitty, 2011; 2013; Xie et al., 2008). Finally, we identified as the main distinction that HHS innovations are marked by functional novelty, so that HHS innovations are a subset of DIY goods developed by individuals in the household sector.

The second contribution is that HHS innovation's embeddedness in DIY helps us to understand better when and how HHS innovations emerge. Specifically, we recognized previous mixed claims about the role of personal resources in HHS innovation and, based on Becker (1965), developed a time-allocation model that helps to explain how personal resources affect the development of DIY goods and HHS innovations. We hypothesized that resource-rich people are more likely to develop DIY goods (as they derive more benefits from the DIY process), while—given that DIY output is realized—people in low-income groups are more likely to develop DIY goods with functional novelty (as the actual consumption value of DIY goods matters more for their decision to engage in DIY). Specifically, the mechanism in our theoretical model that drives the positive effect of income on DIY (process benefits) illuminates that wealthy individuals may develop DIY goods even when the actual use-value of these goods is very low. Such behavior has, e.g., been observed for groups of hackers contributing to open-source software—who are generally relatively wealthy (Hann et al., 2013) and can decide to do so purely for fun without ever using the software that they contribute to (Lakhani and Wolf, 2005). Individuals with fewer resources, however, are less triggered by process benefits and require more use benefits to engage in DIY. As functional novelty results from an individual's focus on the actual use of the individual's good, the resource-poor are more likely to create innovative goods.

For discretionary time, our model did not allow us to formulate an upfront hypothesis about its effect on innovation, but, similar to the effects of income, we found a positive effect on DIY output and a negative effect on HHS innovation. A potential explanation can be that individuals who spend more discretionary time on DIY spend less time on the labor market and, thereby, develop fewer (technical) competencies to employ when self-provisioning goods—leading to less innovative outcomes.

Our findings clarify the previous mixed evidence on the role of income. If we would ignore DIY and simply estimate a regression of HHS innovation on individual-level antecedents (Table 2.6), we find a positive relationship. This is entirely in line with Chen et al.'s (2020) survey of Chinese citizens. In contrast, if we would develop case studies of individuals producing goods for themselves and then explore the characteristics of those who develop goods with functional novelty, we would identify low-income people (see step 2 in Table 2.5). This is essentially the kind of data considered in studies by Praceus and Herstatt (2017), Gupta (2013), and Rajan (2021). Concerning the question posed in the title of our paper, we conclude that resource-rich people are more likely to engage in DIY, but within the population of DIYers, it is the resource-poor who are relatively more innovative in their development outcomes.

As a third contribution, we connect the literature on DIY and HHS innovation to economic theory. Becker (1965) described households not only as consumers but also as production facilities. Rational choice economists usually regarded work (including the development of DIY goods) as an inherent disutility, which is hard to synthesize with the motives and, in particular, process benefits discovered later in DIY and HHS innovation studies. Consequently, some economists struggled to explain the positive effect of income on engagement in DIY using traditional economic theory (Brodersen, 2003). By modeling the process benefits of DIY, our theoretical model can explain how income can positively impact DIY—even when individuals face higher opportunity costs of not working when their income increases.

As a final remark, by broadening its empirical scope and providing evidence that DIY is related to innovation—important for economic growth and societal welfare (Gambardella et al., 2017; von Hippel, 2017)—one can also consider our study a contribution to the DIY literature. We did a large-scale study on individuals that employ personal resources to create goods. Our data show that DIY goods encompass the development of tools and equipment, household items, sports-, hobby- and entertainment, and much more—suggesting that studies of DIYers that only focus on home remodeling and furniture design (e.g., Williams, 2004; 2008) can be broadened. Our findings underline Fox's (2014) theoretical propositions about DIY and innovation. By recognizing today's context of connected and empowered consumers and applying a corresponding definition of DIY (including classical and modern forms), we could link DIY with the development of functionally novel goods.

6.1. Implications for theory

The implications of our study are multifold. Our reconceptualization of HHS innovation as a subset of DIY redefines the position of HHS innovation in the broader literature on consumer behaviors aimed at self-provisioning. Based on a thorough literature study, we developed a conceptual framework (see Figure 2.1) that can assist future studies in carefully addressing the scope of HHS innovation. As we have shown in this paper, doing so is crucial to disentangle the effects of antecedents on the design and production of goods by consumers (i.e., DIY) from the effects of antecedents on the likelihood that consumers are innovative.

An obvious first step is to expand our approach to other antecedents, including gender, education, technical work experience, lead-user characteristics, and personality traits (e.g., Fursov et al., 2017; Kim, 2015; Stock et al., 2016). Similar differences between DIY output and innovation may be hypothesized. For example, when it comes to personality traits, Stock et al. (2016) applied a stepwise approach to investigate how the ideation versus development of HHS innovations is related to individuals' Big Five traits. They found that ideation is associated with openness to experience while development is associated with being introverted and conscientious, and that personality traits required for HHS innovation are often not found within a single person. Although Stock et al.'s (2016) paper had a different focus, their results underline the possibility of antecedents having diverse effects related to various self-production efforts.

Continued work along these lines will also help to detect more relevant antecedents. Our findings regarding discretionary time illustrate this. To our knowledge, we were the first to explore its role in HHS innovation. From a classical regression approach (Table 2.6), we would have concluded that discretionary time is not significant. However, our two-step sequential logit model revealed a positive relationship with DIY and a negative one with innovation. This more fine-grained insight would have remained hidden if we had disregarded the embeddedness of HHS innovation in DIY.

Future work might, of course, also find that some antecedents operate very similarly when disentangling DIY and HHS innovation. This would be an important insight too. Researchers may then want to study these particular antecedents in relation to consumer engagement in DIY alone. This will save them the extensive budgets required to screen HHS innovations from survey data (cf. de Jong, 2016).

Finally, we suggest future work to continue exploring the role of (discretionary) time in detail. As mentioned in section 2.2, Agrawal et al. (2018) found consumers' slack time to positively affect the number of innovative projects they launched on Kickstarter but also to increase the dispersion in the quality of these projects. Our findings somewhat echo these observations, as our data indicate a positive effect of consumers' discretionary time on DIY but a negative effect on the likelihood that their DIY efforts lead to innovative outcomes. The relationship between time and innovation is complex—this also stems from a parallel strand of literature in the business sector that we were notified of, where employees' available slack time was found to be non-linearly related (inverted U-shape) with innovation indicators (Nohria and Gulati, 1996)—and deserves further attention. Our study suggests that it might be worthwhile studying the role of skills learned on the job that consumers may (not) employ when they develop goods and how these skills are affected when consumers decide to spend more discretionary time on DIY at the expense of their work hours.

6.2. Implications for practitioners

The insights derived from our study have implications for practitioners, in particular commercial firms and public policymakers.

Firms can benefit from innovating consumers, e.g., by absorbing their innovations to bring to the market for general sale or learning from the need-information revealed by consumers' innovations (von Hippel, 2017). At a minimum, producers should monitor householders' innovation activities, as HHS innovations can complement or compete with their offerings (Gambardella et al., 2017). Our study provides directions on how HHS innovators can be identified. If a producer cannot identify consumers who are developing goods in their discretionary time (as is the case for most household items, tools, and equipment), a broad search will be needed. As casting a wide net requires substantial resources for screening, focusing on resource-rich individuals would be recommended to increase the odds of detecting innovations—although the producer would also find many goods developed for process benefits, with low actual use-value. In contrast, if a producer can a priori identify a group of DIYers relevant to the company's products (such as in communities of sports, hobbies, entertainment, medical, healthcare, software, or vehicle-related products), we would recommend paying more attention to resource-constrained individuals within these communities, in order to increase search efficiency.

For policymakers, researchers have suggested interventions like sponsoring online knowledge-sharing platforms (de Jong and Lindsen, 2021), maker spaces (Halbinger, 2018), open-source intellectual property rights like creative commons licenses (von Hippel, 2017), and increasing a population's general access to the Internet (Fox, 2014). Our study implies that policy interventions will be more effective when targeted at those deprived of resources.

Beyond that the additionality of timesaving and/or tool-enabling interventions (e.g., platforms, maker spaces), in general, is likely better for poor people, our findings show that providing additional personal resources to wealthy beneficiaries will make them develop relatively many goods without functional novelty. Assuming that particularly HHS innovation (and not DIY) has positive societal welfare effects (Gambardella et al., 2017; von Hippel, 2017), in situations of limited policy budgets, support for individuals with low income and/or discretionary time would be merited.

6.3. Limitations and future research

Finally, our study has limitations that create additional research opportunities beyond the suggestions we have provided already.

First, our study should be replicated with other samples. The context of the UAE was suitable to test our hypotheses because the country has a population with high differences in income and discretionary time (local Emirati and Western immigrants versus immigrants from Asian countries mainly involved in services and construction work). As such, our sample included both people living at first-world and third-world standards—matching our objective to shed new light on conflicting evidence regarding the role of income, which was reported in relatively affluent (Chen et al., 2020) and deprived countries (e.g., Gupta, 2006; Rajan, 2021). We point out that our interest was not to provide population estimates of HHS innovation (as done in previous studies, e.g., von Hippel (2017) or de Jong and von Hippel (2022)). Nevertheless, because citizens from another (first-world) country will likely show less variance in terms of resources (with the potential consequence of weaker correlations between resources, DIY, and HHS innovation), we believe replication studies are necessary to test our study's external validity. For such studies, we recommend cross-country surveys or designs in which resource-rich and resource-poor people are sufficiently present.

A second limitation is that we did not have a sampling frame in which the demographic data of prospects were known. In principle, our sampling method with a random number generator avoids sampling issues (Malhotra and Birks, 2017). Our findings were also consistent in robustness checks with weighted data, and overall, we found no evidence that selection bias distorted our analysis. Yet, we cannot exclude that our sample has been somewhat selective, especially in low-income groups. This is an argument for replication studies with sampling frames in which the distribution of prospects across demographic variables is known—so that the remaining selection bias can be controlled econometrically.

Overall, we conclude that embedding HHS innovation in a broader set of consumer behaviors, particularly DIY, helps us understand in what circumstances HHS innovations emerge.

Chapter three

The household sector innovation ecosystem: A framework and policy implications

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Abstract

After a decade of research on household sector innovation, studies revealed that citizens around the globe continuously develop functionally novel goods at their private cost in their discretionary time. These goods can help overcome (local) challenges and be a source of economic value-creation by inspiring new lines of producer products or opportunities for entrepreneurship. Citizens, however, also face challenges in developing and diffusing innovations. This legitimizes policy interventions, but an integral overview of actors and factors influencing household innovation is missing. We propose an ecosystem approach to provide an overview of factors that matter most, accounting for the fact that household innovation also has a regional dimension that policymakers can intervene on. Based on an extensive literature review and 13 expert interviews, we conceptualize an ecosystem framework of eight key elements that enable the development and diffusion of household innovations. We apply this framework to map policy measures suggested in previous studies. Our framework enables more systematic studies of household sector innovation and policymaking that takes into account regional subtleties and interdependencies.

Keywords: household sector innovation; innovation ecosystems; user innovation; innovation policy.

1. Introduction

Empirical data indicate that around five percent of the world population develops household sector (HHS) innovations: goods developed at citizens' private cost in their discretionary time that add new functions compared to commercial products (Chen et al., 2020). HHS innovations have benefits for societal welfare, as they provide individuals and their communities with solutions better tailored to local needs (von Hippel, 1994), complement or compete with existing market offerings (Gambardella et al., 2017), and help create new businesses at the leading edge of markets (Shah and Tripsas, 2007).

The processes through which citizens develop and diffuse HHS innovations differ from innovation by producer firms in the business sector (von Hippel, 2005; 2017). As opposed to producer firms, citizens have perfect information about the needs that their new products will solve. However, they may lack the solution knowledge and tools required to make goods comparable to a professional standard (Mulhuijzen and de Jong, 2022)—for which HHS innovations often look like rough prototypes. Furthermore, whereas producer innovations are typically driven by consumer demand (Rothwell, 1992), most HHS innovations are developed in the absence of commercial incentives (Tabarés and Kuittinen, 2020). Citizens, first and foremost, solve their own problems or simply enjoy the process of innovation (Chen et al., 2020; von Hippel, 2017).

These differences imply that policy challenges of HHS innovation differ from the business sector. First, there is an imbalance in citizens' need and solution information. Producer firms possess superior technical knowledge and tools required to solve certain problems, but lack accurate information on what citizens want, i.e., need information (von Hippel, 1994). For citizens, it is the other way around: they have superior need information but lack technical know-how and tools, i.e., 'solution information' (von Hippel, 1994). Second, the absence of commercial motives creates a 'diffusion failure' (de Jong et al., 2015): citizens innovate for themselves, hence, do not anticipate a benefit from disseminating their innovations so that other people can benefit. Consequently, HHS innovations diffuse less often than is desirable for societal welfare (de Jong et al., 2015; 2018). Together, these differences justify policies supporting HHS innovation development and diffusion (as we will explain in more detail later).

Over the past decade, researchers proposed numerous policies for HHS innovation—e.g., subsidizing maker spaces (Fox, 2014) or creative commons (Potts et al., 2021)—but a framework to map these policies and an integral overview is still missing. Moreover, insights into HHS innovation are based on national surveys, while innovation processes and outcomes of citizens are often tied to local geographical contexts (Hossain, 2016; Seyfang and Smith, 2007). These research gaps have inhibited systematically studying the (regional) policy implications of HHS innovation. Here, we address these gaps by deploying an ecosystems perspective. Ecosystem frameworks help to identify regional strengths and weaknesses when it comes to enabling certain outcomes (Stam and Spigel, 2016) and are suited to analyze socio-economic phenomena that are propelled by interdependent factors requiring orchestration beyond market interactions, as is the case for innovation in general (Teece, 1992). Hence, we will conceptualize the first ecosystem of HHS innovation by systematically categorizing the elements that matter for its development and diffusion and provide an overview of the policies that can be deployed.

The concept of ecosystems originated in biology to describe interactions between organisms and their physical environment. This line of thinking has also been applied in the context of producer innovation to describe elements relevant to technological development (Edquist and Johnson, 1997; Lundvall, 1992; Nelson, 1993) or innovations brought about by entrepreneurs (Kebebe, 2019; Stam, 2015; Stam and Spigel, 2016). In these contexts, ecosystems are defined as sets of interdependent elements governed in such a way that they enable innovation (cf. Stam, 2015). Ecosystem perspectives have proven especially valuable for business sector innovation policymaking. As knowledge recombination is often at the heart of innovation (Schumpeter, 1934; 1939), interactions between different actors and factors are a major facilitator (Xiao et al., 2022)—with many of these being non-market interactions. Hence, for formulating innovation policy for the business sector, studying actors' non-market interactions matters too. Though its relevant ecosystem elements will differ, the same arguments apply to HHS innovation. Deploying an ecosystem perspective allows us to study the relevant regional market and non-market elements that enable HHS innovation—with the non-market elements probably being even more important than in the context of business sector innovation, as commercial intentions and outcomes are less common in HHS innovation (von Hippel, 2017).

More specifically, our contribution is twofold. First, by conceptualizing the first ecosystem model for HHS innovation, we provide an overview of all relevant factors enabling HHS innovation, which can be used to study HHS innovation more systematically in the future. Previous studies, e.g., de Jong et al. (2021), only highlighted parts of this ecosystem. To facilitate future quantitative assessments of regional HHS innovation ecosystems, per element, we suggest indicators that can be measured quantitatively. More systematic, regional studies of HHS innovation ecosystems will help to map a specific region's strengths and weaknesses when it comes to enabling HHS innovation and contribute to more context-specific policies. Second, by classifying all HHS policy recommendations that have been given in the past in accordance with our ecosystem model, we identify elements where continued research (on policies for HHS innovation) is especially warranted.

Based on an extensive literature review and 13 expert interviews with academic scholars and policy experts, we find eight fundamental elements affecting HHS innovation. In the institutional environment, we find (1) rules and regulations, (2) cultural norms and values, and (3) social capital. As facilitators, we find (4) human capital, (5) innovation tools, (6) producers and industry, (7) (online) platforms and workshops, and (8) general resources and infrastructure. The existing HHS innovation literature has suggested a range of policy measures but these are not equally distributed over the ecosystem framework. Especially, policies aimed at supporting the elements of cultural norms and values and social capital are underdeveloped. Moreover, our analysis of policy measures shows that a lack of ecosystem-thinking has led to inconsistent policy advice.

2. Theory

2.1. Household sector innovation

HHS innovation is the development by citizens of functionally novel products, services, or other applications in their discretionary time without payment (von Hippel, 2017). Consider the invention of the dishwasher (Shah and Tripsas, 2007):

"In 1893, Josephine Cochrane unveiled an innovation at the Chicago World's Fair: the first truly functional dishwasher. A prominent socialite, she had grown tired of her servants' tendency to break her 17th century fine china and began to wash the dishes herself (Casey, 1997; Fenster, 1999). She reportedly said 'If nobody else is going to invent a dishwashing machine, I'll do it myself' (Lemelson Center, 2004). She subsequently formed her own firm, Cochran's Crescent Washing Machine Company, to manufacture the machines, primarily for sale to hotels and restaurants" (Shah and Tripsas, 2007, p. 123).

As can be seen from Table 3.1, the presence of HHS innovators in countries' populations is substantial; seemingly small percentages represent millions of innovating citizens. Naturally, not all HHS innovations are at Josephine Cochrane's dishwasher level. HHS innovations are often rough prototypes not suitable for direct trading on a market (Mulhuijzen and de Jong, 2022).

Table 3.1. Innovation frequency in the household sector

	Average of 10 European countries (n = 10,351)[a,*]	Canada (n = 2,021)[b,^]	China (n = 5,000)[c]	UAE (n = 2,728)[d]	South Africa (n = 1,096)[e]
Innovation frequency	6.6%	5.6%	2.1%	4.5%	2.5%

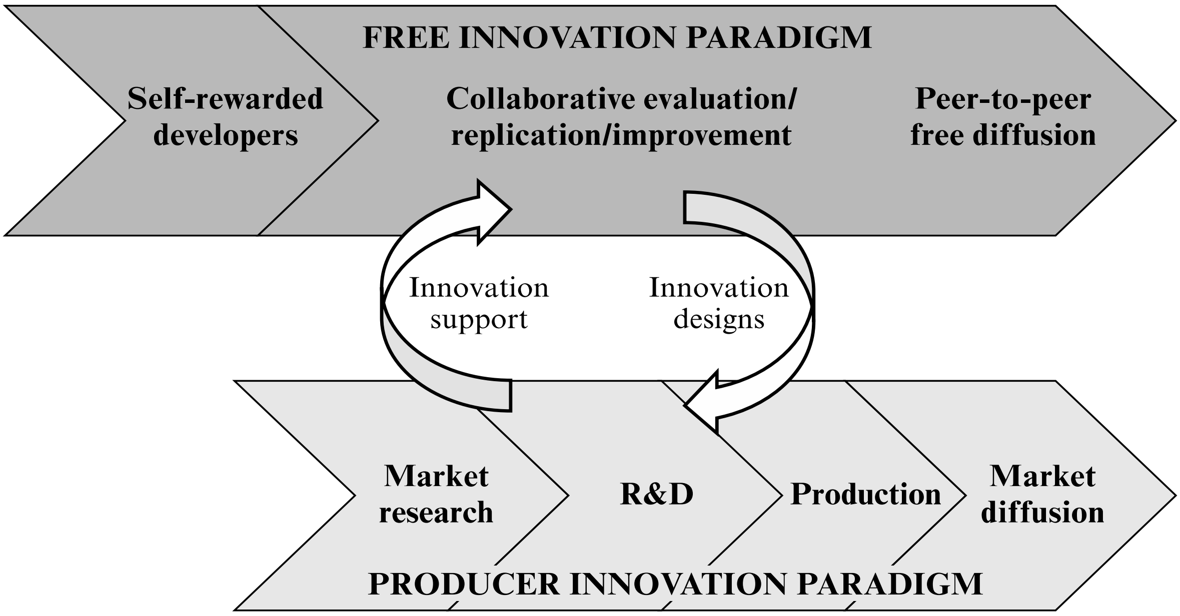
Notes: data from [a]Søndergaard and Thøgersen (2021), [c]Chen et al. (2020), [d]Mulhuijzen and de Jong (2023), and [e]de Jong et al. (2023); [*]average of Germany, the Netherlands, Denmark, Finland, Italy, Spain, Poland, Hungary, France, and the UK; [^]the frequency is based on innovations driven by personal need motives only.

Other examples of HHS innovation include the development of open-source software (Lakhani and Wolf, 2005) and healthcare applications (Oliveira et al., 2015), such as an app that can be used to monitor the glucose levels of Type 1 diabetes patients from a distance (von Hippel, 2017). As the examples symbolize, the most prominent reason for citizens to innovate is a personal need that cannot be satisfied by existing market offerings (von Hippel, 2005). Other reasons include learning or developing new skills, for fun and enjoyment, or helping others—while commercial motivations (making money) are relatively rare (for an overview, see Mulhuijzen and de Jong, 2023). The motivations for HHS innovations are in stark contrast with those driving producer firms to innovate in the business sector. They aim to benefit from innovation by increasing their competitive advantage and commercial sales (von Hippel, 2005).

Because of these motivational differences, von Hippel (2017) explains HHS and producer innovation as separate but complementary paradigms (Figure 3.1). Free innovation, done by citizens who are predominantly self-rewarded by the innovation (process) and require no compensation, generally precedes producer innovation. Citizens have excellent need information and no market demand to take into account and, therefore, more often come up with radical innovations (Hienerth et al., 2014; Riggs and von Hippel, 1994)—which can be a source of inspiration for product development by firms (Bogers et al., 2017; West et al., 2014). To develop innovations, however, citizens may require tools and innovation support from firms—which have more and better resources when it comes to the development of solutions to certain needs.

To fully understand HHS innovation and identify relevant ecosystem elements, it is important to acknowledge other concepts that cover a similar meaning as HHS innovation: consumer innovation, do-it-yourself, user innovation by citizens, makers, and user and informal entrepreneurship. We summarize these concepts and their relationship with HHS innovation in Table 3.2 (also see Mulhuijzen and de Jong (2023) and de Jong and von Hippel (2023) for more detailed discussions). As will be described in further detail in the methods section, we incorporated insights from these different strands of literature into our framework.

Figure 3.1. The complementary paradigms of innovation by citizens and producers



Source: von Hippel (2017), p. 4.

Table 3.2. Concepts related to innovation in the household sector

Construct	*Definition*	*Conceptual relation with HHS innovation*
Consumer innovation	Same as HHS innovation.[a]	Used interchangeably with HHS innovation.[a]
Do-It-Yourself (DIY)	The active design and production by consumers of products, processes, or other applications in their discretionary time without payment.[b]	Broader than HHS innovation: HHS innovations are a subset of DIY goods describing all DIY goods that are functionally novel.
User innovation by citizens	The development by citizens of functionally novel products, services, or other applications in their discretionary time without payment for their personal use.[c]	More narrow than HHS innovation: Subset of HHS innovations specifically driven by a personal need (i.e., citizens innovate to use their innovation).[c]
Makers	Citizens who passionately engage in the production of new objects.[d]	More narrow than HHS innovation: Though makers are ill-defined in the existing literature, with many variations, the concept is often applied to study HHS innovators who are engaged with complex technologies such as 3D printers.[b]
User/ informal entrepreneurship	Citizens who initially developed an innovation for their own use and later realized a market opportunity that they seize through entrepreneurship (oftentimes starting informally).[e]	More narrow than HHS innovation: It describes only the HHS innovations that diffuse through entrepreneurship.[e]

Sources: [a]von Hippel (2017), [b]Mulhuijzen and de Jong (2023), [c]von Hipppel (2005), [d]Dougherty (2012), [e]Shah and Tripsas (2007).

2.2. Legitimacy of policies for HHS innovation

Neoclassical economists legitimize innovation policies with the argument of market failure: where markets cannot efficiently optimize the allocation of resources (Arrow, 1972). Market failures describe “the failure of a more or less idealized system of price-market institutions to sustain ‘desirable’ activities or to stop ‘undesirable’ activities” (Bator, 1958, p. 351)—with the desirability of activities being evaluated relative to the solution of an explicit or implied welfare maximization problem (Bator, 1958). Scholars identified four types of market failure that legitimize innovation policies (Chaminade and Edquist, 2010). 1. A lack of appropriation: actors are unable to reap commercial benefits from innovation due to spillovers. 2. Uncertainty: actors’ inability to know in advance what benefits can be derived from innovation. 3. Indivisible knowledge: innovation requires significant investments in knowledge before new products can emerge at all). This market failure, too, is alleviated by R&D subsidies. 4. Asymmetric information: actors have different private information about themselves and their economic environment, giving rise to moral hazard and adverse selection problems. These market failures have inspired policies like intellectual property rights, R&D subsidies, and binding contracts, to name a few examples (Barbaroux, 2014; Chaminade and Edquist, 2010; Stiglitz, 2000).

HHS innovation comes with its own challenges; these only partially overlap with the aforementioned market failures (von Hippel and de Jong, 2010). For HHS innovation policy, we need to think of failures that harm the societal welfare outcomes (de Jong et al., 2015; von Hippel, 2017). We can distinguish between two main types of failure that justify policies for HHS innovation:

Failures harming the development of HHS innovations. The aforementioned failures of indivisibility and asymmetric information can particularly harm the development of HHS innovations. Indivisibility harms citizens’ investment in innovation tools. Although modern-day prototyping and production facilities, such as 3D printers, are increasingly available to consumers, such innovation tools still require significant monetary investments (for citizens to acquire these tools) and time investments (for citizens to actually deploy them) (Woodson et al., 2019). Asymmetric information harms citizens’ solution knowledge. Whereas citizens have private information regarding their preferences and needs, the actual knowledge of how to develop solutions to these needs is still largely locked away in the R&D divisions of organizations. Technical skills and work experience are powerful predictors of HHS innovation, but surveys unraveled only a minor subsample of the population equipped with this expertise (e.g., von Hippel et al., 2012).

Failures harming HHS innovation diffusion. A lack of diffusion is a market failure unique to HHS innovation. As mentioned above, commercial businesses will try hard to diffuse their innovations in order to benefit, but for citizens, this is not self-evident. Diffusion failure originates from citizens' lack of commercial motivation (de Jong et al., 2015, 2018). Most HHS innovators only want to use their solutions themselves and/or are self-rewarded by process benefits (von Hippel et al., 2017). Consequently, most HHS innovators lack incentives to invest effort in diffusion, which comes at the expense of other people that would benefit from obtaining the same solution (de Jong et al., 2018).

Thus, in the context of HHS innovation, two market failures (indivisibility and asymmetric information) have a differentiated impact—specifically, on the production of innovations. Moreover, an additional and important failure derails the diffusion of HHS innovations. These issues justify a different type of innovation policy. We use an ecosystem perspective to provide an overview of the elements conducive to the development and diffusion of HHS innovations and the policies recommended to support these elements.

2.3. Ecosystems in a producer innovation context

Ecosystem thinking in innovation originated in the 1980s—when scholars recognized that innovation agents are surrounded by a wide range of actors and factors that cannot only be traced by looking at market interactions (Bahrami and Evans, 1995; Dubini, 1989; Pennings, 1982; Van de Ven, 1993). These actors and factors, and the interactions between them, co-evolve in regional territories, allowing for specialization and co-creation of value (Adner and Kapoor, 2010; Frels et al., 2003)—as is also described in the field of open innovation (Chesbrough et al., 2006; Dall-Orsoletta et al., 2022). As such, the value of an ecosystem is greater than the individual actors and factors that make up its parts (Holgersson et al., 2022).

Ecosystem actors are tied together by market and non-market interactions. In particular, non-market interactions are the main reason ecosystems provide a valuable alternative for policymakers (instead of only looking at market conditions) (Stam, 2015). The emergence of ecosystems as configurations of separate actors and factors for which prices alone do not suffice as a coordination mechanism can be attributed to centripetal and centrifugal forces. Centripetal forces are the complementarities between ecosystem elements that push them together—they require coordination beyond market interactions. Consider, for example, the ecosystem of Apple and app developers. This ecosystem arises from the complementarities between the iPhone and iOS applications and requires standards and shared codified interfaces to function (Jacobides et al., 2018). Centrifugal forces, on the other hand, pull ecosystem elements apart.

One of the most prominent sources of centrifugal forces is the dispersion of knowledge, i.e., when knowledge is distributed across several actors. Sticking with the example of the iPhone - apps ecosystem, it is too difficult for Apple alone to manage all the resources required to substitute for the millions of external app developers. Ecosystems arise when centripetal and centrifugal forces are in balance. A lack of centripetal forces induces purely market-based interactions (in the absence of complementarities that require more complex coordination, prices suffice as a coordination mechanism), and a lack of centrifugal forces induces vertical integration (when a company can manage all resources entirely by itself) (Holgersson et al., 2022).

Before we start mapping elements of an ecosystem for HHS innovation, we take stock of two counterpart ecosystems that have been developed for the business sector: national innovation systems and entrepreneurial ecosystems.

National Innovation Systems. One of the first strands of literature that explored the actors and factors constituting innovation ecosystems is the literature on National Innovation Systems (NIS) (Edquist and Johnson, 1997; Lundvall, 1992; Nelson, 1993). This framework argued that, for innovation to flourish, countries needed a strong ‘Triple Helix’ model (Kolade et al., 2022; Ptak and Bagchi-Sen, 2011)—meaning active involvement and collaboration between (1) government, (2) industry, and (3) academia. Together, these actors need to perform a set of ten key activities summarized by Edquist (2006)—see Table 3.3. Though the NIS framework was a pioneering step in studying innovation as emerging from a set of actors and factors working together, it was also criticized. Due to the output studied by NIS—i.e., macro-level technological development—the framework is rather static (Lundvall, 2007). By studying the big, national preconditions for innovation, the framework neglects agency and does not recognize the role of entrepreneurs and other (micro-level) innovation agents (Acs et al., 2014).

Entrepreneurial ecosystems. A multilevel approach to innovation ecosystems was developed in the literature on entrepreneurial ecosystems (e.g., Stam and Spigel, 2016). Entrepreneurial ecosystems study the regional institutional arrangements and resource endowments enabling productive entrepreneurship (Stam and Van de Ven, 2021). Productive entrepreneurship comprises all forms of entrepreneurship that contribute social value next to providing the entrepreneur with private value (Acs et al., 2013; Audretsch et al., 2006; Bosma et al., 2018), with one of the key channels through which social value is realized being the development and diffusion of innovations (Wennekers and Thurik, 1999). Thereby, productive entrepreneurship is an important indicator of innovation in the business sector.

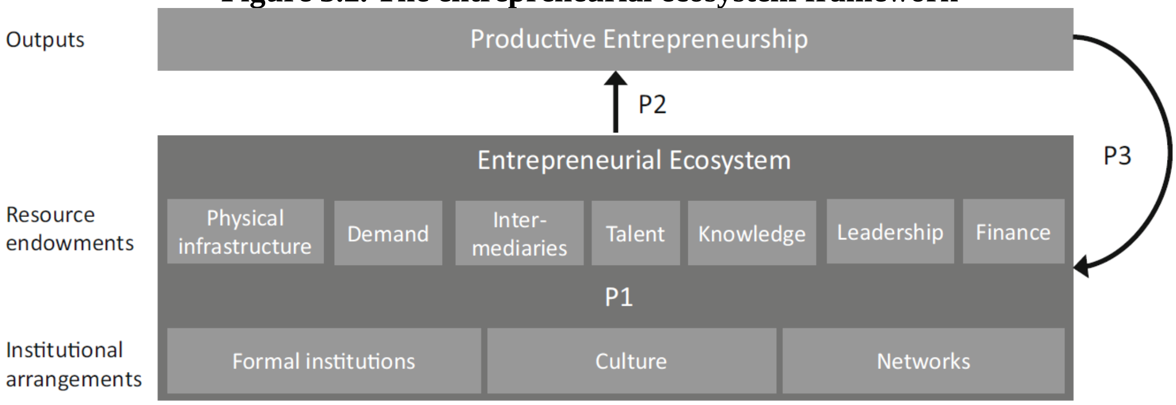
Table 3.3. Key activities of a National Innovation System

Activity	*Definition*
R&D	Provision of Research and Development, creating new knowledge—especially in engineering, medicine, and the natural sciences.
Competence building	Provision of education/ creation of human capital/ production of and reproduction of skills/ individual learning in the labor force to be used for R&D and innovative activities.
Product markets	Formation of new product markets—creation of standards, public procurement of innovations.
Demand	Articulation of quality requirements emanating from the demand side with respect to new products.
Creating/changing organizations	Creating and changing organizations needed for the development of new fields of innovations—e.g., enhancing entrepreneurship to create new firms or intrapreneurship to diversify existing firms, creating new research organizations, or policy agencies.
Networking	Networking through markets and other mechanisms, including interactive learning between different organizations (potentially) involved in innovation. This implies integrating new knowledge coming from different spheres of the system and outside with knowledge already available to the innovative firms.
Creating/changing institutions	IPR laws, tax laws, environment and safety regulations, R&D investment routines—all formal institutions that influence innovation by firms by incentivizing or blocking innovation.
Incubating	Incubating activities—e.g., to provide access to facilities, administrative support—for new innovative activities.
Finance	Financing of innovation processes and other activities that can facilitate the commercialization of knowledge and its adoption.
Consulting	Provision of consultancy services of relevance for innovation activities—e.g., technology transfer, commercial information, and legal advice.

Source: Edquist (2006).

The leading framework of entrepreneurial ecosystems has been developed by Stam and Van de Ven (2021)—see Figure 3.2. On the level of institutional arrangements, Stam and Van de Ven (2021) propose that the most important elements enabling (or constraining) productive entrepreneurship are formal institutions, culture, and the networks in which entrepreneurs and other ecosystem agents are nested. On the more micro level of regional resource endowments, the framework presents physical infrastructure, demand, intermediaries, talent, knowledge, leadership, and finance as ecosystem elements. P1, P2, and P3 refer to the relations between the different boxes and propose that the institutional arrangements and resource endowments co-evolve in a certain territory (P1); together strongly predict levels of productive entrepreneurship (P2); and that the outcomes of productive entrepreneurship feedback into the ecosystem (P3). The complementarities between the ecosystem elements and their predictive power for productive entrepreneurship were recently verified in a quantitative study on NUTS 2 regions in Europe by Leendertse et al. (2022).

Figure 3.2. The entrepreneurial ecosystem framework



Source: Stam and Van de Ven (2021).

Although NIS and entrepreneurial ecosystems employ different levels of analysis and study slightly different outcomes (macro-level technological development versus innovative entrepreneurship), the predictive elements that the frameworks present show a strong overlap. For example, both frameworks include elements related to institutions, networks, demand, intermediaries, human capital, and finance. Furthermore, NIS and entrepreneurial ecosystems are similar in terms of the elemental relationships: the ecosystem elements co-evolve, are a combined predictor of innovation, and absorb previous innovation outcomes. These similarities are important as they describe rather fundamental properties of how ecosystems work in the broader context of innovation. Some of these properties might well generalize also to the specific context of HHS innovation, hence, may help us to construct the first ecosystem model accounting for innovation brought about by citizens.

3. Methods

Similar to the approach taken in the NIS and entrepreneurial ecosystems literature (cf. Stam and Van de Ven, 2021), we take a first step in constructing the ecosystem of HHS innovation by identifying what elements matter for HHS innovation. We conducted an extensive literature review of the seminal papers on HHS innovation and related concepts (Table 3.2) and expert interviews with leading thinkers in the field (academic and non-academic).

3.1. Literature research

As HHS innovation is a relatively new area of research, the classical approach of conducting a systematic literature review is not so effective. Instead, we started with an overview of the relevant work published by von Hippel (2017), in which the results of six national surveys on HHS innovation are summarized together with decades of research on related topics. From there, we expanded our literature review of HHS innovation with studies that illuminated new insights along the dimensions of HHS innovation emergence, diffusion, and policies by doing a Google Scholar, Scopus, and Web of Science search using the keywords ‘household sector innovation’ and ‘consumer innovation’ (as mentioned above, this is used as a synonym for HHS innovation).

Table 3.4. Overview of studies included in literature review

Primary strand of literature	*Relevant keywords*	*References*
HHS innovation	‘household sector innovation’; ‘consumer innovation’	von Hippel and de Jong (2010) Kuusisto et al. (2013) Stock et al. (2016) Nielsen et al. (2016) von Hippel (2017) Gambardella et al. (2017) de Jong et al. (2018) Potts et al. (2021) Claussen and Halbinger (2021) Jeppesen (2021) Mulhuijzen and de Jong (2023)
DIY	‘do-it-yourself’; ‘DIY’; ‘tinkering’	Williams (2008) Wolf and McQuitty (2013) Fox (2014) Hahn et al. (2016) Collier and Wayment (2018)
User innovation	‘user innovation’	Franke et al. (2006) Jeppesen and Frederiksen (2006) Fauchart and von Hippel (2008) Brem et al. (2019)
Maker	‘makers’; ‘maker entrepreneurship’	Mauroner (2017) Troxler and Wolf (2017) Nascimento and Pólvora (2018) Browder et al. (2019) Li and Gao (2021)
Informal/ user entrepreneurship	‘user entrepreneurship’; ‘informal entrepreneurship’	Shah and Tripsas (2007) Williams and Nadin (2010) Grant (2013) Thai and Turkina (2014) Siquera et al. (2014) Williams et al. (2016)

To avoid a too narrow focus, we also considered adjacent strands of literature that we considered to be relevant for the identification of ecosystem elements—i.e., studies on DIY, user innovation, makers, user entrepreneurship, and informal entrepreneurship. To find these studies, we used the keywords ‘do-it-yourself’, ‘tinkering’ (sometimes used to describe DIY behavior), ‘user innovation’, ‘makers’, ‘maker entrepreneurship’, ‘user entrepreneurship’, and ‘informal entrepreneurship’. We read the abstracts of the resulting studies to verify whether they were conducted in the context of HHS innovation or could reveal anything about the diffusion patterns of HHS innovation, then read their introductions to check for new insights about HHS innovation emergence, diffusion, and/or policy.

We also consulted our interviewees (see hereafter) to mention relevant papers, articles, or book chapters and asked for feedback on whether we missed any relevant input in our literature search. We continued our literature search until we reached theoretical saturation—in qualitative terms, meaning that newly found studies no longer revealed new properties of ecosystem elements along the dimensions of HHS innovation emergence, diffusion, and policy (cf. Glaser and Strauss, 1967). Table 3.4 lists the studies we finally included.

3.2. Expert interviews

To facilitate the analysis of our literature review, we conducted 13 interviews with experts. These interviews informed our coding process by helping us to distinguish ecosystem elements that should be prioritized because they have a more profound impact on HHS innovation emergence, diffusion, and policy. Furthermore, we used the interviews for feedback purposes. We conceptualized an initial version of the ecosystem framework based on our literature review and asked whether the framework resonated and if we overlooked any key references or insights. Our interviewees were distributed over three groups:

1. HHS innovation scholars. These interviews were particularly useful in informing our coding process and providing feedback on our literature review.
2. Ecosystem scholars studying innovation in the business sector. Conducting these interviews helped us with making sure the elemental relationships in the framework reflected a sensible ecosystem model. Also, some of these scholars pointed us to adjacent literature (particularly, informal entrepreneurship) that turned out to be informative HHS innovation ecosystems—especially, concerning (commercial) diffusion.
3. Policy experts. These interviews helped us to carefully address the policy measures targeted at the HHS innovation ecosystem. Though many measures have been suggested by previous studies, it was incredibly valuable to discuss how these can be applied in practice. Furthermore, the interviewees pointed us to additional policy measures that have not been suggested in the HHS innovation literature. The policy experts we interviewed were all active in South Africa. South Africa is a suited context because the country has a huge informal sector (Herrington et al., 2010), with many informal businesses emerging from HHS innovation (de Jong et al., 2023)—which is why HHS

innovation is a more central issue for policy in South Africa than in most (Western) countries.

An overview of the interviewees is displayed in Table 3.5 below.

Table 3.5. List of expert interviews

Interviewee	*Job occupation*	*Organization*	*Main field of expertise*	*Duration in minutes*
H1	Academic scholar	MIT	HHS/ user innovation	60
H2	Academic scholar	NYU	HHS/ user innovation	60
H3	Academic scholar	RMIT University	HHS/ user innovation	60
E1	Academic scholar	Harvard	Innovation/ entrepreneurial ecosystems	60
E2	Academic scholar	Utrecht University	Innovation/ entrepreneurial ecosystems	30
E3	Academic scholar	University of Stellenbosch	Innovation/ entrepreneurial ecosystems	60
E4	Academic scholar	University of the Witwatersrand Johannesburg	Innovation/ entrepreneurial ecosystems	30
E5	Academic scholar	University of Johannesburg	Innovation/ entrepreneurial ecosystems	45
E6	Academic scholar	WU Vienna	Innovation/ entrepreneurial ecosystems	45
P1	Policy expert	UNDP / Government of South Africa	HHS innovation policy	60
P2	Policy expert	UNDP	HHS innovation policy	90
P3	Policy expert	Private company in Johannesburg	HHS innovation policy	60
P4	Policy expert	Government of South Africa	HHS innovation policy	60

The interviews lasted 55 minutes on average (range 30 - 90 minutes) and were all conducted by the same person (one of the authors of this paper). The interviews were semi-structured, in which we first presented our initial ecosystem framework and findings from the literature review and then asked questions. We asked the interviews (1) if they felt the enablers and constraints of HHS innovation were well represented in the framework and resonated with the interviewees' knowledge of HHS innovation; (2) if not, what elements were missing in the initial framework and what literature could support these missing elements; (3) if the visualization logically explained the dynamic structure of the ecosystem and elemental relationships; and (4) if we had missed any policy measures targeted at the different elements of the ecosystem and how these policy measures were applied in practice. As the interviews were semi-structured, we left room for the interviewees' input, and we changed the weight attributed to the questions above dependent on whether the interviewee was an HHS innovation scholar, ecosystem scholar, or policy expert.

3.3. Analysis

We started the analyses using the data from the literature review only. The 31 papers listed in Table 3.4 above were studied in detail, first, to identify ecosystem elements affecting HHS innovation. We highlighted all parts of the text where the papers referred to a specific enabler or constraint of HHS innovation emergence or diffusion, and we wrote short summaries of the papers' findings with regard to these enablers and constraints. Next, we processed the short summaries into first-order codes explicitly stating what kind of ecosystem element was referred to and, if the paper provided a quantitative assessment, what kind of indicators were used to measure the element. Drawing on the literature on innovation ecosystems in the business sector (cf. Stam and Van de Ven, 2021) (see section 2.3 above), we grouped the first-order codes by the dimensions of the (1) (institutional) environment, (2) facilitators, and (3) outcomes. When we had an overview of first-order codes by these dimensions, we analyzed how we could process the first-order codes into second-order constructs that would represent the ecosystem elements in our framework. Processing the first-order codes into second-order constructs was necessary as the first overview consisted of more than 80 specific enablers and constraints of HHS innovation and its diffusion.

After we finished a first code-aggregation diagram of specific enablers and constraints (first-order codes) and ecosystem elements (second-order constructs) by the dimensions of (institutional) environment, facilitators, and outcomes, we constructed a first ecosystem framework that we could present during the expert interviews for feedback purposes. The feedback received through the expert interviews helped us to bring more focus to our coding. Our initial model still visualized 27 distinct ecosystem elements, which made for a framework that was deemed overly complex by our interviewees. Drawing on our interviews, we regrouped the first-order codes into more aggregate second-order constructs and decided to drop some second-order constructs that were not perceived as specifically relevant to HHS innovation. Furthermore, as mentioned above, the interviewees noted some references we missed in our initial literature review, and were later added and coded for ecosystem elements.

Table 3.6 displays our final code-aggregation diagram. We identified 53 specific enablers and outcomes of HHS innovation (diffusion), which we grouped into 12 ecosystem elements.

Table 3.6. Code-aggregation diagram of household sector innovation ecosystem elements

Specific enablers/constraints/outcomes (first-order codes)	Ecosystem elements (second-order constructs)	Aggregate dimensions
Rule of law[a] IPR[f,j] Formal government institutions[f,r,t,v,w,x,z]	Rules and regulation	(Institutional) environment
Innovation commons[f] Maker culture[i,j,k,l,q,ac] Culture[t] Community norms[a,b,j,k,l,ae] Norm of generalized reciprocity[a,b,j,aa]	Cultural norms and value	
Networks[a,b,g,j,k,l,o,p,s,x,ab,ac,ae] Social environment[c,i,q,r] Social capital[e,l,s]	Social capital	
Education level[a,h,i] Technical education[c] Technical experience[j,n,x,z] Expertise[k] Character traits[c,i] Ambition[j] Risk propensity[i] Lead user characteristics[e,p,x] Need information[a,b,c,i,p,x,z,aa] Need for (system) change[w,z] Need for individuality/self-expression[q] Commercial motives[a,z,aa,ab]	Human capital	Facilitators
Toolkits[a,d,x,z] Tools: hardware and software[j,k,l,o,s] CAD technologies[i,x] Diffusion tools, e.g., protests, spreading of symbols[w]	Innovation tools	
(Online) platforms[a,b,g,i,j,o,p,aa,ad] Hacker and maker spaces[i,j,k,l,o] Crowdfunding platforms[aa]	(Online) platforms and workshops	
Discretionary time[a,b,d,h,n,o,q] Income[b,h,m,n,o,q,r,t] Informal finance[s,u] Access to finance[o,aa] Access to internet[i,o,p] Infrastructure[s,u]	General resources and infrastructure	
Producers[a,d,f,z,ad] Access to/quality of tradespersons[m] Offerings by commercial firms[n] Formal employment (opportunities)[r,s,t] Industry characteristics[d,u] Market opportunities[s] Solution information[x]	Producers and industry	
Free innovation[a] User innovation[e,x,z,ab,ad] Social movement innovation[w] Innovation[i,l,o]	HHS innovation	Outcomes
Peer-to-peer diffusion[a,d,g] Non-commercial maker[k]	Free (peer-to-peer) diffusion	
Producer adoption of free designs[a,d]	Commercial diffusion through producer adoption	
User entrepreneurship[b,w,z,aa] Maker (entrepreneurship)[i,j,k] Informal entrepreneurship[r,s,t,u,v]	Commercial diffusion through entrepreneurship	

Sources: von Hippel (2017)[a], Shah and Tripsas (2007)[b], Stock et al. (2016)[c], Gambardella et al. (2017)[d], Franke et al. (2006)[e], Potts et al. (2021)[f], Claussen and Halbinger (2021)[g], Mulhuijzen and de Jong (2023)[h], Mauroner (2017)[i], Troxler and Wolf (2017)[j], Browder et al. (2019)[k], Li and Gao (2021)[l], Williams (2008b)[m], Wolf and McQuitty (2013)[n], Fox (2014)[o], Hahn et al. (2016)[p], Collier and Wayment (2018)[q], Williams and Nadin (2010)[r], Grant (2013)[s], Thai and Turkina (2014)[t], Siqueira et al. (2014)[u], Williams et al. (2016)[v], Jeppesen (2021)[w], von Hippel and de Jong (2010)[x], Kuusisto et al. (2013)[y], Nielsen et al. (2016)[z], Brem et al. (2019)[aa], de Jong et al. (2018)[ab], Nascimento and Pólvora (2018)[ac], Jeppesen and Frederiksen (2006)[ad], Fauchart and von Hippel (2008)[ae].

Next, we used the 31 papers listed in Table 3.4 to identify what policy measures have been suggested to facilitate the development and diffusion of HHS innovations. When reading the papers in detail, we shortly summarized each policy measure and ordered them in line with the code-aggregation diagram. Specifically, we ordered the policy measures by the second-order constructs from our code-aggregation diagram in the dimensions of the (institutional) environment and facilitators—to study what ecosystem elements were targeted by the measures in order to achieve a more favorable HHS innovation outcome. Again, drawing on our expert interviews, we continuously re-ordered the policy measures such that they were in line with the emerging ecosystem framework, and we added HHS innovation policy measures that were suggested by our interviewees but that did not emerge from the literature. In the appendix (see C.1), we added the full list of policy measures identified. We present a shorter version in the findings section (section 4.5 below).

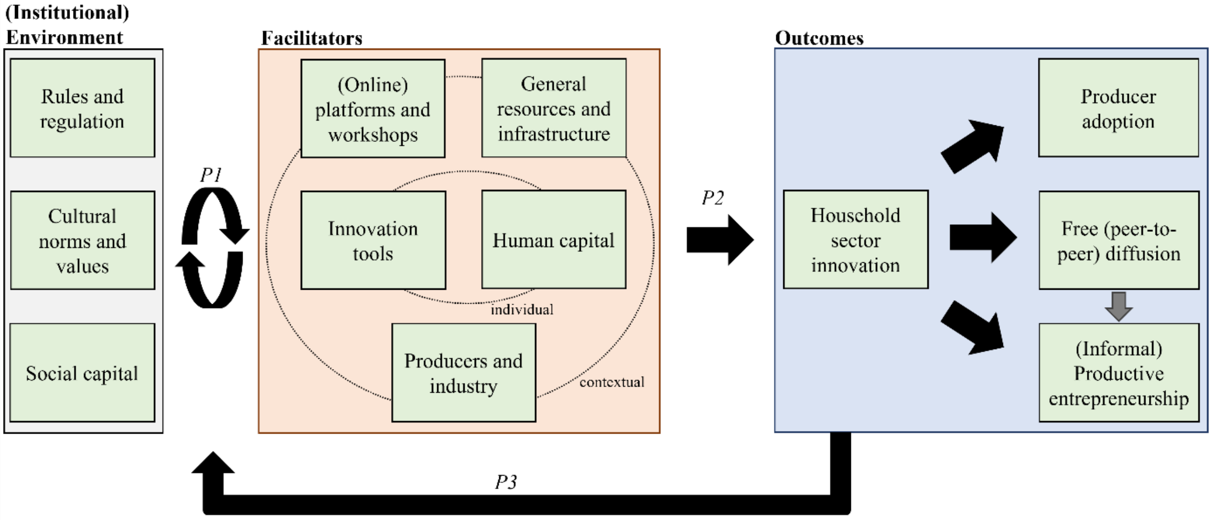
4. Findings

4.1. An ecosystem framework for household sector innovation

The resulting ecosystem framework for HHS innovation is displayed in Figure 3.3. Its key elements are (1) rules and regulation, (2) cultural norms and values, and (3) social capital in the dimension of factors in the (institutional) environment; (4) human capital, (5) innovation tools, (6) (online) platforms and workshops, (7) general resources and infrastructure, and (8) producers and industry in the dimension of facilitators; and (9) household sector innovation, (10) free peer-to-peer diffusion, (11) commercial diffusion through producer adoption, and (12) commercial diffusion through entrepreneurship as outcomes. Similar to business innovation ecosystems, arrows P1, P2, and P3 refer to the relationships between the different boxes. P1 posits that factors in the (institutional) environment and facilitators co-evolve in a certain territory. P2 posits that, together, these ecosystem elements determine regional levels of HHS innovation development and diffusion. Finally, P3 posits that these HHS innovation outcomes feedback into the ecosystem elements.

As suspected, the ecosystem elements enabling HHS innovation show *some* overlap with those relevant in the business sector. For example, formal institutions, social capital, and human capital are important facilitators in both strands of literature (e.g., Edquist, 2006; Stam and Van de Ven, 2021). However, the specific interpretation of these elements—i.e., the first-order codes we aggregated from—differs. In sections 4.2 to 4.4, we will carefully explain each ecosystem element and suggest regional indicators that can proxy these elements in future quantitative assessments of HHS innovation. Unlike the NIS literature, this regional perspective is important for HHS innovation. Citizens often develop innovations to solve their local problems, draw on local resources, and diffusion is (initially) oftentimes tied to local regions—with contributions to online user communities being the exception (e.g., Dahlander and Frederiksen, 2012).

Figure 3.3. Household sector innovation ecosystem



4.2. (Institutional) Environment

Institutions are the formal and informal rules that organize social, political, and economic relations (North, 1991). Institutional factors are (re)produced through routine actions and, therefore, dependent on the environment in which individuals are rooted. They can take the form of explicit contractual agreements, but they can also be rules that individuals internalize unconsciously. The (social) environments of people and the institutions that rule these environments shape people's behaviors in every facet of life—thereby, they also influence the development and diffusion of HHS innovations.

4.2.1. Rules and regulation

Rules and regulations are the foremost formal institutions that influence HHS innovation. For the development of HHS innovations, influential factors are rules concerning intellectual property rights (IPR) (e.g., Potts et al., 2021) and innovation support (e.g., von Hippel and de Jong, 2010). For the diffusion of HHS innovations, the most influential factors are overregulation and bureaucracy (Jeppesen, 2021; Nielsen et al., 2016; Thai and Turkina, 2014; von Hippel, 2017; Williams and Nadin, 2010; Williams et al., 2016).

Let us first discuss how rules and regulations enable or constrain citizens' ability to develop innovations through IPR and innovation support. IPR concerns all the legislation aimed at protecting companies from unwanted spillovers of their intangible, intellectual property—e.g., patent law, copyrights, trademarks, or trade secrecy law. Though IPR has been an influential instrument to incentivize private companies to invest in R&D, it can also be a constraint for HHS innovation. Due to IPR, citizens have limited access to innovation-related information, contributing to their lack of solution knowledge. Moreover, as the returns to private ownership of data are sharply increasing, companies are expanding their data ownership where they can—leading to growing problems when it comes to freely accessible data (Potts et al., 2021). Creative commons licenses, allowing inventors to be acknowledged, while also allowing for the free flow of information are a promising solution that has been shown to be a key asset for HHS innovation to take off (Kuusisto et al., 2013; Troxler and Wolf, 2017; von Hippel, 2017). For companies, transferring information to the creative commons can also provide them with advantages, as it will enable possibilities for open innovation (Potts et al., 2021)—citizens' innovation efforts provide valuable signals on future product trends and consumer demand (Franke et al., 2006). Public support for innovation (e.g., tax credits for R&D expenses or R&D subsidies) is another channel through which regulations affect HHS innovation—once again, they form a constraint rather than an enabler. This is (1) because citizens are not eligible for such benefits, creating an imbalance in the distribution of innovation support (von Hippel and de Jong, 2010), and (2) because these measures disincentivize open innovation (Gambardella et al., 2017). Though it can be more efficient for companies to work together with citizen innovators, it is more likely for them to keep R&D within the boundaries of their organizations when receiving R&D subsidies (so they accumulate more intellectual property).

Second, rules and regulations affect the diffusion of HHS innovations. Particularly, through overregulation and bureaucracy. An example can be given by patient innovations. Many healthcare solutions for which there is limited demand (e.g., in the case of rare diseases) are invented by patients (Oliveira et al., 2015). Though these can be promising solutions that can serve more patients of similar conditions, overregulation oftentimes inhibits the diffusion of patient-developed medicines and other healthcare solutions (von Hippel, 2017). However, not only peer-to-peer diffusion suffers from overregulation and bureaucracy—but it also affects commercial diffusion. Studies show that overregulation and bureaucracy can disincentivize people from registering a business, making it more likely that their informal activities stay informal (Thai and Turkina, 2014; Williams and Nadin, 2010; Williams et al., 2016).

Quantitative indicators. To date, few studies have quantitatively assessed the role of rules and regulations in the context of HHS innovation. We suggest future studies conducting regional surveys containing questions that elicit citizens' perceptions of the availability of innovation-related information (cf. Potts et al., 2021). Furthermore, studies can look into the regional number of non-cooperative R&D subsidies provided to firms (see Broekel (2015), who uses this data to analyze innovation in the business sector)—from the theory, we would expect a negative effect on HHS innovation (Gambardella et al., 2017). For a quantitative assessment of the diffusion of HHS innovation, as the theory suggests overregulation and bureaucracy as important factors, studies can make use of the Quality of Governance survey for regional quantitative indicators (see Stam and Van de Ven, 2021).

4.2.2. Cultural norms and values

Cultural norms and values represent the main informal institutions influencing HHS innovation development and diffusion. Specifically, studies find that a certain 'maker culture' and the norm of generalized reciprocity facilitate HHS innovation (Browder et al., 2019; Collier and Wayment, 2018; Li and Gao, 2021; Mauroner, 2017; Troxler and Wolf, 2017; von Hippel, 2017). The maker culture is defined by three principles: (1) hands-on creation of goods by citizens, (2) transdisciplinary collaboration between citizens, and (3) free sharing of designs. Related to the latter, when individuals follow a norm of generalized reciprocity, they freely share innovation-related information with the community while expecting other community members to do the same. Hence, the individuals do not require direct compensation but expect the community, as a whole, to reciprocate its members (von Hippel, 2017).

The maker culture and related norm of generalized reciprocity are powerful informal substitutes for formal institutions governing intellectual property (Nascimento and Pólvora, 2018). Instead of allowing people to protect their intellectual property, they require everybody who benefits to be open. Nowadays, there are countless citizen innovation communities around the globe, both active on online platforms like Thingiverse and offline platforms like Fab Labs, adhering to these informal institutions (Fox, 2014; Tabarés and Kuittinen, 2020). To join and benefit from such communities, (prospect) members are trusted to share their designs for free and co-create innovation solutions with the community. Sometimes, these principles are operationalized with the assistance of Creative Commons licenses and open-source software platforms but they can also remain completely informal (Nascimento and Pólvora, 2018). These informal institutions are enforced by community consensus—i.e., when the community detects a violation of the norms and values, they may deter the violator from entry to community facilities such as information sharing (Fauchart and von Hippel, 2008).

The maker culture and norm of generalized reciprocity enable the development of HHS innovations, as open sharing of information-related information helps citizens in finding solutions to their needs or, the other way around, needs that fit with a solution that they may already have made (cf. von Hippel and von Krogh, 2016). Obviously, these cultural norms and values also facilitate the diffusion of HHS innovations, as they prescribe the free diffusion of designs (Troxler and Wolf, 2017). Finally, the governance of communities through cultural norms and values comes at a lower cost than governance through formal institutions (e.g., court cases) and, therefore, is highly efficient at regulating communities of innovative citizens (cf. Fauchart and von Hippel, 2008).

Quantitative indicators. The studies we reviewed on cultural norms and values in the context of HHS innovation did not yet provide quantitative operationalizations. However, as suggested by von Hippel (2017), the norm of generalized reciprocity can be a proxy of citizens' adherence to norms of open design, and this norm has been measured in the management literature, in general—see Wu et al. (2006). We suggest regional studies of HHS innovation to include similar measurement items. These studies will indicate if cultural norms, such as generalized reciprocity, are regionally correlated.

4.2.3. Social capital

Finally, what matters as an environmental element is the social context of the people in the ecosystem and the information flows between them. Citizens are embedded in different kinds of networks—these can be small and large, composed of strong and weak ties, and individuals can take central or peripheral positions. The social capital accessed through individuals' networks can be instrumental for HHS innovation and dissemination (e.g., Franke et al., 2006).

Social capital directly facilitates the development of HHS innovations by providing people access to solution information (Franke et al., 2006). As argued throughout this paper, citizens often lack the information necessary to develop solutions to their needs. Networks may help to overcome this deficiency, simply because some people in the network may have needs for which others have solutions (Brem et al., 2019; von Hippel and von Krogh, 2016). Regarding the diffusion of HHS innovations, Claussen and Halbinger (2021) show that people's networks do not only facilitate the diffusion of HHS innovations, naturally, by providing them with more exposure but related to the development of HHS innovations, social capital also facilitates the quality of HHS innovations and their documentation. Finally, social capital positively affects the commercial diffusion of HHS innovations through entrepreneurship. When citizens share their innovations peer-to-peer with their networks, their peers may provide them important signals regarding the quality of the innovations and, related, the broader consumer demand potential. In some cases, these signals can be interpreted as a market opportunity, leading some citizens to start a venture in order to diffuse their innovations (Shah and Tripsas, 2007).

Quantitative indicator. Two of the publications we studied used quantitative methods to assess the role of social capital. Franke et al. (2006) operationalized citizens' innovation-related social capital using six items proxying the context-relevant solution information citizens could acquire through their networks—one tapping specifically into citizens' local networks that may be especially relevant in regional studies of HHS innovation. Claussen and Halbinger (2021), on the contrary, studied HHS innovation on an online platform spanning geographical boundaries. To proxy the role of social capital, they studied how users of an online platform commented on each other's designs.

4.3. Facilitators

We now discuss the ecosystem elements that facilitate HHS innovation more directly. First, we discuss the factors most proximate to citizens: their human capital and the innovations tools they can access. Second, we discuss facilitators in their surroundings: (online) platforms and workshops, general resources and infrastructure, and producers and industries.

4.3.1. Human capital

Human capital, in the context of HHS innovation, refers to citizens' knowledge, skills, abilities, and other personal characteristics that enhance their capability to develop and diffuse innovations (cf. Ployhart and Moliterno, 2011).

In the dimension of knowledge, surveys indicate that, in general, the level of education is a strong predictor of HHS innovation development (von Hippel, 2017). Another factor in the dimension of knowledge, and more particular to HHS innovation, is citizens' need information (e.g., von Hippel and de Jong, 2010). Being the end-user of consumer products, citizens first-hand experience all efficiencies and deficiencies of firms' market offerings. Thereby, they are in a superior information position when developing innovations that address their needs, facilitating citizens' innovation capability (von Hippel, 1994). Concerning citizens' skills and abilities, the strongest enablers are their experience in technical education or a technical work domain (Nielsen et al., 2016; Troxler and Wolf, 2017; Wolf and McQuitty, 2011). Finally, considering personal characteristics, an important enabler of HHS innovation is citizens' 'lead userness', being the extent to which they display lead user characteristics (Franke et al., 2006; Hahn et al., 2016; von Hippel and de Jong, 2010). Lead userness exists of two components: (1) the extent to which a citizen anticipates obtaining high benefits to developing a solution to the citizen's need; and (2) the extent to which a citizen is ahead of a marketplace trend in experiencing this need (von Hippel, 1986). Other, more general personal characteristics that enable HHS innovation development and diffusion are: openness to experience (development), introversion (development), conscientiousness (development/ commercial diffusion) (Stock et al., 2016); ambition (diffusion) (Troxler and Wolf, 2017); risk propensity (diffusion) (Mauroner, 2017); and citizens' commercial motives to innovate (diffusion) (de Jong et al., 2018).

Quantitative indicators. Existing HHS innovation studies have used a range of indicators to measure relevant dimensions of citizens' human capital, i.e., level of education, whether the citizen followed technical education, whether the citizen has experience in a technical work discipline (see, e.g., Chen et al., 2020; von Hippel et al., 2012), the citizen's lead user characteristics (see Franke et al., 2006), the citizen's relevant personality traits (see Stock et al., 2016), and the citizen's commercial motives to innovate (see de Jong et al., 2018). For ecosystem studies, however, more regional indicators would be warranted. Either the measures above could be aggregated on a regional level—that is basically what is done with human capital measures used in entrepreneurial ecosystem studies (cf. Leendertse et al., 2022)—or one could use proxies for human capital creation that are inherently more regional, e.g., total university R&D expenditure in a region, the total number of university degrees awarded by universities in a region, or the total number of patents assigned to universities in a region (Goldstein and Renault, 2004).

4.3.2. Innovation tools

Innovation tools resemble all the tools citizens can use to develop and diffuse innovations, ranging from hardware to software.

The most discussed tools that specifically enable innovation by citizens are computer-aided design (CAD) technologies (e.g., Mauroner, 2017; Troxler and Wolf, 2017) and producer-leveraged toolkits (e.g., Gambardella et al., 2017). More generally, scholars have also emphasized the role of more basic handicraft tools (e.g., Fox, 2014). CAD technologies encompass all computer-based tools allowing for the digital design and production of physical goods—with the most prominent example being the 3D printer (e.g., Browder et al., 2019). Tools such as the 3D printer are increasingly accessible to citizens and have enabled the digital revolution brought about by Web 2.0—the active generation of online content by users—to expand offline (Rayna and Striukova, 2021). Thereby, 3D printers have become incredibly powerful tools for co-designing and prototyping HHS innovations (von Hippel and de Jong, 2010). Next, producer-leveraged toolkits are tools provided by producer firms that allow users to innovate within the product range of the firms. By making these tools user-friendly, they allow for the powerful combination of users' need information and producers' solution information to develop new (product) innovations). An example is the statistical software STATA, where the producer firm (i.e., StataCorp) allows users to develop their statistical tests within STATA's software environment—lowering the threshold for users to develop and implement their own tests (Mulhuijzen and de Jong, 2022). Finally, as HHS innovations can also be built using more traditional tools for handicrafts, these matter too (e.g., Fox, 2014).

Innovation tools have mostly been discussed in relation to the development of HHS innovation. There is, however, one special case of HHS innovation, i.e., social movement innovation by citizens, where there are specific tools used for the diffusion of such innovations. Social movement innovations are HHS innovations (often a novel combination of behaviors) that address a common cause and system change rather than individual goals. For these innovations, specifically, powerful diffusion tools are protests and symbols (see Jeppesen, 2021).

Quantitative indicators. Despite the attention that has been given to the role of innovation tools, a quantitative assessment of citizens' access to these tools is lacking in the literature. A first step could be to include questions on the innovation tools used and citizens' perceived (lack of) access to these tools in future HHS innovation surveys and study if these responses correlate by geographical location, hence, could be meaningful regional indicators.

4.3.3. (Online) Platforms and workshops

Platforms are (online) knowledge repositories that allow citizens to share innovation-related content (e.g., Potts et al., 2021). Workshops serve a similar function but are restricted to the physical space. Furthermore, workshops have an additional function in providing citizens access to (physical) innovation tools (cf., Fox, 2014).

Platforms and workshops both benefit the development and the diffusion of HHS innovations. Concerning the development of HHS innovation, platforms and workshops facilitate (online) knowledge-sharing (e.g., Claussen and Halbinger, 2021), hence, the redistribution of need and solution information so that more need and solution couples can be made and innovations are developed (von Hippel and von Krogh, 2016). In addition, workshops benefit the development of HHS innovations by functioning as central hubs that grant users access to innovation tools (e.g., Li and Gao, 2021).

The role of platforms and workshops as facilitators of knowledge-sharing naturally also benefits the diffusion of HHS innovations (Claussen and Halbinger, 2021; Troxler and Wolf, 2017). Beyond information-sharing, platforms—specifically, crowdfunding platforms—can facilitate the (commercial) diffusion of HHS innovations by providing citizens with funding opportunities (Brem et al., 2019). The commercial diffusion of HHS innovations through entrepreneurship is also facilitated by innovation workshops, such as Fab Labs, that can provide incubation services to citizens who detected a market opportunity after having developed a successful HHS innovation (Benashvili, 2017).

Quantitative indicators. For regional ecosystem assessments of HHS innovation, especially promising indicators are measures of citizens' proximity to maker spaces and Fab Labs or the total number of accessible workshops of this kind in a region. As online platforms span geographical boundaries, they are less suited for quantitative assessments of geographical regions. A way to circumvent this problem would be to include a measure of online visits to online innovation platforms in HHS innovation surveys (Halbinger, 2018) and use regional aggregates of the responses, as these may capture regional spillover effects of citizens' engagement with online-knowledge sharing platforms.

4.3.4. General resources and infrastructure

The ecosystem element of general resources and infrastructure refers to citizens' (infrastructural) resources that can be deployed for a range of activities, including HHS innovation but not uniquely so. Specific factors discussed by scholars belonging to this category are citizens' income, discretionary time (e.g., Mulhuijzen and de Jong, 2023), access' to (informal) finance (e.g., Brem et al., 2019), access to the Internet (e.g., Fox, 2014), and infrastructure, in general (Siquera et al., 2014).

The role of income and discretionary time in the development of HHS innovation is elaborated on most extensively by Mulhuijzen and de Jong (2023). In a study of HHS innovation in the United Arab Emirates, they find that citizens' production of goods, services, and other applications generally increases with income and time. However, within the subsample of the population engaged with the active production of goods it is the more income- and time-constrained group of citizens who are more likely to be innovative in their efforts.

Naturally, citizens' income—just as their access to finance—also influences the potential commercial diffusion of their innovations, as these factors may be enablers or impose constraints on their ability to create a venture after detecting a market opportunity with their innovations (Brem et al., 2019; Fox, 2014). Finally, concerning infrastructure (i.e., access to the Internet and infrastructure in general), scholars have most extensively discussed its influence on the commercial diffusion of HHS innovation through entrepreneurship (Fox, 2014; Mauroner, 2017)—though, obviously, many facets of citizens' innovation process are affected by infrastructure. That is because infrastructural factors directly influence citizens' physical and digital connectedness to others, enabling or constraining the dissemination of their products and services (Grant, 2013; Siquera et al., 2014).

Quantitative indicators. To proxy citizens' general resources, we suggest studying regional levels of GDP per capita in relation to HHS innovation and diffusion (cf., Mulhuijzen and de Jong, 2023). Indicators of regional access to finance and infrastructural quality have been suggested in more detail in the entrepreneurial ecosystems literature. For example, for EU countries, suitable indicators could be the average amount of venture capital per capita and measures of infrastructural quality provided by the Regional Competitiveness Index (see Leendertse et al., 2022).

4.3.5. Producers and industry

There is also a role for producer firms in the business sector as they interact with HHS innovation by offering (1) complementary, substitutable, or supplemented goods (e.g., Gambardella et al., 2017); (2) jobs to citizens that can enhance citizens' technical (innovation) skills (e.g., von Hippel, 2017); and (3) toolkits and solution information to detect and absorb HHS innovations (e.g., von Hippel and de Jong, 2010). The second and third points have been elaborated on in sections 4.3.1 and 4.3.2 above, respectively. Here, we highlight the role of producers' market offerings.

Studies indicate that HHS innovations can complement or compete with market goods, having differential effects on their development and diffusion (Gambardella et al., 2017). In markets where HHS innovations and market goods are complementary, the value of both increases with their existence. Consider, for example, the production of computer-controlled music instruments by professional firms and the user-developed add-ons that can be used to enrich the sounds produced by these instruments (Jeppesen and Frederiksen, 2006). In such markets, producers and industry facilitate both the development and diffusion of HHS innovations. The market offerings by firms can inspire the production of HHS innovations and—as shown for the example of computer-controlled music instruments—firms can decide to establish platforms and communities facilitating the diffusion of complementary HHS innovations, as this also adds to the value created by their products (Mulhuijzen and de Jong, 2022; Potts et al., 2021).

This is different in the case where HHS innovations compete with market goods. In such markets, firms are incentivized to drive the HHS innovations out of the market or, at least, to hamper the diffusion of these innovations. Then, producers and industry become a constraint (Gambardella et al., 2017). Certainly, when markets are concentrated—with a few powerful firms generating the most revenues (Siquera et al., 2014).

Lastly, there is also the case in which HHS innovations supplement producers' market offerings—in which producers and industry indirectly inspire the development of HHS innovations. Sometimes, people cannot access the products they desire on the market—either because of geographical constraints or because firms simply do not make the desired product. Such lack of functions accessible through the market can be an important antecedent of HHS innovation (Williams, 2008; Wolf and McQuitty, 2013).

Quantitative indicators. So far, the presence of producers and industry and their role in enabling or constraining HHS innovation have been studied through case studies (e.g., Jeppesen and Frederiksen, 2006; Mulhuijzen and de Jong, 2022) or conceptual studies (e.g., Gambardella et al., 2017; Kleer and Piller, 2019). For empirical studies, such analyses are not straightforward, as these will require in-depth accounts of the complementarity or substitutability of HHS innovations and the presence of firms that offer the concerning goods. As a first step, empirical studies can consider measures of the geographical concentration of economic activities, as these will broadly reflect the regional impact that producers and industry can have on processes such as HHS innovation (see Panzera et al., 2021).

4.4. Outcomes

Finally, we consider the outcomes studied by the ecosystem framework as displayed in Figure 3.3 above. That is, HHS innovation and (commercial) diffusion through producer adoption of designs, peer-to-peer sharing of innovation, or entrepreneurship.

To give a sense of the occurrence of these outcomes, we see that—when aggregating based on observations from Finland, Canada, China, UAE, and South Africa—around 4.6% of the population develops HHS innovations (weighted by the number of observations) (de Jong and von Hippel, 2022). From the HHS innovations developed by these citizens, on average, 5.0% diffuse through producer adoption, 26.8% diffuse peer-to-peer, and 4.6% diffuse through entrepreneurship (de Jong et al., 2023).

The arrow that connects peer-to-peer sharing to entrepreneurship refers to the dynamic described by Shah and Tripsas (2007). Sometimes, after citizens share their innovations with their peers and communities, they may receive signals that there is demand for their innovations, hence, a market opportunity. Through this mechanism, peer-to-peer sharing can also precede entrepreneurship.

Quantitative indicators. HHS innovation development and diffusion, so far, have been studied using (national) surveys. For the development of HHS innovation, people are asked if they developed any good at their private costs in their discretionary time in the last three years—specifically, respondents are offered proof-tested cues asking if they developed any computer software; household items; transportation and vehicle-related goods; tools and equipment; sport-, hobby-, and entertainment-related goods; children- and education-related goods; healthcare and medical products; or other goods. Next, the respondents are asked to describe their most recently developed good, if they had not created this good for the respondent's employer, what novel function it adds, and whether it could not have been bought on the market. Combining the respondents' answers to all of the above, the goods are coded either as goods that belong to the business sector, HHS innovations, or as DIY goods (self-created goods that do not add a distinct function when compared to market offerings) (de Jong, 2016; Mulhuijzen and de Jong, 2023).

The diffusion is assessed with a range of questions asking whether the respondent invested any effort in diffusion (e.g., shared it with friends or relatives or showcased it to firms) and whether diffusion was realized (through peer-to-peer sharing, producer adoption, or entrepreneurship).

4.5. Example policies

With the ecosystem framework at hand, which summarizes key elements (especially in a regional context), we now evaluate what policies have been suggested by previous studies. To that end, in Table C.1 (see Appendix C), we summarized all policy measures we found with our literature review (Table 3.4), classified by the ecosystem elements targeted by these policies. In total, we identified 36 separate policy measures—with eight measures targeted at the element of rules and regulation, two at cultural norms and values, two at social capital, five at human capital, three at innovation tools, four at (online) platforms and workshops, seven at general resources and infrastructure, and five at producers and industry. Particularly for the elements of cultural norms and values and social capital, policy ideas still seem underdeveloped, both in terms of their variety and the extent to which they are elaborated on in the literature. Table 3.7 below provides an illustrative policy measure for each ecosystem element.

Table 3.7. Example policies targeted at the HHS innovation ecosystem

Dimension	Ecosystem element	Typical policy measure to tackle the diffusion failure
(Institutional) environment	Rules and regulation	*Enforce open standards.* For example, governments can fund easy-to-use knowledge repositories for innovation-related information, where all contributing users are required to adhere to open documentation standards.[a]
	Cultural norms and values	*Promote the entrepreneurial spirit.* To increase the likelihood that HHS innovations diffuse through entrepreneurship, governments should cultivate an entrepreneurial culture—e.g., by making goal-orientation part of educational programs and publicly recognizing entrepreneurial successes.[t]
	Social capital	*Grow HHS innovation communities.* Some countries already provide government support for maker spaces and Fab Labs. To grow HHS innovation communities, such support can be made conditional on the maker spaces and Fab Labs organizing free network events for interested citizens.[l]
Facilitators	Human capital	*Elicit citizens' need to commercialize their HHS innovations.* To increase the effort that citizens put in to disseminate their HHS innovations, governments can elicit citizens' commercial incentives to do so—e.g., by educating citizens about technology licensing.[ab]
	Innovation tools	*Collect and share data as an innovation tool.* With the production of immaterial goods (e.g., software) taking over the world, data have become incredibly important for innovation. To close the between private companies and citizens in data ownership, governments should invest in collecting and sharing data useful to innovation, that are shared with the public for free.[f]
	(Online) platforms and workshops	*Fund the foundation of maker spaces.* A powerful way through which maker spaces can be funded and made sure to be promoted and used is by setting them up as part of schools.[o] For example, the University of Pretoria has opened a maker space as part of its library, which has already seen the development of the first successful HHS innovation.
	General resources and infrastructure	*Subsidize access to the Internet and electricity.* Though in many parts of the Western world, access to the Internet and electricity is taken for granted, there are still many people who cannot access these resources due to infrastructural or financial constraints. At the same time, the potential for HHS innovation is widespread across the world, just as the importance of access to the Internet and electricity as enablers of HHS innovation. Subsidizing these resources is, therefore, warranted.[x]
	Producers and industry	*Educate the business sector about the benefits of open innovation.* Firms can be important supporters of HHS innovation (e.g., by supplying toolkits) but they are not always aware of the benefits of HHS innovation for them (e.g., the complementarity of designs). Therefore, the business sector should be educated (e.g., through MBA courses) about the benefits of open innovation and, particularly, involving citizens.[y]

Sources: von Hippel (2017)[a], Gambardella et al. (2017)[d], Franke et al. (2006)[e], Browder et al. (2019)[k], Fox (2014)[o], von Hippel and de Jong (2010)[x], Kuusisto et al. (2013)[y], Nielsen et al. (2016)[z].

As can be seen from Table 3.7, when the entire HHS innovation ecosystem is targeted, innovation policies can support HHS innovation from various angles—cultivating both top-down (e.g., the enforcement of open standards) and bottom-up initiatives (e.g., eliciting citizens' need for commercialization). One can, however, also spot controversies in the policy measures suggested to date. For example, in Table 3.7, we see that scholars have called for, on the one side, the enforcement of open standards (von Hippel, 2017) and, on the other side, the promotion of technology licensing (de Jong et al., 2018) to support HHS innovation outcomes. Though both of these policy measures make sense based on the studies individually, these are likely to have counterproductive effects when executed at once by a government seeking to support HHS innovation. It signals that a holistic perspective on HHS innovation policy is missing (cf. Bengtsson and Edquist, 2022). A problem we believe can be alleviated if future publications position their suggested policy measures in the HHS innovation ecosystem framework displayed in Figure 3.3 and analyze, for each element, if the measures can be supportive or constraining.

5. Discussion

In this paper, we presented the first version of an ecosystem framework for HHS innovation. Drawing on insights from the business innovation ecosystem literature (i.e., NIS and entrepreneurial ecosystems), we made a distinction between elements in the (institutional) environment of citizens and elements that are direct facilitators (cf. Stam and Van de Ven, 2021). We then identified (based on literature research and expert interviews) that enablers of HHS innovation in the citizens' (institutional) environment can be aggregated to the elements of (1) rules and regulation, (2) cultural norms and values, and (3) social capital. As facilitators, we identified the elements of (4) human capital, (5) innovation tools, (6) (online) platforms and workshops), (7) general resources and infrastructure, and (8) producers and industry. We argue that these eight elements co-evolve in regional territories, show interdependence, and together determine regional levels of HHS innovation. Moreover, for each element, we suggested quantitative indicators that can be applied to regional analyses so that this argument can be tested empirically.

The main contribution of our ecosystem framework applies to policymaking. Suggestions from (individual) HHS innovation studies, so far, have had little impact on innovation policy—there is a need for a more systematic approach (cf. Bengtsson and Edquist, 2022). Our framework facilitates such an approach by providing an overview of the regional elements enabling or constraining the development and diffusion of HHS innovations (Figure

3.3) and the previously suggested policies that intervene with each of the elements (see Table 3.7 and Table C.1). This provides scholars with a framework in which they can position their policy suggestions, as to facilitate the complementarity of measures and a holistic approach, and this provides policymakers with a toolbox of the measures that can be applied to support HHS innovation development and diffusion.

5.1. Implications for theory

Our findings have several implications for theory. First, we show that the ecosystem elements enabling innovation and diffusion in the household sector are clearly distinct from those of the business sector (e.g., Edquist, 2006; Ptak and Bagchi-Sen, 2011, Stam, 2015; Stam and Van de Ven, 2021). Looking at the aggregated elements in Figure 3.3, there is some overlap, but even the overlapping elements warrant a specific interpretation in light of HHS innovation. This is important, as the opposite (i.e., a high similarity between the different models) would imply that there is no need for focusing on HHS innovation separately—measures taken by formal innovation policy programs would then naturally spill over to citizens. But, HHS innovation is different from innovation in the business sector, characterized by different ecosystem elements and different required policy measures. We enrich previous studies that only highlighted a number of enabling factors of HHS innovation but never attempted to capture the full picture (see, e.g., de Jong et al., 2021) and studies that did attempt to do so but tried incorporating insights from the business sector into HHS innovation one-on-one (see, e.g., Bengtsson and Edquist, 2022).

Second, our ecosystem framework enables systematically studying HHS innovation at a regional level. HHS innovation studies, so far, are predominantly based on insights derived from national surveys, leading to rather generalized findings—e.g., that innovating citizens are "more likely than the average citizen to be highly educated, to have a technical education, and to be male" (von Hippel et al., 2011, p. 5). Though we do not discard these findings, they do not account for local contextualities that may help to tease out in more depth what enables or constrains HHS innovation and how supportive policies can be developed. Whilst, for HHS innovation specifically, local contextualities can be highly important. As mentioned before, the innovation process and outcomes of citizens are more likely to be bound by geographical constraints than innovation in the business sector (cf. Hossain, 2016; Seyfang and Smith, 2007). By suggesting regional, quantitative measures that can assess the role of the ecosystem elements we theorized, our studies contribute to systematic empirical assessments of HHS innovation development and diffusion that account for more of a region's contextual subtleties. Therefore, our study also informs policymaking that is more sensitive to regional characteristics (e.g., rural versus metropolitan areas) and can make a stronger impact on supporting citizens in their innovation efforts—as studies on entrepreneurial ecosystems have managed to do for supporting entrepreneurship (Stam and Spigel, 2016).

Third, our ecosystem framework challenges future HHS innovation studies to position their policy suggestions in accordance with the ecosystem elements we identified. This will enhance both theory and policy by evoking in-depth analyses of the complementarity of research findings and implications. A lack of such analyses in past publications has resulted in inconsistent suggestions for HHS innovation policy, as we illustrated in section 4.5 using the contradicting suggestions by von Hippel (2017) and de Jong et al. (2018). By providing a framework for the enabling factors of HHS innovation such contradictions may be avoided.

5.2. Implications for policy

The first, rather obvious policy implication of our study is that we provide a framework summarizing all of the elements that can be influenced by policymakers to enable more favorable HHS innovation outcomes (Figure 3.3) and an overview of all of the policy levers that can be pulled as suggested by previous studies (Table 3.7 and Table C.1). As such, our study gives an integral overview of what can be done to facilitate HHS innovation and enhance societal welfare—i.e., a toolbox for policymakers seeking to support HHS innovation.

Another implication of our study results from the connection between the ecosystem model we developed (Figure 3.3) and previous innovation ecosystem models conceptualized to study the business sector (e.g., Edquist, 2006; Stam and Van de Ven, 2021). As mentioned above, though we must be careful to respect the intricate meaning of the elements, there exists a slight degree of overlap between the (aggregate) ecosystem elements as we identified enabling HHS innovation and the ecosystem elements enabling innovation in the business sector. This degree of overlap provides opportunities for more careful policymaking in the future, as the effects innovation policies have on functions enabling innovation in the business sector can spill over to citizens—generating both positive and negative externalities. We will illustrate our argument with an example of both.

Human capital has an important role in both HHS and formal innovation processes (Anderson et al., 2014; Franke et al., 2006; Unger et al., 2011; von Hippel, 2017), as also stems from the ecosystem models studying these innovation paradigms (cf. Edquist, 2006; Stam and Van de Ven, 2021). Moreover, scholars have also argued similar effects of more specific human capital components. For example, for innovation in the business sector, Amabile (1996) argues that employees' expertise, factual knowledge, and technical proficiency are key to innovation. Similar observations have been made in the HHS innovation literature for citizens' innovation process (Nielsen et al., 2016; Troxler and Wolf, 2017; von Hippel, 2017; Wolf and McQuitty, 2011). Examples of policy measures aimed at growing human capital in the business sector—e.g., subsidizing lifelong learning programs—are, therefore, likely to positively spillover to HHS innovation.

To illustrate the case of a negative externality, we consider the following. The HHS innovation ecosystem framework and innovation ecosystems studying the business sector both highlight the role of formal institutions—implying that regulating the business sector might indirectly also mean regulating HHS innovation. An example can be given by R&D subsidies, which are provided to firms to alleviate the market failures of uncertainty and indivisibility (Chaminade and Edquist, 2010). Providing these R&D subsidies to firms, however, may also have a negative spillover effect on HHS innovation. As Gambardella et al. (2017) show, R&D subsidies may promote closed R&D by firms even when open R&D, inclusive of HHS innovation, is more favorable for the firm and social welfare (conditional on the complementarity of firms' and citizens' innovation efforts).

By visualizing what ecosystem elements matter for HHS innovation, policymakers can easily identify the elements where HHS innovation and formal innovation policy may overlap, hence, where (positive or negative) spillovers may occur. Thereby, we hope our study will contribute to more careful innovation policies in the future.

5.3. Limitations and future research

The ecosystem framework in Figure 3.3 enables future work toward more regional, quantitative assessments and holistic policymaking regarding HHS innovation—but obviously, a lot of follow-up work has to be done. To take a first step, the conceptual analysis in this paper has been limited to identifying what ecosystem elements (and connected policy measures) are relevant for HHS innovation while assuming that these elements co-evolve in a territory and complement each other. Even though we believe these assumptions are not farfetched looking at the resulting ecosystem elements and similar approaches were taken in the first studies of ecosystems in related fields (e.g., Stam and Van de Ven, 2021), one can still consider a limitation of this work that we did not provide an in-depth analysis of the interdependencies between the ecosystem factors. Future theoretical and quantitative studies may want to go into this particular avenue so that the dynamics of the HHS innovation ecosystem become clearer.

A second limitation is our current lack of indicators that can be easily backed up with data, i.e., a quantitative assessment of the HHS ecosystem is lacking. Future quantitative assessments of HHS innovation ecosystems will give us an indication of the extent to which the elements are truly correlated, hence, can be considered part of an ecosystem and not isolated antecedents of HHS innovation (cf. Leendertse et al., 2022). Moreover, future regression analyses will give us a sense of the completeness of the ecosystem model presented in this paper—i.e., to what extent regional variations in HHS innovation development and diffusion can be explained by the ecosystem elements in our framework. To facilitate such quantitative analyses, we suggested an initial set of indicators that can be used on a regional level.

Finally, we would like to note that although a great diversity of policy instruments have been suggested in the HHS innovation literature—which also stems from this paper and Table C.1 in particular—very few have been evaluated on effectiveness. Panel data on HHS innovation is lacking, hampering the thorough analysis of policy interventions (von Hippel, 2017). Hence, the policy measures presented in this study provide an overview of what has been suggested by previous studies but not of what has been proven effective by previous studies. We hope that future data collection efforts will propel HHS innovation, as a field, toward more thorough quantitative assessments of the new innovation paradigm. One in which citizens, not only firms, are considered drivers of social and technological developments.

Chapter four

The diffusion of user innovations in firm-hosted communities: Contributions by professional versus amateur users

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Abstract

Users can develop innovations that improve or complement a firm's product. To benefit from user innovation, the firm may start an online firm-hosted user innovation community (UIC), where users can share and adopt innovations developed by their peers. However, the antecedents of peer diffusion in firm-hosted UICs are rarely investigated. We explore if contributions by professional users (generating income with the firm's product) diffuse better than innovations by amateurs. We hypothesize better diffusion for professional contributions due to professionals' more advanced expertise in design and marketing, which may facilitate the development of designs that are (relatively) easy to adopt for others. We also hypothesize that the diffusion of professional contributions increases with commercial motivation and/or a central network position in terms of closeness. Our empirical context is YouMagine, a firm-hosted UIC where users share innovations related to the Ultimaker 3D printer. Analyzing multiple-source data of 614 innovations contributed by 122 users, we find that contributions by professionals diffuse better but only when their commercial motivation or closeness centrality is high. Our findings imply that, unlike the rosy impressions about amateur users that previous studies may leave, it is more likely a professional who develops innovations that diffuse to peers in firm-hosted UICs.

Keywords: user innovation; user communities; diffusion; professionalism; social networks.

1. Introduction

It is well known that users of products external to the producers of these products may innovate themselves rather than leaving all innovation efforts to the producer firms (von Hippel, 1978; 2005). Users sometimes develop improvements to a firm's product or complementary modules (like plug-ins) to expand the product's functionality (Gambardella et al., 2017). Some users are professionals who generate income using the firm's products, while others are amateurs who use the firm's products for leisure activities (Jeppesen and Frederiksen, 2006). Regardless of who innovates, firms are advised to leverage value embodied in user innovations related to their products (Bogers et al., 2017; West et al., 2014).

To benefit from user innovation, firms may host online communities where users share their improvements or complements (Ma et al., 2019). Firm-hosted user innovation communities (UICs) have been documented for producers of software (Dahlander and Magnusson, 2005), computer-controlled musical instruments (Dahlander and Frederiksen, 2012), and 3D printers (Amza et al., 2017; West and Kuk, 2016), to name only a few. In a typical firm-hosted UIC, users freely reveal innovations to an online platform (Yan et al., 2018)—putting the firm in a favorable position to (a) integrate promising innovations in their future products and (b) create immediate value for users, who can adopt innovations revealed on the platform (Jeppesen and Frederiksen, 2006; Ma et al., 2019).

Previous studies of firm-hosted UICs dealt with questions alongside the following three topics. First, why users contribute to firm-hosted UICs—they may do it for, e.g., recognition (Jeppesen and Frederiksen, 2006), community responses and feedback (Zhang et al., 2013), or expected benefits like extrinsic rewards (Kankanhalli et al., 2015). Second, how firms can best manage such communities, e.g., with toolkits (Jeppesen, 2005), embedded employees (Dahlander and Wallin, 2006), rating systems (Nambisan and Nambisan, 2008), and charismatic moderators (Becker et al., 2022). Third, if and when user contributions are valuable to the firm—by looking at the novelty and perceived usefulness of contributions for new product development (e.g., Dahlander and Frederiksen, 2012; Poetz and Schreier, 2012) and, more recently, at antecedents of actual adoption by the hosting firm (e.g., Jensen et al., 2014; Ma et al., 2019).

Direct diffusion of user innovations to peers, however, is under-investigated. This is an omission, as diffusion to peers directly affects the value that users extract from firm-hosted UICs. Moreover, peer diffusion can serve as a valuable signal to firms of the potential demand for certain product improvements or complements (Ma et al., 2019). This paper contributes to the literature on firm-hosted UICs by analyzing the antecedents of diffusion of user innovations to peers.

We compare the contributions of professional and amateur users. Professional users are those who generate income using the firm's products (Jeppesen and Frederiksen, 2006). They are usually employees, business owners, and self-employed external to the producer firm using the product in a business environment. In contrast, amateur users work with the product in their leisure time, mainly as a hobby. The same distinction was made in Jeppesen and Frederiksen's (2006) study of computer-controlled music instruments, in which users contributed innovations to the UIC of Propellorhead—a producer of computer-controlled music instruments. Some contributors were professionals (e.g., owners of recording studios or professional musicians), while others were amateurs (e.g., hobbyist musicians or fanatics about modifying or tweaking sounds). There are good reasons for expecting professional contributions to firm-hosted UICs to diffuse better.

In general, previous studies sketched a rosy view of the value of innovation by external users. For example, compared to firms' employees, external contributions to firm-hosted UICs are deemed more novel and useful (Dahlander and Frederiksen, 2012; Poetz and Schreier, 2012). Yet, previous studies did not consider factors that *compromise* diffusion to peers. We detected three problems and will argue that especially contributions by professional users are less hindered by these.

First, users differ in their *ability* to develop innovations that are easy to adopt by others. Most users develop rough prototypes that are good enough to serve themselves but not yet full-fledged products that can be 'plugged and played'. Compared to producer firms, the prototypes by external users are more likely to enable novel functions, but unfortunately, these are not designed to facilitate broad diffusion. Users tend to have superior knowledge about their own needs but lack solution knowledge of how to develop reliable, durable solutions that can be adopted by many. User innovations typically contain bugs, lack standardization, and require technical skills to be replicated (de Jong et al., 2022).

Second, users have different *motives* to innovate, which has implications for diffusion to peers. The classical view is that users innovate for personal needs; they build innovations to use themselves (von Hippel, 1978; 2005). More recently, studies found users' motivation can also be hedonic (for enjoyment, intellectual stimulation, or learning purposes) or commercial (to generate income) (Raasch and von Hippel, 2013a). Motivation has consequences for the dissemination effort users are willing to put in. Those who are commercially motivated try harder to deliver value to others (i.e., their proposed customers), while diffusion incentives are lacking for those motivated only by their personal needs or hedonic reasons (de Jong et al., 2015).

Third, users who participate in firm-hosted UICs have different *network positions*, enabling some of them to do a better job at developing innovations that diffuse more effortlessly. Users in core positions are not only more likely to become innovators (Dahlander and Frederiksen, 2012), but they are also in a superior position to obtain detailed information about others' needs and solutions—which is helpful to develop innovations that are more novel and better received by peers (Resch and Kock, 2021).

Our research addresses these three factors compromising peer diffusion in firm-hosted UICs. Our central hypothesis is that the innovations of professional users will diffuse better than those of amateur users. As we will elaborate in our theory section, professional users can operate at standards that their customers appreciate, and—on average—they will have more context-specific design and marketing expertise compared to amateurs. This expertise helps them to create innovations that can diffuse more effortlessly. Interestingly, in the user innovation literature, professionals are often portrayed as a less valuable source of innovation. When it comes to truly novel and first-of-a-kind innovations, heroic amateurs (innovating in their leisure time) are promising actors (von Hippel, 2017), also when directly compared to employees of producer firms (e.g., Poetz and Schreier, 2012; Pollok et al., 2021). Our research enables an analysis of whether this view should be nuanced. Perhaps, professionals are better at developing innovations up to a stage where these can be adopted by others and should be recognized for the (different) value they can add to UICs.

Next, while we hypothesize professionalism as the central driver of peer diffusion, we consider commercial motivation and network position as moderating factors. As we will explain below, professionalism proxies ability, while commercial motivation and network positions provide user innovators with a reason and information advantage helping to deploy their ability to develop innovations that can diffuse more effortlessly. Accordingly, we expect the relationship between professional user status and peer diffusion to be stronger, the more a user is commercially motivated or has central network positions in the firm-hosted UIC.

Investigating the role of professional users is important, both for the academic debate and practitioners. Our study helps develop knowledge about the characteristics of users who come up with innovations that diffuse. Thereby, we respond to earlier calls to investigate the antecedents of user innovation diffusion (de Jong et al., 2021; von Hippel, 2017). Diffusion implies immediate value creation to other community members and enhances the general value of the firm's product.

To test our hypotheses, we analyzed 614 innovations contributed by 122 users to YouMagine—a UIC hosted by Ultimaker, a leading manufacturer of 3D printers. We find the contributions by professional users to diffuse significantly better compared to those by amateurs, but only if users are highly commercially motivated or hold a central network position in terms of closeness by outdegree. Our findings illustrate that—for peer diffusion in firm-hosted UICs—professional users are more relevant than has been recognized in previous studies.

2. Theory and hypotheses

In firm-hosted UICs, one can distinguish two types of contributors: professional and amateur users (Jeppesen and Frederiksen, 2006). Professional users are those who generate income using the hosting firm's products. Their activities can be diverse, depending on the product at hand. For example, in our research context of 3D printing (see section 3), professional users are mainly employees, self-employed, and business owners who are using 3D printers to produce and sell items, for prototyping tasks, or to resell as distributors. They may also make money with consultancy or training services in rapid prototyping or by popularizing 3D printing as influencers or bloggers.

The professional-amateur distinction highly overlaps with the distinction between business-to-business and business-to-consumer users, but not entirely. Individuals in the household sector sometimes generate income using the firm's product—e.g., as informal home-based entrepreneurs. In our research context of 3D printing, one can think of individuals who print items for other users in exchange for a fee or who (also) sell their designs on platforms like eBay and Shapeways.com. We regard such (business-to-consumer) contributors also as professional users; what matters is whether the user generates income with the hosting firm's products (Jeppesen and Frederiksen, 2006; Pollok et al., 2021).

We label all other users as amateurs, working with the hosting firm's products as a leisure activity. To denote amateur users, we avoid the term 'hobbyist'. This is because earlier studies defined hobbyists as *all* users external to the hosting firm, regardless of whether or not they generated income. In these studies, 'professionals' indicated employees that worked for the hosting firm itself (e.g., Poetz and Schreier, 2012; Pollok et al., 2021). In our study, the hosting firm's employees are not part of the focus.

2.1. Professional user status and diffusion

We expect that in firm-hosted UICs, contributions by professional users will diffuse better than those by amateurs. Our reasoning revolves around users' ability: professional contributors have more expertise in areas helpful to develop innovations that can be adopted more effortlessly.

One of the main problems with peer diffusion is that user innovations are often insufficiently developed to be 'plugged and played' (de Jong et al., 2022)—which can be explained by von Hippel's (1994) early work on sticky information. Users have superior knowledge about their personal needs. As this knowledge is difficult to transfer to producer firms, users are inclined to develop solutions that perfectly fit their context-of-use. User innovations, therefore, often embody novel functions that are the first of a kind (Ogawa, 1998; Riggs and von Hippel, 1994; von Hippel, 2005). However, a downside is that users generally lack knowledge related to design, engineering, and marketing (von Hippel, 2005)—this is what producer firms are good at. Producers are generally much better capable in developing improved versions of products that address well-known needs (Riggs and von Hippel, 1994), which can disseminate broadly. For user innovations, in contrast, adoption requires technical skills and high replication effort, putting an extra burden on adopters (de Jong et al., 2022). Many user innovations are prototypes, not yet in a format that peers can adopt effortlessly, and this also applies to many contributions to firm-hosted UICs.

Compared to amateurs, professional users know how to operate at standards that other people appreciate and are willing to pay for. To generate income using the hosting firm's products, they create value for others (e.g., customers, colleagues, or their manager) by delivering quality and reliability, and by working with a particular empathy—as counseled by the basic principles of product development (Schilling, 2022) and marketing (Jobber and Ellis-Chadwick, 2020).

When professional users develop innovations related to the hosting firm's products and disclose these to the UIC, they are not expected to do an amateurish job but rather to maintain their professional standards. We argue that this applies even when professionals innovate without direct commercial interests—for example, when they develop solutions to work-related problems (Schweisfurth and Dharmawan, 2019; Wu et al., 2020) or simply for fun (Kankanhalli et al., 2015). In this context, Lukoschek and Stock-Homburg (2021) demonstrated that job-related knowledge and resources that people obtain at work spill over to the development of user innovations that people develop for other reasons.

Beyond the prototyping skills that all contributors to UICs have (to develop their user innovations in the first place), we argue that professional contributors have more expertise in design and marketing—helping them with developing innovations that are better standardized, more reliable, and better tailored to adopters (Cohen, 2015) so that diffusion is more likely.

First, on average, professional users are expected to have better design skills. Professional designers are individuals "who apply their knowledge to their vocation with rigor and probity, usually within a professionally oriented community" (Swindells et al., 2001, p. 130). Professionalism requires the accumulation of specialized design competencies, obtained from education, training, work experience, and frequent practical application (Füller et al., 2017). A key characteristic distinguishing professional work from other work is that it is judged upon a social standard; whether the professional has shown the ability to produce designs that do justice to the rigorous application of knowledge (Parkan, 2008). Professionalism also requires continuous inquiry into the latest developments and advancements in a field (Parkan, 2008). In contrast, amateurs' design competencies are mainly accumulated by the trial and error of individual practice (cf. Moore, 1970).

Second, professional users will have more marketing expertise in the area of the hosting firm's products—which is another competence facilitating the development of innovations that speak to a broader audience (Zhu et al., 2017). Marketing expertise enables individuals to develop innovations that cater to the needs of other users and shape those into products that are easier to adopt (Jobber and Ellis-Chadwick, 2020). Obviously, marketing is crucial for self-employed professionals, business owners, and sales agents, but—actually—most employees develop some marketing expertise, even if this does not explicitly follow an employee's job requirements (Grizzle et al., 2009). Moreover, marketing expertise tends to be domain-specific (Dreyfus and Dreyfus, 2005; Füller et al., 2017). Consequently, user innovators generating income with the hosting firm's products will be better able to empathize with other users and deploy their marketing expertise to develop innovations.

In all, we recognize that professional and amateur users may both have unique needs and prototyping skills that enable them to innovate but—ceteris paribus—professional users have more expertise facilitating the development of innovations that diffuse (i.e., diffusion-related expertise) so that we hypothesize:

H1: In firm-hosted user innovation communities, the diffusion to peers of innovations contributed by professional users is better compared to innovations contributed by amateur users.

2.2. Moderating role of commercial motivation

We follow an interactionist approach (Woodman and Schoenfeldt, 1990), recognizing that the relationship between professional user status and diffusion to peers may be stronger under specific conditions.

We first propose commercial motivation as a moderator. Users may innovate for various reasons, influencing the extent to which they put their diffusion-related expertise to practice. Specifically, we anticipate that when users (also) seek commercial benefits with their innovations, adoption by others becomes more important to them—so that they are more likely to deploy their design and marketing expertise. As a consequence, the relationship between professional user status and peer diffusion will strengthen.

Previous studies indicate a variety of motives driving users to innovate (Chen et al., 2020; Stanko and Allen, 2022), with this variety observed for both amateur and professional users. The classical case is that users innovate to address personal needs (e.g., 'I needed this innovation to make the product work better for me') (von Hippel, 1978). More recently, scholars recognized users are not driven purely by personal needs (Chen et al., 2020; von Hippel, 2017). Part of their motivation may be hedonic: they enjoy innovation, seek personal development, or aim to learn or practice new skills (e.g., 'I enjoy developing extras to the product to see what is possible') (Raasch and von Hippel, 2013a). Also, users may be driven by a desire to generate income (e.g., 'this innovation improves the use-value of the product, which enables me to generate income') (Chen et al., 2020; Raasch and von Hippel, 2013a).

It is important to notice that when professional users contribute to firm-hosted UICs, their motivation is usually not as commercial as one might think. Many professional users improve products that they use at work or develop complementary innovations to do their job more efficiently (need-related motivation) (e.g., Wu et al., 2020). Also, they are often product enthusiasts, motivated to learn and practice with the latest developments in their professional field (hedonic motivation) (Parkan, 2008). In this context, from the related literature on open-source software, we know that many professional coders contribute to open-source projects for their use, fun, to showcase their skills, or to meet like-minded others (e.g., Bitzer and Geishecker, 2010; Lakhani and Wolf, 2005).

Regardless of their motivation, (professional) users may freely reveal their innovations to firm-hosted UICs. In general, users share because they empathize with other users or hope that others will improve their innovations so that they can obtain a better version themselves (Harhoff et al., 2003; von Hippel, 2005). When users are commercially motivated, they may have additional reasons to reveal: to develop an expert reputation, to generate demand for complementary products, or to develop network relationships that provide commercial benefits (de Jong and Flowers, 2018; Henkel et al., 2014). Users then obtain commercial benefits indirectly.

Users' motivations impact their dissemination efforts (de Jong et al., 2015). Typically, when their motivation is need-related and/or hedonic, adoption by other users is less or not important to them. Such users have low incentives to continue developing their innovations up to a stage at which adoption by others becomes more effortless. Thus, they spend less time on standardization, fine-tuning, and documentation (de Jong et al., 2015; 2018). Need-driven and hedonic users are self-rewarded: once they have developed an initial prototype enabling a fix, learning, or them to enjoy the innovation process, the benefits adopters would obtain are an externality to them (von Hippel, 2017). In contrast, the more users are commercially motivated, the more fundamental adoption by others becomes. In sum, we expect commercially-driven users to deploy their diffusion-related expertise more than users not driven by such motives.

We already theorized that professional users possess the design and marketing expertise required to develop innovations that can diffuse broadly (H1). When they are also commercially motivated, this provides professionals with a reason to deploy their expertise—while amateurs, on average, lack design and marketing skills in the domain of the hosting firm's products. Our second hypothesis is:

H2: In firm-hosted user innovation communities, the relationship between professional user status and the diffusion of contributions to peers will be stronger, the more a user is commercially motivated.

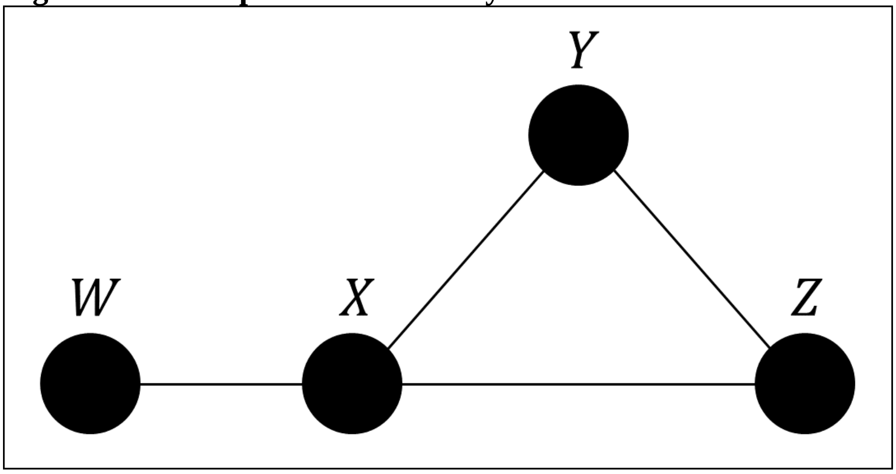
2.3. Moderating role of network position

We propose users' network position as a second moderating variable. When users have a central network position, they can better observe the needs and contributions of other user innovators. In combination with diffusion-related expertise, we expect such a network position to enable users to develop innovations matching with adopters' context-of-use and prior knowledge—for which diffusion to peers is more likely.

In UICs, typically, few devoted participants account for the majority of community interactions (Dahlander and Frederiksen, 2012; Garton et al., 1997; Lakhani and von Hippel, 2004), leading to skewed distributions in network centrality. Network positions (and the accompanied levels of centrality) have implications for users' ability to innovate and the kind of innovations emerging—as they provide users with differentiated access to information. Information accessed through user communities has been proven significant in steering innovation outcomes. For example, Franke et al. (2006) found that information resources obtained from user communities positively affect the likelihood that users develop commercially attractive innovations. Other studies associated users' network positions and the related information benefits with the development (Dahlander and Frederiksen, 2012) and radicalness of innovations (Resch and Kock, 2021). To our knowledge, the diffusion of user innovations to peers has not been studied yet as a dependent variable.

Given our focus on diffusion to peers in firm-hosted UICs, closeness is the most relevant social network measure for our purposes. Here, closeness indicates the network distance of a user to all other users active in the firm-hosted UIC. For example, if we consider Figure 4.1, user X is most central in terms of closeness. To all other users, X's path length is only one. Z and Y hold the second most central position, while W is located the least central. Since most information in user communities spreads through indirect connections (Resch and Kock, 2021), the further two users are separated, the less likely information transfer occurs. Therefore, user innovators are best exposed to information when connected to others through the shortest possible path length—which is captured by having the most central position in terms of closeness (Vriens and Corten, 2018).

Figure 4.1. Example of a community network with four members



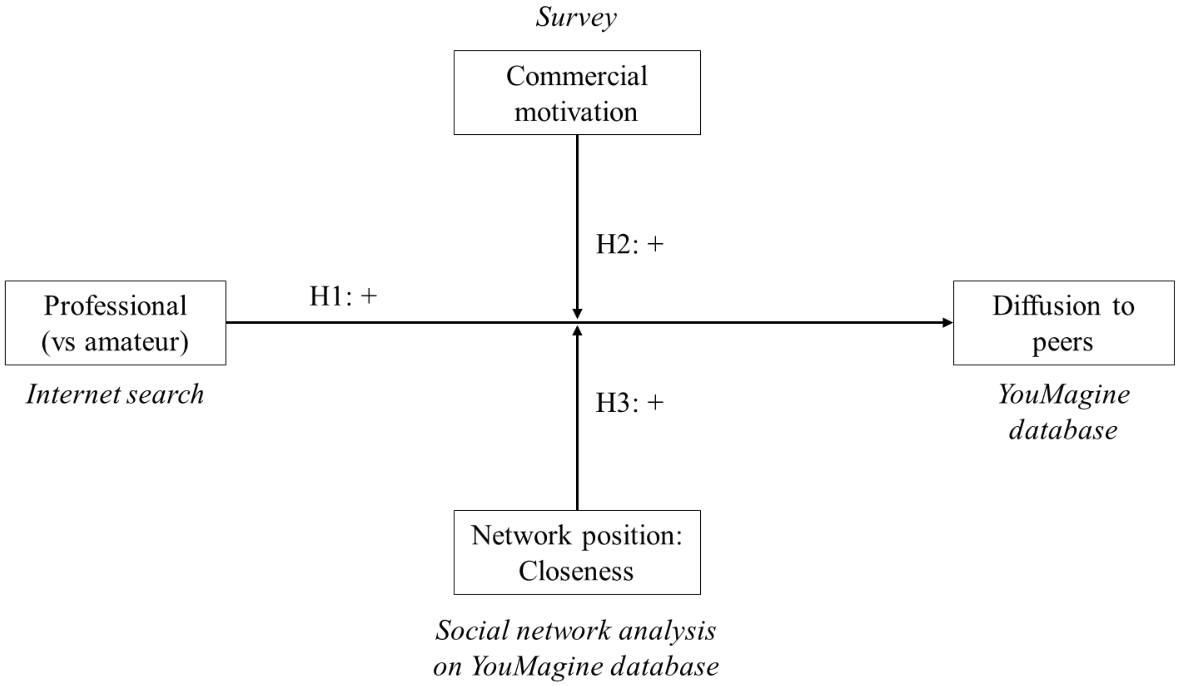
At high closeness, users have two information benefits. First, they can learn more about other users' needs and the community's demands (Claussen and Halbinger, 2021; Oehlberg et al., 2015). Second, they obtain more knowledge about the solution space by observing the peculiarities of other users' innovations and the feedback and help offered by others (Oehlberg et al., 2015). They can also copy modules and best practices from other users to improve their designs (Claussen and Halbinger, 2021).

We expect that the information benefits accrued through a central network position in terms of closeness positively moderate the relationship between professional user status and peer diffusion. Even when professionals and amateurs would have an equally central network position in terms of closeness, professional users are still more likely to have the design and marketing expertise required to innovate designs that are easy to adopt. Expertise is their enabler, while information from the network reveals where to go. Our line of argumentation resembles Poetz and Schreier (2012). In a study of user contributions to a crowdsourcing experiment, they argued that professional expertise facilitates understanding *"how existing solutions work and how they can be modified in the development of new products"* (p. 247). Our third hypothesis is:

> *H3: In firm-hosted user innovation communities, the relationship between professional user status and the diffusion of contributions to peers will be stronger, the more central a user's network position is in terms of closeness.*

Our hypotheses are summarized in Figure 4.2.

Figure 4.2. Conceptual framework



Notes: Data sources in italics.

3. Methods

Our empirical context is YouMagine (www.youmagine.com), an online knowledge-sharing platform where users of the Ultimaker—one of today's leading commercial 3D printers—can share 3D printing designs. A part of YouMagine's environment is dedicated to incremental improvements and complements to Ultimaker's printers. The designs posted in this category fit with our definition of user innovations contributed to a firm-hosted UIC.

An example of an incremental improvement contributed to YouMagine is a nozzle tool developed by Anders Olsson (www.youmagine.com/designs/nozzle-torque-wrench). The nozzle of a 3D printer has to be replaced regularly, especially when crafting with hard materials. Olsson both designed a new nozzle block and a torque wrench that allow for the quick replacement of the nozzle. Reaching the right torque is essential to avoid damaging printed objects due to over-tightening or leaking. Olsson's tools ensure proper force every time a nozzle is changed. After reaching optimal torque, the tightening tool starts slipping and produces clicking sounds. Users massively adopted Olsson's tools. Later on, Ultimaker included his nozzle block in its new generation of 3D printers.

An example of a complementary application that expanded the general value of the Ultimaker printer is a camera mount created by Erik Cederberg (www.youmagine.com/designs/ultimaker-2-camera-mount). To users of 3D printers, filming the printing process can be enjoyable and serve a purpose—to detect errors if printing fails. Cederberg's camera mount is a module that users can click on the machine and has been downloaded many times.

3.1. Data

We collected data from three sources. First, YouMagine provided us with access to its databases, including data on the (diffusion of) users' innovations and their social network positions. Second, we searched the Internet using the details of all users in our database, to code them as professional or amateur. Third, we surveyed the user innovators to learn how much their motivation had been commercial and to collect data on several control variables. The combination of sources helped us to avoid problems with endogeneity and common method bias (Lindeboom and Kerkhofs, 2009).

First, we elaborate on YouMagine's database. In September 2019, we mined a copy of all recorded data, including posted designs and registered platform users. We selected all designs that could be regarded as incremental improvements of Ultimaker's products or complements that expand its general use-value. Hence, we looked at designs that—based on Ultimaker's offerings—improved existing functions or enabled new features (Hoonsopon and Ruenrom, 2012). Users uploaded these to YouMagine's category of "Ultimaker printer parts and enhancements". We manually inspected all designs to exclude erroneous uploads. Our initial database included 1,426 user innovation designs uploaded by 378 members. Next, we saved the details of these users, as well as the details of all platform users that were followed by any of the 378 users, to construct our network measure of closeness by outdegree (see hereafter).

Our second source is an Internet search done in October 2020 to trace if users were professionals (i.e., whether they generated income using or working with Ultimaker's 3D printers). Most users had filled in their personal profile page at YouMagine and/or provide links to their personal websites. If neither a description nor a personal weblink was provided, we used users' names and e-mail addresses to find their details on other knowledge-sharing platforms (e.g., Thingiverse), personal web pages, and social media.

Our third source is a survey sent in November 2020 to all 378 users in the database. The survey was announced by YouMagine's platform manager, after which we sent the survey link. After sending one reminder, within two weeks, we received completed 122 responses (32% response rate). We used the survey's introduction page to explain that our questions were concerned with innovations designed to improve or enhance Ultimaker's 3D printers. To avoid confusion, we printed the description of the users' designs on the first page. We then asked about the users' innovation motives and a range of control variables (see hereafter). On average, our survey respondents worked with 5.4 different 3D printers and had 7.2 years of experience in 3D printing. Thirty-six percent had a Master's or doctoral degree. In terms of education and experience, these figures are highly similar to previous samples of Makers surveyed about 3D printing (Moilanen and Vadén, 2013).

Combining the YouMagine database with our web research and survey responses, our final dataset includes 614 innovations uploaded by 122 users.

3.2. Variables

The key variables in our analyses (diffusion to peers, professional, commercial motivation, and closeness by outdegree) are obtained from distinct sources. Table 4.1 shows the variables we analyzed to test our hypotheses, their data sources, and measurement levels. Notice that part of our data is measured at the individual level and the other part is measured at the design level. Hence, we deal with multilevel data with designs nested in the portfolios of individuals.

Table 4.1. Variables and descriptive statistics

Variable	*Source*	*Description*	*Mean*	*SD*
Individual level (n = 122)				
Professional	Web search	User innovator is a professional (coded 1) versus amateur (coded 0)	.164	.372
Commercial motivation	Survey	User created designs to generate income in the past five years (1 = never; 5 = always)	1.426	.726
Closeness by outdegree	Database	User's closeness centrality by outdegree	.714	.026
Master/doctorate	Survey	User obtained a Master's or doctoral degree (0 = no; 1 = yes)	.361	.482
Experience 3D printing	Survey	User's experience in 3D printing (in years)	7.172	2.068
Lead userness	Survey	Construct of two items: 'When I think of the available tools, equipment, methods and processes in 3D printing…I am dissatisfied with some pieces of commercially available 3D printers' and '…I have needs which others experience only later' (1 = never; 5 = always) (α = .77)	2.553	.888
Design level (n = 614)				
Diffusion to peers	Database	Log-transformed index variable composed of three variables: downloads of a design's CAD files, downloads of a design's instruction files, and number of times the design was favorited by other users (α = .88)	-.130	.418
Words	Database	Number of characters used to describe the design	823.7	1217.1
Days	Database	Number of days since the design was posted	1901.5	450.7
License	Database	Presence of a license constraint on commercial derivates or continued development (0 = no; 1 = yes)	.215	.411

Notes: M = mean, SD = standard deviation.

Our dependent variable is the extent to which designs diffused to other users of the YouMagine community. Similar to Claussen and Halbinger (2021), we composed an index of multiple variables: (1) the number of downloads of a design's computer-aided-design (CAD) files, (2) the number of downloads of the instruction files submitted with a design, and (3) the number of times other YouMagine users had added the design to their collection of favorites. These three metrics were standardized and merged into a latent construct (α = .88). As we found that the distribution of the resulting diffusion index was positively skewed, we log-transformed the variable.

Our main independent variable is a dummy indicating whether the user innovator is a professional or not. We coded this variable with an Internet search (similar approaches were taken by Jeppesen and Frederiksen (2006) and Pollok et al. (2021)). Two researchers independently checked respondents' affiliations and relevant web profiles. Users were deemed professional if they somehow generated income from, or by working with, Ultimaker's 3D printers. We encountered a range of professional users, including employees, business owners, and self-employed who were resellers of 3D printers, trading materials or components, doing consultancy work, or running a business revolving around applications of 3D printing (e.g., manufacturers of tailor-made tools or artifacts). Other users that we coded as professionals made money by popularizing 3D printing or by sharing expertise in a blog or online platform, usually in combination with the provision of commercial services or selling advertisements and affiliate marketing activities. If no income-generating activities could be detected, we regarded users as amateurs. Inter-rater agreement was excellent (kappa = .88) (Landis and Koch, 1977). A few ambiguous cases were discussed by the coders and usually conservatively coded as amateurs.

Our first moderating variable measures the extent to which the users created designs for commercial reasons. We first asked respondents to think of all the designs they had created in the past five years to make the Ultimaker printers better, easier, or more convenient. To make sure they understood what we meant with such designs, we displayed a list of the users' improvements and complements that they had posted to YouMagine. In line with previous studies (e.g., Chen et al., 2020), we then offered the statement 'I created my 3D printer designs to generate income' (1 = never; 2 = sometimes, 3 = regularly, 4 = often, 5 = always).

Our second moderating variable is closeness centrality, obtained from a social network analysis. YouMagine enables participants to follow other platform users. In accordance with the structure of the YouMagine platform, we constructed a directed social network—YouMagine users can follow others but reciprocity is not guaranteed. Our survey respondents followed 2.66 other users on average. The complete network structure had 1,435 nodes—of which 122 were survey respondents—and 2,118 directed connections between the nodes. To indicate the effect of knowledge acquired from other users, we constructed our measure of closeness based on outdegree. Closeness centrality by outdegree takes into account the number of other users that are followed and the indirect connections resulting from following others. High closeness by outdegree implies that a user has a shorter path length to other network members and is thereby more likely to access useful information (Vriens and Corten, 2018). Since our purpose is to measure the extent to which user innovators access information from observing other users' activities, outdegree is most relevant.

We added various control variables to our analysis. At the individual level (n = 122), we included experience in 3D printing (in years) and level of education (dummy for those with a Master's or doctorate degree)—both we obtained from our survey. These controls help ensure that our main independent variable (professional user status) better reflects users' design and marketing expertise; and not the differences that emerge because respondents may simply be more experienced in 3D printing or have better cognitive skills in general. We also control for users' lead userness (two-item measure; items with the highest factor loadings taken from Franke et al. (2006), α = .77). Lead users are ahead of other users with regard to important trends (in our case, concerning the use of 3D printing equipment) and strongly expect to derive benefits from developing solutions to unsatisfied needs. As such, they are more likely to innovate (von Hippel, 2005). We controlled for lead userness to ensure that our main independent variable (professional user status) truly reflects the differences in users' diffusion-related knowledge and not differences in how their personal needs may have triggered them to innovate in the first place.

At the design level (n = 614), we controlled for the number of words in the design description and days since the design was posted—as detailed documentation and the duration of how long a design is online influences diffusion. We also controlled for diffusion restrictions embodied in the license attached to the design. By default, YouMagine's designs are shared with a CC BY-SA license, the Creative Commons license that allows other users to share and adapt the designs (also for commercial purposes), as long as credits are given and follow-up designs are shared under the same license. However, users can put limitations on commercial derivates or continued development/improvement (e.g., CC BY-ND or CC BY-NC licenses). Our dummy variable indicates whether users have put restrictions on their design concerning derivatives and/or commercial diffusion.

3.3 Analysis

As we deal with a nested data structure, we conducted multilevel regression analyses to test our hypotheses. Ignoring the multilevel structure of data would violate the critical assumption of independence amongst observations (Julian, 2001), as unobservable individual characteristics of users are likely to influence the diffusion of their designs. Our multilevel regressions estimate the effects of design- and individual-level variables on design diffusion, accounting for *"the existence of the heterogeneity caused by non-observed characteristics which cannot be considered in the model but which explain in part the variation"* (Bellavance et al., 2009, p. 448). To illustrate, our first model—containing only control variables—is given by:

$$diffusion_{i,j} = \beta_0 + \beta_1 words_{i,j} + \beta_2 days_{i,j} + \beta_3 license_{i,j} +$$
$$\beta_4 lead\ userness_j + \beta_5 master/doctorate_j + \beta_6 experience_j + u_{0j} + \varepsilon_{i,j}$$

In this equation, diffusion to peers of design i developed by user j is explained by level one variables defined both at the level of designs i as individuals j and level two variables only defined at the level of individuals j. We estimated random intercept models in which the intercept u_{0j} differs across users.

4. Results

Before we turn to our regression results, we first consider bivariate correlations—see Table 4.2. For diffusion to peers, we find significant correlations with the design-level control variables: words, days, and license.

Table 4.2. Correlation matrix

Variables	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1 Diffusion to peers									
2 Professional	-.001								
3 Closeness by outdegree	-.049	.105**							
4 Commercial motive	-.073	.297**	.039						
5 Words	.308**	-.038	.061	-.064					
6 Days	.470**	-.004	-.005	-.151**	.026				
7 License	.143**	-.192**	.178**	-.037	.212**	-.095*			
8 Lead userness	-.028	.449**	.088*	.305**	.066	-.082*	-.085*		
9 Master/doctorate	-.028	-.130**	-.052	-.040	.115**	-.095*	.073	.010	
10 Experience 3D printing	.047	.298**	-.086*	-.085*	-.083*	.256**	-.233**	.125**	-.297**

Notes: n = 614. Pearson correlations are shown. $^{**}p<.01$; $^{*}p<.05$.

Professional users are more experienced ($r = .298$, $p < .01$) and consider themselves lead users of 3D printing equipment ($r = .449$, $p < .01$). Again, in our multilevel regression analyses (hereafter), we control for these variables, to ensure that the relationship between professional user status and diffusion to peers reflects the differences in design and marketing expertise that we theorized, instead of differences in users' needs that motivated them to innovate or general experience with 3D printing. Also, being a professional user is significantly and positively related to closeness by outdegree ($r = .105$, $p < .01$) and commercial motivation ($r = .297$, $p < .01$). As can be expected, professional users are more commercially motivated, but the correlation coefficient also shows that this relationship is far from perfect (both professionals and amateurs can innovate for the full range of motives).

4.1. Testing the hypotheses

Table 4.3 displays the results of our multilevel regression analyses, in which we first standardized users' commercial motivation and closeness centrality by outdegree to ease the interpretation of the interaction effects.

Model 1 contains only the control variables. The diffusion of user innovations to peers increases when the design is described in more detail (words), has been online for a longer time (days), and its license puts restrictions on unprecedented future use. Our interpretation of this latter result is that users who choose a more restrictive license probably more carefully considered the broader value of their innovations.

Model 2 tests our first hypothesis (H1). A direct relationship between professional user status and diffusion to peers is absent in our data (dy/dx = .034, p = n.s.), so our first hypothesis (H1) is rejected.

Models 3 and 4 test the effects of professional user status in interaction with commercial motivation and closeness centrality by outdegree, respectively. Model 5 estimates both interaction effects simultaneously. We find that the designs by professional users diffuse better than those offered by amateurs, the more a user is commercially motivated (model 3: dy/dx = .170; p < .05). This supports our second hypothesis (H2). The relationship between professional user status and diffusion to peers is also stronger, the more central a user's network position in terms of closeness by outdegree (model 4: dy/dx = .093; p < .05), in line with our third hypothesis (H3). These findings are maintained when both interaction terms are estimated simultaneously (model 5), although the interaction term of closeness by outdegree then is only marginally significant.

Table 4.3. Multilevel regression models of diffusion to peers

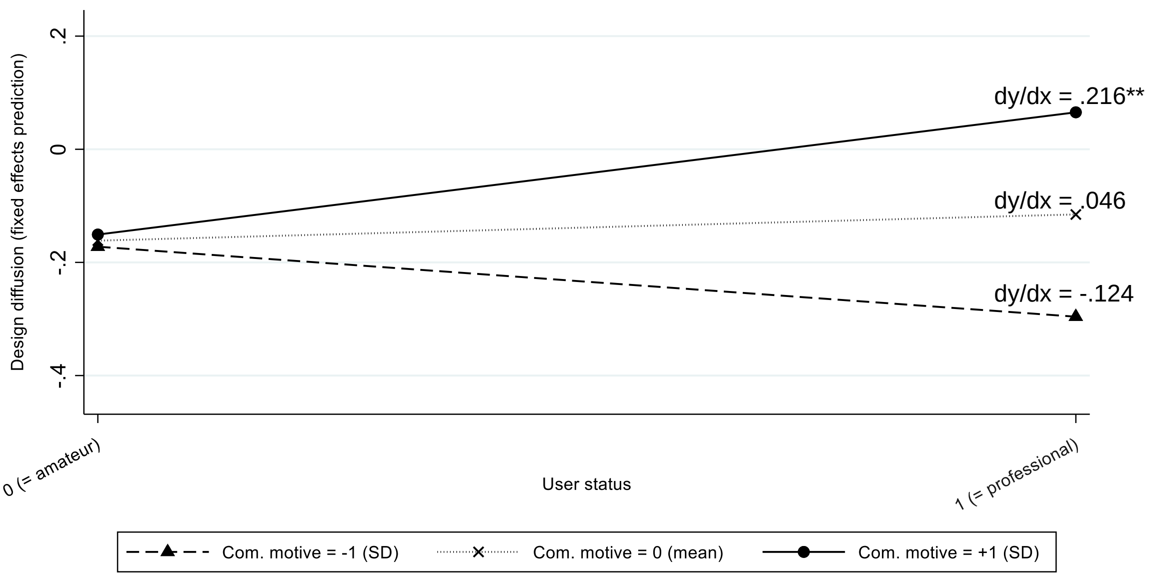
	(1)		(2)		(3)		(4)		(5)	
	dy/dx	*S.E*	*dy/dx*	*S.E.*	*dy/dx*	*S.E.*	*dy/dx*	*S.E.*	*dy/dx*	*S.E.*
Professional (P)			.034	.059	.046	.053	.020	.061	.033	.055
Commerc motive (CM)			.022	.019	.011	.018	.019	.018	.009	.018
Closens outdegree (CO)			-.037^	.022	-.040^	.023	-.055*	.025	-.056*	.025
P*CM					.170*	.068			.158*	.067
P*CO							.093*	.045	.080^	.047
Words	.000**	.000	.000**	.000	.000**	.000	.000**	.000	.000**	.000
Days	.001**	.000	.001**	.000	.001**	.000	.001**	.000	.001**	.000
License (restricted)	.169**	.063	.175**	.064	.177**	.064	.177**	.065	.178**	.065
Lead userness	-.036	.023	-.038	.024	-.045^	.024	-.035	.023	-.042^	.024
Master/doctorate	.003	.054	-.001	.053	.001	.051	.008	.051	.008	.051
Experience 3D printing	-.008	.013	-.006	.013	-.002	.014	-.006	.013	-.003	.013
AIC score	331.91		334.65		333.00		334.64		333.48	
Wald-χ^2 (df)	215.48(6)**		241.26(9)**		253.97(10)**		245.32(10)**		247.09(11)**	

Notes: Estimates based on 614 designs by 122 individuals. Marginal fixed-effects are shown (dy/dx) with robust standard errors (S.E.). All independent variables pass the VIF test for multicollinearity (highest VIF = 1.51). significance **p<.01; *p<.05; ^p<.10.

4.2. Probing interaction effects

To better interpret the interaction effects, we estimated simple slopes based on Cohen et al.'s (2003) procedures. In Figure 4.3, we see that when users are highly commercially motivated to develop their innovations, the contributions of professional users diffuse better compared to those of amateurs. At high commercial motivation (M + 1 SD), the relationship between professional user status and diffusion to peers is positive and significant (dy/dx = .216, p < .01). Specifically, at one standard deviation above the mean level of commercial motivation, design diffusion is 24.11% higher for professionals as compared to amateurs. We find no significant effects when users' commercial motivation is at average or low levels.

Figure 4.3. Simple regression of diffusion on professional user status at levels of commercial motivation



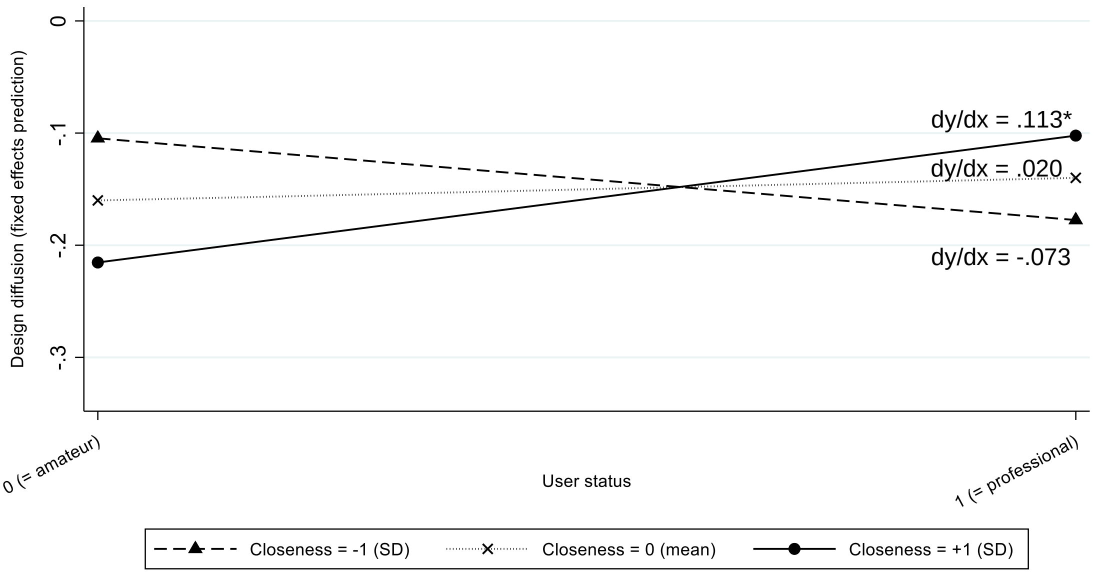
Notes: **p<.01; *p<.05.

We find similar results when probing the interaction effect of professional user status and closeness centrality by outdegree—see Figure 4.4. At high levels of closeness centrality by outdegree (M + 1 SD), the effect of professional user status on diffusion is positive and significant (dy/dx = .113, p < .05). When users' closeness centrality is one standard deviation above the mean level of closeness, we find that peer-to-peer diffusion is 11.96% higher for the contributions of professionals versus amateurs. At average or low levels of closeness by outdegree, we observe no significant effects.

4.3. Robustness checks

We first checked whether a multilevel model best fits our data. Julian (2001) finds that only when intraclass correlations exceed .05, ignoring nested data structures leads to biased estimates. In each of our models, the intraclass correlation coefficient for users exceeded .05 (e.g., in model 5, the intraclass correlation equaled .36)—so using a multilevel model is merited.

Figure 4.4. Simple regression of diffusion on professional user status at levels of closeness centrality by outdegree



Notes: **p<.01; *p<.05.

Second, we verified if—instead of only random intercepts—modeling random slopes for each independent variable of interest would change our findings. As suggested by Bell et al. (2019), we re-estimated our regressions by allowing random slopes of professional user status, commercial motivation, and closeness by outdegree. Our findings are similar. Given that random slope models are less parsimonious (Matuschek et al., 2017) and require high cluster sizes (i.e., more designs per user) (Snijders, 2005), we here reported random intercept models. Moreover, a likelihood ratio test indicated no improvement in model fit from random slopes.

Third, we analyzed whether our findings were sensitive to adding or removing control variables. We included additional variables from our survey that measured alternative innovation motives: personal need (i.e., 'I created these designs for personal need; I use (prints of) my designs myself') and hedonic motives (i.e., a two-item measure 'I created these designs for the fun/enjoyment of the design process / for intellectual stimulation'; α = .89). Their inclusion did not change our findings. We also re-estimated our models while leaving out individual-level control variables (lead userness, experience, master/doctorate) one by one, with similar results.

Fourth, we considered an alternative network measure. In our theory section, we explained that closeness by outdegree best proxies a superior network position for obtaining information from others (Vriens and Corten, 2018). Yet, we could have used an alternative indicator by simply counting how many others a user was following and, thereby, ignoring indirect knowledge flows. Our findings are maintained using such a simpler network measure.

Fifth, we recognized that users may follow other YouMagine users in the hope of reciprocity. When other users start following them in return, this increases their exposure and potentially the diffusion of their designs—by this mechanism, users may follow others for the very commercial reasons central to our second hypothesis. We would then expect to find a strong, positive correlation between a user's outdegree (the number of others a user is following) and indegree (a user's number of followers). However, in our data, the correlation between indegree and outdegree is weak and insignificant ($r = .078$; p = n.s.), indicating no role for this alternative explanation.

Sixth, we checked potential selection bias in our survey responses. We estimated a Heckman regression in which survey response (1 = yes, 0 = no) was the dependent variable in the selection equation, and diffusion to peers was the dependent variable in the main regression equation. The selection equation included the independent variables we obtained from YouMagine's database and our Internet search: professional user status, closeness by outdegree, words, days, and license. In the selection equation, only the variable 'days' was negative and significant—indicating that users who had posted their designs a longer time ago had responded less to our survey. The main regression equation included all independent variables, with results similar to Table 4.3.

5. Discussion

With our study, we took a new direction in researching firm-hosted UICs. Previous research looked into why external users contribute innovations, how UICs should be organized, what kind of innovations emerge, and when hosting firms absorb innovations for product development purposes (Ma et al., 2019). Here, we took the first step in investigating when contributions diffuse directly to peers—the other fundamental purpose of firm-hosted UICs (Jeppesen and Frederiksen, 2006).

We first recognized the kind of problems that arise with peer diffusion, related to: contributors' lack of (a) expertise to develop innovations that can be adopted effortlessly, (b) motivation to deploy this expertise, and (c) network centrality helpful for acquiring need and solution information from others. We then argued that external users are diverse. Some generate (some) income with the hosting firm's products and can be considered professionals, while others use the firm's products as a leisure activity—considered amateurs.

In firm-hosted UICs, the distinction between professional and amateur users has implications for the extent contributions directly diffuse to peers. Being a professional user may mitigate the first problem we detected, i.e., a lack of expertise to develop innovations that are (relatively) easy to adopt. Our data confirm that professional users' contributions diffuse better, but only when users are highly commercially motivated or hold a central network position in terms of closeness. This suggests that diffusion-related expertise (design, marketing) helps to develop user innovations that are easier to adopt, provided that users are commercially motivated—so that they deploy their expertise—or are in a network position to learn about other users' needs and the solution space, in general.

5.1. Implications for theory

Our study has numerous implications for user innovation theory. First, we found that commercially-motivated professionals are more important to reap the societal benefits of user innovation than was previously thought. Previous studies concluded very positively about the value of innovations developed by amateur/hobbyist users: they offer highly novel and first-of-a-kind innovations while they are willing to reveal their innovations freely (von Hippel, 2005). Scholars reported similar findings specifically for users in firm-hosted UICs, provided that users get recognition (e.g., Jeppesen and Frederiksen, 2006) or want to help their community (Franke and Shah, 2003). Obviously, the benefits that amateur user innovators can provide to others are undeniable, but the state-of-the-art in the user innovation literature might leave the impression that amateurs, hobbyists, and volunteers are a panacea. As a nuance, our study provides an existence proof that—in particular contexts of user innovation—professional expertise and commercial motivation is beneficial. Without the active involvement of a hosting firm, professional user involvement makes a positive difference when it comes to the direct diffusion of user innovations to peers.

Recent work shows that the initial development of user innovations and their subsequent diffusion is associated with different challenges (de Jong et al., 2015; 2022; von Hippel, 2017). Indeed, amateur users (innovating in their leisure time) are a valuable source of innovations with high novelty and perceived usefulness (e.g., Pollok et al. 2021). Firms that host UICs can adopt these for their product development. With active involvement and processing by a hosting firm, users' lack of diffusion-related expertise does not hurt as much. The firm takes care of continued development, professional design, and marketing—which is what producers are good at (von Hippel, 1994; 2005). However, as illustrated by the three problems mentioned above, users' lack of diffusion-related expertise does hurt when it comes to peer-to-peer diffusion.

Peers (unlike the hosting firms) may not be able to adopt user innovations developed without expertise facilitating their ease of use. Our study shows that, for peer diffusion, professional expertise is very helpful for dissemination to occur. Professional expertise indicates users' ability to develop their innovations until the stage at which other users can adopt those (also) without the active involvement of a hosting firm that can rely on a sophisticated, technical knowledge base to process user innovations.

To our knowledge, the study by Jeppesen and Frederiksen (2006) provided the only comparison of professional and amateur contributions to a firm-hosted UIC so far. They studied users of computer-controlled music instruments and found that the contributions by amateur users were more innovative than those of professionals. This is in sync with our study, as Jeppesen and Frederiksen (2006) looked at the novelty of contributions as a dependent variable (whether participants had developed new-to-the-world, regular, or no user innovations), not diffusion to peers. Their finding fits well with our reasoning that—for novelty—amateur users may be preferential, but—for diffusion to peers—contributions by professional users are more likely to be effective.

A second implication, and contribution of our study, is that we expanded our knowledge about the role of commercial motivation. As we discussed in our introduction, users often lack incentives to disseminate innovations—a rough prototype is enough to solve their personal needs or to have enjoyed the benefits of the innovation process. Commercially motivated users, however, do actively try to disseminate: they may start businesses (Shah and Tripsas, 2007) or transfer their innovation to a producer firm in exchange for a license fee (de Jong et al., 2015). Previous studies also suggested that the diffusion failure problem diminishes in community environments. When users operate in a community, they feel more inclined to help their peers and to offer their innovations back to the community (Franke and Shah, 2003; von Hippel, 2017). The new insight from our study is that, even in a context where users freely reveal their innovations, commercial motivations are helpful as they may trigger professional users particularly to create designs that can be adopted effortlessly.

Third, we find additional evidence that, beyond users' personal characteristics, embeddedness in the community network influences innovation outcomes. Dahlander and Frederiksen (2012) were one of the first to bring this to general awareness. We add that how users are embedded in the UICs network is not only important for innovation emergence (Dahlander and Frederiksen, 2012) and the novelty and popularity of innovations (Resch and Kock, 2021) but also for the dissemination to peers of the innovations that these users developed. Interestingly, by looking exclusively at network centrality based on outdegree, our findings suggest that the information benefits accruing to users is a significant factor that explains variation in peer-to-peer diffusion outcomes.

The significant interaction effect of closeness by outdegree (Table 4.3) is consistent with Resch and Kock's (2021) theorizing about information overload. They argued that—unless users can couple such information with specialized knowledge—information acquired through superior network positions can be overwhelming for them. Recalling our findings that professional users benefit from network centrality while amateur users do not, we can interpret our significant interaction effect as evidence that professional expertise equips users with the skills necessary to mitigate information overload. Professional expertise helps users to incorporate information about other users' needs and solutions to develop innovations that are easier to adopt.

5.2. Implications for practitioners

Our findings have implications for managers striving to take advantage of innovations developed by users of their firms' products. Studies of firm-hosted UICs, so far, considered the adoption of user innovations by hosting firms—how to incorporate these innovations in their next generation of products (e.g., Jensen et al., 2014; Ma et al., 2019). Hosting firms should obviously consider absorbing promising incremental improvements, as Ultimaker did with the nozzle block (which we described in section 3). However, facilitating peer-to-peer diffusion is another objective of firm-hosted UICs. Stimulating the diffusion of incremental product improvements and complements creates extra value for customers and, thereby, for the company itself.

Based on our study, we can offer three suggestions to hosting firms. First, it seems wise for firms to attract professional users to join their UICs and increase the contributions of those already present. In principle, professional user status is relatively easy to identify, unlike previously proposed antecedents of user innovation emergence like lead userness (Franke et al., 2006). Yet, simply attracting new community members is not enough. When hosting firms want user contributions that can spread effortlessly to peers, it is important that professional users developed their innovations with commercial motivation (at least partially) and/or occupy central network positions. Accordingly, firms can give professionals more prominent, formal roles as ambassadors, core community members, or moderators. When such recognition is made visible to outsiders, it will help professional users to generate income indirectly, for example, by providing consultancy services. Alternatively, hosting firms can consider compensating professional users for their efforts with a fee or favors when they increase their contributions (e.g., discounts on the firm's products, free samples, etc.). Absent commercial motivation, professional users will probably not respond to such incentives.

Second, we recommend tailoring the community environment, recognizing that users have diverse motives by also providing tools for commercialization. Although personal needs and hedonic reasons are typically the most important, some users are (also) commercially motivated. Free revealing should still be central, but the hosting firm could offer appropriate tools specifically relevant for commercially-driven participants. For example, they may include buttons on their platforms where adopters can order copies of user innovations—to save the hassle of downloading design files and replicating designs for themselves (a convenient option for adopters who only want a copy to solve a personal problem). Of course, the challenge would be to avoid disbalance: too much focus on commercialization may alienate user innovators who are mainly need- or hedonically-driven. Alternatively, firms can create a second platform facilitating the commercialization of full-fledged innovations. In 3D printing, an example of such a platform is Shapeways.com, which offers a 'marketplace' to developers willing to sell their designs.

A third suggestion is to directly stimulate the continued development effort required to make user innovations easier to adopt. Hosting firms may, for example, lower the threshold for adopters to ask questions to developers or to file problems encountered during replication. Their platforms could offer facilities to nominate innovations as 'high-potential designs' that should be improved or think of other ways to visualize potential demand—which triggers user innovators to increase their diffusion effort (C. von Hippel and Cann, 2021). Alternatively, hosting firms could embed their employees in the community (Dahlander and Wallin, 2006) to initiate and stimulate dissemination processes. Finally, they may offer extra diffusion incentives to user innovators, like awards, prizes, certificates, or rankings.

In any case, we advise hosting firms to design their UICs for different kinds of users, including both professionals and amateurs. It is still true that amateur users are valuable sources of prototypes with high functional novelty (Jeppesen and Frederiksen, 2006) that potentially address a broad demand (Franke et al., 2006). A mixed community is merited because professional users do not innovate in isolation but require a critical mass of other users—including amateurs signaling their needs and solutions by posting designs, providing feedback, and remixing and adopting existing designs. Moreover, we observed in our internet search (where we coded professional user status) that many professional users once started as amateurs—a pattern common in 3D printing (Mauroner, 2017). In all, our study certainly does not imply the end of firm-hosted UICs as we know them.

5.3. Limitations and suggestions

Our study was not free from limitations, creating opportunities for new research.

First, we assumed that all user innovations in our sample had the same chance to be observed by other users. However, users with commercial interests may invest more in informing potential adopters. By controlling for the number of words (i.e., quality of the design's documentation) and time since designs were posted, we have partially controlled for factors related to how much a design is broadcasted. However, users may have called upon other channels (e.g., their weblog or social media) to promote their innovations. An alternative explanation for the patterns we observe is that professional user status helps diffusion also through increased effort invested in promoting the users' designs and not only through professional expertise. The implications of our research would not dramatically change (since dissemination to peers occurs anyway, adding to social welfare), but it is worth investigating in the future.

Next, our measure of professional user status merged all professionals with different business models to generate income, e.g., resellers, producers of 3D printed items, professional designers, or bloggers. Our dataset did not allow us to delineate types of professional users as the subsamples would become too small. In future research, it is worth investigating if different relationships between professional user status (H1) and diffusion to peers are detected for various types of professionals.

Moreover, our dependent variable for design diffusion was an index variable based on the numbers of downloads and times being favorited by other users. Since firm-hosted UICs are online environments where knowledge is shared (e.g., Becker et al., 2022; Dahlander and Magnusson, 2005; Jeppesen and Frederiksen, 2006; Ma et al., 2019; Yan et al., 2018), this is a valid measure. Nevertheless, it would be interesting to see if our study can be extended to offline user communities, where innovation is encouraged and facilitated by the manufacturer of a product and where knowledge exchange partially takes place at periodic events. For example, the British kit car industry brings together groups of consumers and professionals who build and innovate their own cars, based on a manufacturer's kit (e.g., https://midascars.co.uk/). In offline environments, alternative measures of diffusion should be sorted out.

In line with de Jong et al.'s (2021) call for continued work on diffusion, we hope that this study inspires a line new of research concerned with peer diffusion instead of adoption by the hosting firm. Clearly, other antecedents can be investigated. Ma and colleagues (2019), for example, studied if the adoption by the hosting firm of innovations from UICs is related to various innovation, innovator, communication, and scarcity-related factors. Perhaps, a similar framework can be used to investigate what triggers peer diffusion. Other researchers are welcome to join in this endeavor.

Chapter five

The nature of underground innovations: Missionary, user, and explorer orientation

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Abstract

Underground innovation studies, so far, focused on bootlegging employees: developing projects under the radar, initiated with organizational benefits in mind, that are revealed at some point for organizational acceptance. Recent studies identified underground innovations that deviate from this view: employees kept their innovations hidden or refrained from active diffusion. We enhance our understanding by exploring the nature of underground innovation, looking at the level of underground projects rather than at the level of individuals. Employing a mixed methods approach (literature research, interviews, survey study) in a multinational automotive organization, we find that underground innovations can be characterized along three dimensions: a(n) missionary orientation (how much are underground projects meant to change company practices), user orientation (to solve work-related problems or challenges for their developers), and explorer orientation (to pursue developers' passion for exploring). Each orientation is associated with different objects of innovation, involvement of others, resources, and diffusion effort. They can be present exclusively or in mixed form. In the absence of missionary orientation, underground projects are unlikely to diffuse optimally—preventing the organization from reaping benefits.

Keywords: underground innovation; bootlegging; creative deviance; user innovation; open-source; innovation diffusion.

1. Introduction

Ever since Schon (1963) and Knight (1967) coined the concept, researchers have studied underground innovation in organizations. These are innovations emerging bottom-up without managerial approval (Augsdörfer, 1996; 2005; Eicher, 2020). We define underground innovations as the proactive initiation and development of innovations by employees without official company resources and that are unapproved, at least initially. Underground innovations differ from ‘skunk works’, where employees conduct projects hidden from part of the organization but with explicit managerial consent (Masoudnia and Szwejczewski, 2012). Managers usually passively allow for underground innovation behavior of their employees (Augsdörfer, 2008; Eicher, 2020), as positive outcomes have been shown: company growth (e.g., Abetti, 1997; Aram, 1973), better innovation performance (Criscuolo et al., 2013), and innovations with higher newness (Globocnik et al., 2022).

The mainstream underground innovation research focuses on bootlegging, defined as the process by which individuals take the initiative to work on ideas without formal organizational support, often hidden from senior management but undertaken to benefit the company (Criscuolo et al., 2013). A related concept is creative deviance: employees who ignore managerial orders to stop innovating, to take their projects underground before revealing them back to the organization (Mainemelis, 2010). Both concepts enable employees to achieve greater autonomy over the direction of their innovation efforts and to escape accountability constraints (Criscuolo et al., 2013). When employees expect high resistance, such a ‘stealth mode’ is considered a viable alternative (Augsdörfer, 2008; Miller and Wedell-Wedellsborg, 2013). Whereas bootlegging is about employees innovating without permission, creative deviance only concerns the explicit violation of managerial orders to stop innovating. Therefore, bootlegging is generally regarded as the broader construct, and creative deviance is regarded as a subset (Lin et al., 2016).

Employees engage in bootlegging and creative deviance with organizational benefits in mind (Criscuolo et al., 2013; Eicher, 2020; Masoudnia and Szwejczewski, 2012). When organizations have innovative goals but insufficient resources to pursue all submitted ideas, employees may temporarily work on legitimate innovation goals in illegitimate ways (Globocnik and Salomo, 2015; Mainemelis and Sakellariou, 2023). Bootlegging and creative deviance are, therefore, often encountered in the fuzzy front end of the innovation process (Augsdörfer, 2008). Importantly, such underground projects will eventually be revealed by their developers to become formalized (Eicher, 2020; Mainemelis and Sakellariou, 2023). Active revealing by underground innovators implies that organizations can take advantage—by incorporating new products or better processes.

However, recent studies have contradicted these observations, indicating underground innovations not primarily focused on organizational benefits and where dissemination within the organization did not reach its full potential. The user innovation literature identifies that employees may innovate to address work-related problems or challenges—they develop innovations to use themselves (e.g., von Hippel, 2005; Wu et al., 2020). Recent studies showed that user innovations can be developed out of managerial sight. For example, Zejnilovic (2016) explored employees' contributions to an idea management system (IMS) in a telecom business. They found many employees with user innovations, of which only a fraction became visible in the IMS. Likewise, Hartmann and Hartmann (2023) reported that employees in Danish police and military organizations developed innovations to enhance effectiveness, safety, or efficiency while performing their jobs. Severe bureaucracy made them hide their user innovations or, at best, selectively share with colleagues, depriving uninvolved colleagues of taking advantage.

Another context where studies showed underground innovations remaining hidden is in open-source software. Perhaps unexpectedly, open-source contributions are often made by professionals during work time. Many keep their contributions hidden from their organization (Hars and Ou, 2002). For example, Lakhani and Wolf (2005) found that more than half of all open-source participants contributed mainly during their work time, while only one out of eight was paid and instructed to do so. Seventeen percent kept their involvement completely hidden from their employer. They were motivated by enjoyment, intellectual stimulation, reputation enhancement, and opportunities to collaborate with like-minded others (Lakhani and Wolf, 2005).

These and similar findings suggest that the nature of underground innovations is more complex than previously thought. Not all underground innovations seem to be observed by managers—an observation also made by Sakhdari and Bidakhavidi (2016). Our premise is that underground innovation includes more than unsanctioned initiatives for organizational benefit and that some underground innovations remain invisible at the expense of an organization's value-creation potential.

Our contribution is that we enhance our understanding of the nature of underground innovation. In recent studies, the focus was on underground employee behavior and its contextual circumstances, with analyses at the level of individuals. Central variables included bootlegging behavior (e.g., Criscuolo et al., 2013; Globocnik et al., 2015), bootlegging tendency (Globocnik et al., 2022), and creative deviant behavior (Lin et al., 2016)—to mention the most prominent examples. Here, our focus is on the level of projects, recognizing that employees can develop multiple underground innovations (Criscuolo et al., 2013; Globocnik and Salomo, 2015) for which their considerations and behaviors may differ. We expect that a detailed account of the nature of underground innovation will enable researchers to study the phenomenon more effectively and practitioners to develop interventions to take full advantage.

We employed a mixed-methods approach, starting with an inventory of the literature on bootlegging, creative deviance, user innovation, and open-source to learn about various forms of underground innovation that may exist. Next, we interviewed 39 R&D workers in a multinational organization about underground innovation and analyzed survey data of 420 underground projects to identify and refine new insights about the nature of underground innovation.

To give an overview, we find that underground innovation projects can be described along three dimensions: a(n) missionary, user, and explorer orientation. The missionary orientation of an underground project is the extent to which its developers aim to change company practices. For such projects, employees exert a lot of effort to reach organizational acceptance. User orientation is the extent to which projects address a work problem or challenge. When underground projects are exclusively use-oriented, their developers lack dissemination incentives. Finally, underground projects can be more or less exploration-oriented: how much their developers are driven by a passion for exploration and moving frontiers. In these projects, developers are generally willing to showcase their innovations but are not active disseminators. The three orientations can coexist in a single underground project, but, especially when missionary orientation is absent, the organization tends to miss out on benefits.

2. Theory

We discuss various strands of literature that deal with or are related to underground innovation: bootlegging, creative deviance, user innovation, and open-source. From our literature study, we infer that underground innovations can be developed for different purposes and can be characterized by different kinds of involvement of other people, employed resources, and efforts to disseminate.

2.1. Bootlegging and creative deviance

Employees engage in bootlegging and creative deviance with the aim of creating benefits for their organization. It is often “the response of an employee within an organization that seeks innovation but provides limited resources for idea elaboration" (Globocnik and Salomo, 2015, p. 507). When (investment in) innovation is expected while resources are limited, structural strain theory (Merton, 1968) counsels that employees have an incentive to first undertake initial development efforts, before reaching out to the formal company channels for innovation (Globocnik and Salomo, 2015; Mainemelis and Sakellariou, 2023). Employees may innovate underground to develop a full proof of concept so that managerial approval becomes more likely.

In previous studies, employees' bootlegging (and creative deviance) behaviors have been associated with personality traits, e.g., mastery orientation (Tenzer and Yang, 2020) and risk-taking propensity (Globocnik, 2019); job design variables, e.g., job autonomy (Augsdörfer, 1996; Eicher, 2020; Masoudnia and Szwejczewski, 2012); and contextual variables, e.g., managerial responses (Lin et al., 2016), managerial support (Globocnik, 2019; Globocnik et al., 2022), organizational support (Tenzer and Yang, 2020), and idea management systems (Eicher, 2020; Globocnik et al., 2022). Bootlegging has been related mostly to positive outcomes, including fit with corporate strategy (Augsdörfer, 2005) and newness of the innovation portfolio (Globocnik et al., 2022). Finally, researchers have looked into processes of bootlegging, for example, how underground innovations become formalized (Demir and Knights, 2021), may alternate between underground and formalized status (Mainemelis and Sakellariou, 2023), and are promoted internally to increase the odds of approval (Eicher, 2020).

A common insight is that underground innovations are often developed with the help of others (Augsdörfer, 2008). Bootleggers seek informal support from colleagues and key decision-makers (Eicher, 2020). Successful underground projects are often developed by teams of workers (Augsdörfer, 2008). Also, bootlegging improves general innovation performance, particularly in situations when employees are embedded in teams where bootlegging is common (Criscuolo et al., 2013).

Another insight is that a broad range of resources may be mobilized. For example, Mainemelis and Sakellariou (2023) documented that bootlegged projects can temporarily be applied to the formal system to secure legitimacy and/or to obtain official company resources but may also go underground again for autonomy and to bypass decision-making barriers. Bootlegged projects are initially done in slack time but are likely to be revealed towards the end of the innovation process to obtain official company resources (Abetti, 1997; Augsdörfer, 2008; Eicher, 2020).

For the purpose of this paper, the bootlegging and creative deviance literature shows that underground innovation projects can be aimed to generate company benefits and are usually undertaken with informal help from colleagues by employing a mix of informal and organizational resources. These projects likely surface at some point for organizational acceptance.

2.2. User innovation

User innovation studies focus on individuals or firms who innovate to address personal or process-related needs; they intend to use the innovations themselves (von Hippel, 2005). Within organizations, employees may develop user innovations to address work-related problems or challenges (e.g., Morrison et al., 2000; Wu et al., 2020). Employees are known to create workarounds in situations where processes are deemed slow, information is unavailable, technological solutions are missing, or situational constraints make work challenging. Workarounds imply that workers engage in particular activities that deviate from or complement existing work processes, which may temporarily affect the nature of work systems (Alter, 2014). User innovations can emerge from this repeated activity; employees may develop permanent solutions to their problems by developing new processes, work methods, software, tools, or devices (Wu et al., 2020).

For years, the user innovation literature has been silent about whether user innovations in organizations are developed underground. Recently, however, Zejnilovic (2016) studied employee contributions to an IMS of a multinational telecom business. They found that 31 out of 71 interviewees had personal innovation projects, mostly to address work-related problems or challenges. Interestingly, only a fraction of these was submitted to the company’s IMS. While their acceptance rates were high, most cases remained unreported. Likewise, Hartmann and Hartmann (2023) studied innovations developed by employees at four sites of the Danish police and military. They found many underground user innovations to improve personal effectiveness, efficiency, or safety at work—including potential life savers found amongst soldiers who had served on international missions. These innovations were developed underground because severe bureaucracy kept workers from finding solutions via official pathways. To implement and keep using their solutions, many workers shielded innovations from their managers (58% of 112 identified innovations were kept hidden, and in other cases, dissemination occurred only passively). These studies show that employees may keep user innovations out of sight or refrain from active diffusion.

Stylized facts about user innovation show that users may collaborate to develop solutions (e.g., de Jong and von Hippel, 2009; Franke and Shah, 2003) but can also be a solo effort (Baldwin and von Hippel, 2011). Also, users typically employ locally available, informal resources. They do not require resources of the best quality nor skills to develop professionally engineered solutions as long as they solve the problems at hand (Riggs and von Hippel, 1994; von Hippel, 2005). Finally, users lack incentives to actively diffuse their innovations. Having solved a personal problem, most users see no or few benefits from dissemination (de Jong et al., 2022; von Hippel et al., 2017). This implies that user innovations often fail to provide value beyond the individual user; colleagues facing similar problems are deprived of using solutions that may already be available.

In all, the user innovation literature points us to the existence of underground projects that aim to address work-related problems or challenges. These may be developed with colleagues or solo. User innovators mostly employ locally available resources. Since their primary concern is themselves, user innovators are generally less active disseminators.

2.3. Open-source

Open-source studies shed light on a different kind of motivation for underground innovation: benefits derived from the innovation process as such, rather than organizational benefits or personal needs. In open-source, communities of individuals freely and openly contribute to a collective innovation project (von Krogh and von Hippel, 2006). Contributors can be motivated by a mix of reasons, including personal needs, i.e., they intend to use the open-source product, resembling user innovators (von Hippel, 2007). Most important, however, are the enjoyment and opportunities to practice new skills, engage with like-minded others, and enhance personal status (Hars and Ou, 2002; Lakhani and Wolf, 2005).

As mentioned, open-source contributions are often developed underground by employees in organizations. In an early study, Hars and Ou (2002) found that half of the programmers in a survey of open-source contributors were professionals. Sometimes, they were paid and instructed by their employers, who wanted to be involved in the project for strategic reasons. More common, however, was that employees contributed during work hours without asking for managerial consent. Likewise, Lakhani and Wolf (2005) surveyed open-source participants and found that 55% contributed during their work time, while only 13% were paid to do so. Seventeen percent of all respondents were professionals hiding their contributions from their management. Central motivations reported by Lakhani and Wolf are intellectual stimulation, reputation enhancement, and a preference to work with a team of like-minded others.

Open-source contributors, by definition, collaborate with others and freely reveal what they have built (Baldwin and von Hippel, 2011). Such contributions are presumably made during their slack time at work (Lakhani and Wolf, 2005). However, many professional contributors keep working on open-source projects in their leisure time, being driven by enjoyment and self-actualization (Bitzer and Geishecker, 2010).

In overview, the open-source literature suggests that underground projects may be done for benefits derived from the process of innovation and not so much its potential outcomes: enjoyment, practicing skills, meeting like-minded others, and self-actualization. In such projects, employees may work with like-minded others and broadly reveal what they are doing.

2.4. Key factors

From the aforementioned literature, we identified four factors on which underground innovation projects may differ. First, underground innovations may be initiated for different purposes: organizational benefits, addressing work problems, or benefits from the innovation process as such. Second, underground projects can differ in how they involve other people: not at all, with few or more colleagues, or many dispersed contributors. Third, underground innovations can employ different resources: informal slack time at work, official company resources (especially in later phases of the innovation process), and even leisure time. Fourth, underground projects can be disseminated in different ways: pushed actively towards organizational acceptance, passively revealed or hidden, or freely revealed to anyone interested. These four factors are central to our data collection effort to study the nature of underground innovations.

3. Interviews

Our research was at an automotive firm with global reach. We interviewed employees from two departments in Germany. The first department conducts research that is of longer-term strategic importance. In particular, concerning powertrains, safety and driver assistance systems, and vehicle dynamics and chassis technologies. The second department performs most of the company’s product development in Europe. Workers from both departments intensively collaborate. Our study context is suitable as most employees are R&D workers concerned with formal innovation tasks. On top of their formal innovation projects, we suspected some would engage in underground innovation.

3.1. Participants and procedure

We sought interviewees through various sources to maximize variance in our data (Strauss and Corbin, 1998). First, we consulted our contact persons at the company with many informal contacts on the shopfloor: an internal coordinator concerned with employee innovation, a job coach, and a coordinator of an internal maker space where employees could make use of tools and informal networking facilities. They were very interested in underground innovation and had already identified some relevant employees, including employees from whom our contact persons detected underground innovations just by observation, without employees explicitly telling them about it. Second, our contact persons asked around at coffee corners, lunch meetings, and informal networking events—whether employees had done underground projects themselves or could point to relevant others. The maker space coordinator also observed employees who used tools in ways that could not be linked to formal projects (which indicated potential underground innovation behavior). Third, our key contacts asked their local management to nominate staff members, as it was reasonable to assume that at least some projects would have been revealed to them, after being developed underground. Fourth, we asked interviewees for suggestions (snowballing)—assuming some underground innovators know other underground innovators. Finally, we spent multiple days at the maker space, coffee corners, and lunch facilities ourselves—asking around and identifying potential underground innovators with which we followed up.

Investigating underground innovation is a sensitive topic, so interviewees were invited with great care (Augsdörfer, 1996; Eicher, 2020). Our key contacts, who were trusted among our interviewees, first explained to them that the interview would be about their formal and informal innovation activities at work, then made the appointment on our behalf. Whenever interviewees asked us for more clarification in advance, we sent them details about our purposes: that our main interest was underground innovation. What helped us was that in the company's culture underground innovation was not considered a bad thing but potentially beneficial. Many interviewees were actually eager to talk about their underground projects as long as confidentiality was assured.

We conducted 39 interviews (18 at the research department, 21 at the product development department), all in person. The average interview time is 70 minutes. We processed notes and audio recordings into transcripts immediately. Interviewees were at various hierarchical levels and with different backgrounds. Eight of them had a role as supervisor or manager. Twelve were researchers, primarily concerned with long-term strategic research. Thirteen were engineers, primarily occupied with product development activities. Another six interviewees had other roles, e.g., buying coordinator, project planner, or full-time work council representative. Their average tenure (years at the company) was 12.6 years. Their average age was 41.3 years. Seven interviewees were female. These demographics are in line with the company's overall demographic profile. Due to space restrictions, details of the interviewees are in Appendix D.

During the interviews, we first established rapport by assuring confidentiality and asking about the interviewees' jobs and involvement in formal innovation. Next, we explained the underground innovation concept (innovations that are proactively initiated and developed without official company resources and permission from management or the company, at least initially) and clarified its distinction from formal innovation (projects approved by management or the company in advance; with a planned budget and timeline; and visible within the organization's formal systems). We then asked if the interviewees had developed any projects underground in the past three years. If yes, they elaborated on the kind of innovation (product or car part, process, software, work method, etc.) and why they considered it an underground project (we required that some development effort was done underground to filter out employees who had only made suggestions to the formal system). If no underground project came to mind, we asked again, now showing a card with definitions of user innovation, bootlegging, creative deviance, and open-source to trigger interviewees' recall. In the absence of any underground project, we checked if interviewees had contributed to a colleague's underground project in the past three years. Twenty-seven interviewees (69%) had developed at least one underground project themselves. Another four (10%) had contributed to others' projects. The other interviewees (21%) did not engage in underground innovation activities; most had repeatedly proposed ideas to the organization but performed no underground development activity.

We proceeded to ask for details about the specific underground project interviewees had developed or contributed to (when they had multiple examples, we focused on their first mentioned valid case). We asked for their motives and purposes, the involvement of others, the kind of resources used, and the effort done to disseminate the innovation. Appendix D gives a description of the underground projects that were discussed. Examples included new products and parts (e.g., *"a brake warning system using sensors that indicate overheating of brake pads"* (interviewee #17)), technologies (e.g., *"new way to smartly align a car's steering motion with its electronics, like the blinking lights*" (#7)), processes and work methods (e.g., *"I developed a machine to recycle leftover plastics for injection molding"* (#9)), and software (e.g., *"It was a simulation tool for power energy requirements, to optimize cars' energy use"* (#33)). The interview script is available upon request.

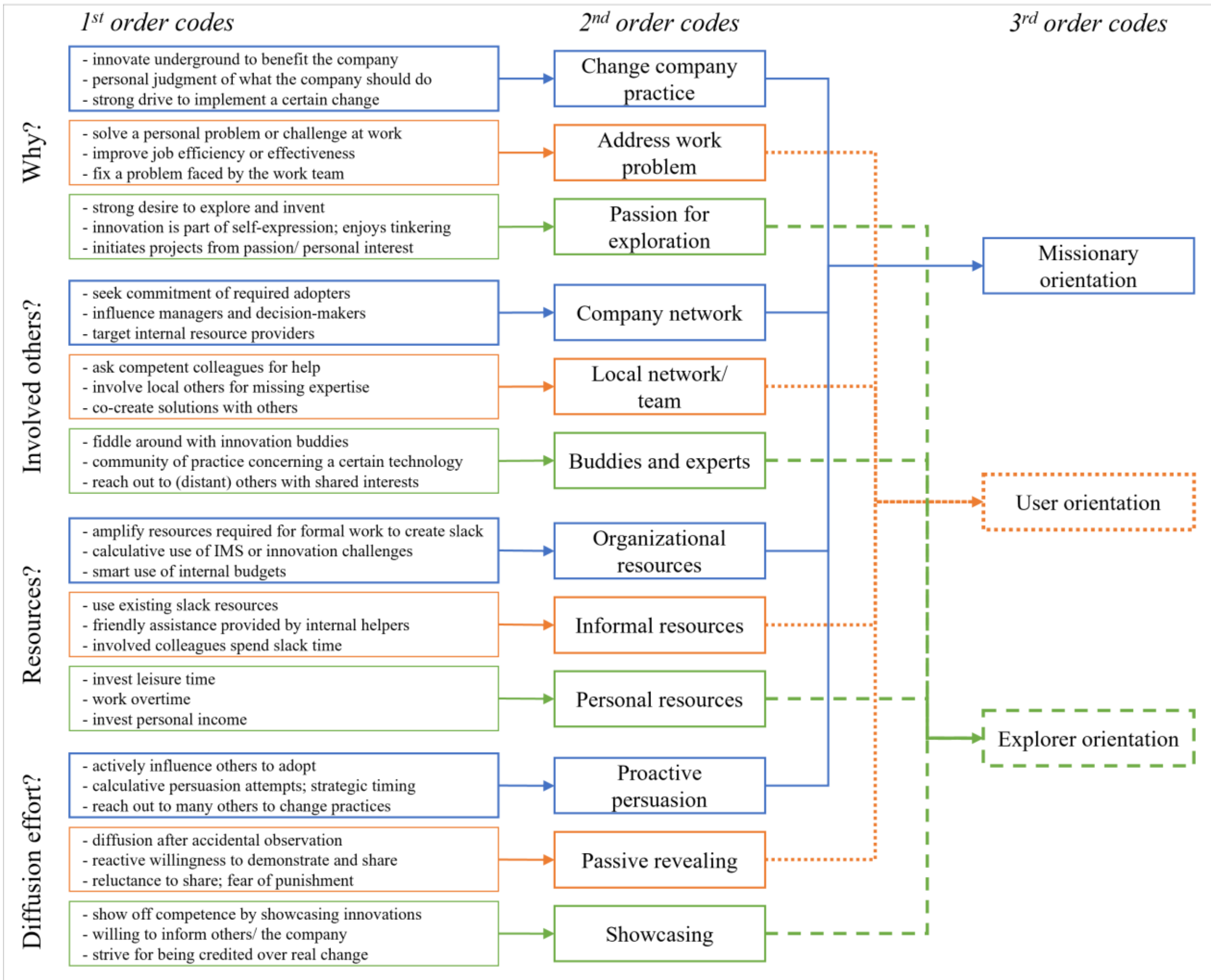
3.2. Analysis

Our analysis consisted of six steps. First, we conducted open coding (Strauss and Corbin, 1998). The underground innovation projects were our unit of analysis. After nine interviews had been done, we started identifying first-order codes about the purposes of the underground project, the involvement of others, employed resources, and diffusion efforts. Second, during this first-order coding process, the authors of this paper regularly engaged with each other in the process of 'interviewing the investigator' to improve the robustness of the emerging codes (Chenail, 2011). Third, while we added new interview data, we did additional iterations of coding, analysis, and discussion, finetuning and developing new first-order codes. Fourth, halfway through our interviews, we did axial coding to classify the first-order codes into second-order categories (Gioia et al., 2012; Strauss and Corbin 1998). Afterward, we kept comparing our emerging categories across the growing base of underground innovation cases to refine our second-order categories. Fifth, we applied selective coding to identify overarching dimensions of underground innovation. While the interviews progressed, we started noticing particular patterns in the reasons to innovate underground, with implications for others' involvement, employed resources, and diffusion efforts. We eventually identified three dimensions: a(n) missionary, user, and explorer orientation. Our coding results are summarized in the data structure (Gioa et al., 2012) in Figure 5.1.

Sixth, we cross-checked our data structure by adding a few more interviews, while searching for confirming and disconfirming evidence (Miles and Huberman, 1994). We continued taking interviews until our insights became saturated. We also presented our preliminary findings to our key contacts at the company, plus a group of interested managers and interviewees to help us refine our data structure.

During the coding process, we continuously went back and forth to the literature—a process typical for qualitative research (Strauss and Corbin, 1998). The literature discussed in section 2 was informative and helpful, but we also observed clear deviations. For example, we observed some underground projects by interviewees who had fanatically pushed for organizational acceptance, being determined to change organizational practices. We, therefore, concluded that underground projects can be more or less mission-oriented. The examples interviewees mentioned most spontaneously often resembled highly mission-oriented projects. We also detected use-oriented projects addressing work-related problems or challenges in line with the user innovation literature. These were sometimes brought up spontaneously, but often only detected after we asked for their existence explicitly. Finally, we did not find much evidence for employees' involvement in open-source projects. Nevertheless, the motivations and behaviors described in the open-source literature helped identify another third-order dimension: explorer orientation. These were underground projects where interviewees showed a passion for exploration in their field of interest, satisfying their curiosity, and expressing themselves. In the next section, we elaborate on our findings.

Figure 5.1. Coding scheme



3.3. Findings

Underground innovation projects can be characterized along three dimensions: a(n) missionary, user, and explorer orientation (see Table 5.1). Sometimes, we encountered the three orientations in isolation, but they could also be jointly present. Each orientation is primarily associated with a particular purpose to innovate underground. This purpose has implications for the involvement of others, employed resources, and diffusion effort.

Table 5.1. Three orientations of underground innovation projects

	Missionary orientation	*User orientation*	*Explorer orientation*
Purpose of innovation	Change company practices	Address work problem or challenge	Passion to explore
Associated with:			
Involved others	Company-wide network, many collaborators	Local network/team, few local collaborators	Buddies and experts, few collaborators
Resources	Organizational resources, seek new company resources	Informal resources, existing slack	Personal resources, leisure time
Diffusion effort	Proactive persuasion; high effort and persistence	Passive sharing; low effort or hiding	Showcasing; modest effort

3.3.1. Purposes

From our interviews, we identified three main purposes of underground innovations: changing company practices, addressing work problems or challenges, and pursuing a passion to explore.

Underground projects could be more or less mission-oriented. This corresponded with our interviewees' purpose and determination to accomplish organizational change. Highly missionary projects were initiated by employees who were convinced of the value of their ideas for the organization. They claimed to 'know better' than their superiors and dared to violate their orders, or simply did not bother asking permission: *"During the development of my virtual reality technologies, I got told many times that I should stop. But I truly believe in the potential of VR and its value for the company"* (#5). Without organizational acceptance, they regarded their project as a failure. Accordingly, they pushed hard for acceptance: *"It is not about the sheer fun of it. I engage in underground innovation to make a change within the company!"* (#26).

Underground projects also differed in their degree of user orientation—whether projects were meant to address work-related problems or challenges. For example: *"I was increasingly bothered by the limitations of the standard software provided by the company, so I started thinking about extensions I could develop myself. Due to the extensions I developed, my tasks become easier and less time-consuming"* (#34). Strictly use-oriented projects were driven by personal needs. Their developers faced problems or challenges or operated in a team where such issues were present: *"I built tools to analyze the crankshaft, piston, and Conrad parts of our cars. These tools were testing if friction could be reduced. We needed these to more efficiently conduct a crankshaft efficiency project*" (#30).

Finally, underground projects were more or less exploration-oriented—the extent to which innovations were driven by developers' passion for exploration and moving frontiers. For instance: "*I am not driven by cost reductions or increasing efficiency, not winning a battle* *for the company. My effort is purely driven by curiosity"* (#7). In these projects, developers almost regarded innovation as a purpose in itself: *"I am triggered by the challenges I observe in daily life and get excited by the process of developing solutions. It is an inner drive for problem-solving using my technical skills. After all, that is what engineers love to do"* (#7). In their projects, they strived to develop and practice their skills, and were driven by self-actualization: "*I like to maintain and improve my engineering skills. With some buddies at the company, we developed a device to integrate smartphones into the car's touchscreen. It helped me practice my skills. We applied for a patent, not so much for the bonus, but just because it is nice to have"* (#2).

3.3.2. Involved others

Underground projects were typically done with the help of others providing informal assistance or advice: *"Networks among employees, other than the formal teams, are important for this but not facilitated by the company. You have to initiate them yourself"* (#16). We observed that the different purposes were associated with how underground developers involved other people. In general, contributions were made by company-wide networks (along hierarchical lines), colleagues nearby, and buddies and experts throughout the company.

When projects were highly mission-oriented, their developers mobilized a lot of help from company-wide networks, including decision-makers and opinion leaders. Interviewees proactively involved them to improve the odds of organizational acceptance. They expanded their networks, reaching out to those who could influence decision-making or provide extra resources. Doing so they were calculative in timing their requests and kept a good sense of the internal political environment: *"I chose the right employees to champion my idea. Those I knew management would listen to"* (#10).

When underground innovations were mainly use-oriented, developers limited themselves to existing informal networks—i.e., predominantly colleagues from their work team or others nearby with relevant expertise to address the challenges at hand. Compared to mission-oriented projects, their collaborators were more limited in numbers and mainly local. Reaching out further was often not necessary since the interest was only to solve their own work-related problem, and local colleagues were often working in contextually similar environments: "*For the training program, I knew some colleagues who are also part-time lecturers. They could easily develop the modules for electrical engineers I needed"* (#4).

In highly exploratory projects, there were also fewer collaborators. Here, developers spent more time interacting with like-minded others throughout the company, sometimes even across the company's borders. They worked with innovation buddies who shared their passion for exploring a domain of interest: *"I love communicating and collaborating with individuals having the same mindset"* (#19). In these exploratory projects, developing innovations seemed part of and to contribute to employees' social identity—e.g., they often referred to themselves as engineers or inventors—and they enjoyed being part of an informal network that resembled a community of practice.

3.3.3 Resources

Elaborating on how interviewees developed underground projects, we identified informal, organizational, and personal resources. The type of resources most often employed (found in all underground projects) was informal resources. That is, slack time of the innovator and any colleagues providing help beyond their formal responsibilities: "*Workload can be quite heavy. Therefore, time to engage in underground innovation is limited during the workweek. In periods where the workload is less, I invest more time in my personal projects"* (#4).

Projects that were mainly use-oriented did not employ other resources than slack time. Employees developed these in their spare time between formal innovation projects: *"I just built this animation tool, not sure where I found the time. Having it also saved me time, so then you just do it"* (#35).

Highly mission-oriented projects deviated because employees actively sought organizational resources. For example, interviewees created additional slack by amplifying the required budgeting time on regular innovation projects. Others leveraged resources from idea management systems: *"I applied to an internal challenge with the software I had already worked out partially as if it was still an idea. There I got extra time to further work on it"* (#33). Instead of using company ideation and training facilities in their predetermined way, employees sometimes relabeled missionary projects to secure a budget.

Projects dominantly motivated by passion employed a different resource: leisure time and personal income. Some developers continued working on underground projects after office hours and during the weekends. They even invested their own money: *"I invested private money and leisure time to come up with a new machine that could reuse the materials for the plastic injection mold before being reduced to powder"* (#9). Personal resources were never reported in underground projects that were strictly mission- and/or use-oriented.

3.3.4. Diffusion effort

We observed stark differences in how developers disseminated their innovations. When missionary orientation was high, developers invested a lot of effort to persuade decision-makers of the value of their project. They were persistent and reached out to many but were always aware of the internal political environment. Some refrained from revealing innovations early but rather waited until the time was right: "*In my work team, we were already using this facility but did not get official permission. After it was rejected, I waited until my manager got a new position, then applied again and had it approved"* (#25).

In projects that were mostly use-oriented, employees only revealed passively, or no effort was invested at all. Diffusion did occur, but mostly at a local level - where colleagues observed the innovations in use or because they had offered informal help to develop them. Broader organizational benefits were considered of secondary importance or overlooked. Diffusion depended a lot on accidental events, e.g., *"Disseminating my software extensions was not my intention, I only developed them to make my job easier. If the student had not spent the time to show it off, I would probably still be the only one using them"* (#34). Most interviewees with use-oriented projects were willing to share passively, i.e., after being asked: "*Jim sometimes meets with Andreas at the coffee corner. Andreas happens to be more skilled in developing technical solutions. Only after Jim shared some of his problems, Andreas shared an advanced Excel macro he recently wrote"* (#3).

We encountered a range of reasons to refrain from dissemination, especially when projects were use-oriented. Some feared stricter monitoring: "*My manager would blame me for working on projects without his consent and give me extra projects as if I would not have enough at hand"* (#29). Others did not like the standardization that would come after organizational acceptance: *"If Jim's software would get picked up by the company, he would need to make changes to meet the company's official standards. The implication is that the software no longer does for 100% what Jim wants"* (#3). Moreover, many user innovators preferred avoiding time investments accompanied with dissemination: "*Colleagues would ask me to make a version easier to operate. I would lose interest as it takes away the challenging part. Adoption by others would require me to invest time in activities I do not like"* (#33).

Employees with highly exploratory projects were in-between the diffusion effort of those with mission- and use-oriented projects. Generally, they were very enthusiastic about their projects and showcased their results—mainly to colleagues and innovation buddies. Showcasing contributed to their sense of self-actualization: "*I show it off so that others know—like this is what good engineers do"* (#29). Exploration-oriented innovations were also often reported to the company's patent office. A positive patent evaluation was regarded as a form of personal recognition, but the inventors would not go all the way to have their innovations adopted by the organization.

Employees with exploratory projects also had reasons to avoid or delay their showcasing. Some wanted to secure recognition by offering a full proof of concept. Others feared negative feedback—whereas (the failure of) formal innovations can be attributed to senior management and company strategy, underground innovations are self-initiated. They believed sharing a project perceived as low quality would signal incompetence: *"Naturally, engineers do not want to look incompetent"* (#14).

3.3.5. General observations

We made three more observations about underground innovation projects. First, missionary, user, and explorer orientations could well occur simultaneously. For example, one project was started to solve a work problem (user orientation), but the developer immediately felt it was something many colleagues could use and actively promoted it (missionary orientation), e.g., "*I developed a database application to help me monitor our powertrain research projects. Then, I realized that the whole organization could us this, so I promoted it. It is now a company standard"* (#1). Table 5.1 reflects our observations when the three orientations were exclusively present.

Second, we experienced that analyzing underground innovation at the project level was beneficial. Out of the 27 interviewees with underground innovations, at least 16 mentioned other projects beyond the one we elaborated on. The orientation of these underground projects could differ, even when developed by a single person. If we had asked about person-level underground innovation, our findings would have been biased more towards the missionary type, as projects with this orientation came to mind first.

Third, the underground projects' distinction from formal, company-approved innovation projects was sometimes blurry. We observed many mixed projects that were at some point approved by management, especially when missionary orientation was high: *"I prefer to remain under the radar until a proof of concept can be shown to increase the odds of implementation. If I would ask permission right away, I would not be allowed to work on such projects"* (#8). This is in line with the bootlegging literature, where scholars reported underground activities to be most present in the fuzzy front end of innovation processes (Augsdörfer, 2008). We noticed a similar grey zone in our interviews.

4. Survey

In our next step, we collected survey data in the same organization to see if the three orientations would replicate in a bigger sample and, possibly, to finetune them.

4.1. Participants and procedure

We surveyed employees to identify underground innovation projects they had developed, then asked questions about these specific projects. Similar data collection methods have been used frequently in past studies on user innovation and open-source (e.g., de Jong and von Hippel, 2009).

We contacted respondents at three locations: the two departments where we interviewed and another product development department in the United Kingdom. The sample included R&D workers (researchers and product developers) and support staff concerned with car warranty policies, human resources, administration, IT, and infrastructure (e.g., operators at test tracks, communication officers, IT specialists, or management support).

We first surveyed the research department with a pen-and-paper questionnaire. Over two days, the questionnaires were handed out personally with a recommendation letter from the department manager. Confidentiality was assured in advance. We received 99 responses out of 190 employees. They reported 57 underground innovation projects to us. We used these initial data to develop multiple-item measures (see hereafter). Next, we distributed an electronic, shorter version of the survey to employees of the other departments. Their general managers first announced the survey. Then, our contact person sent a web link through the organization's e-mail system. A reminder was sent one week later. Out of 3,513 employees, we received 830 responses. They reported another 363 underground innovation projects.

Overall, we received 929 responses from 3,703 invited employees (response rate 25%). Fourteen percent were female. Their average tenure and age were 15.3 and 44.7 years, respectively. Twenty percent had a bachelor's degree, 61% had a master's degree, and 10% had a doctorate. The other 9% were less educated. The demographic profile of respondents was in line with the general characteristics of the three departments.

Altogether, out of the 929 survey respondents, 420 identified and reported an underground innovation project. The company's privacy policies kept us from a detailed non-response analysis but this was not detrimental given our research objective. We had no intention to estimate or explain person-level underground innovation behaviors (as other studies have done, e.g., Globocnik et al., 2022; Lin et al., 2016). Our unit of analysis is at the project level to explore the nature of underground innovations. Our purposes only required a sample of underground innovations with sufficient variance, and we have no indication of the sampled projects being biased.

4.2. Survey questions

The survey (questionnaire available upon request) took three to twenty minutes. To screen for underground projects, the survey first defined innovation as 'the development and introduction of new products, technologies, software, processes, or work methods'. Then, 'informal innovation' was defined as 'projects starting proactively, without advance approval and without (initially) claiming official resources'. We preferred the word 'informal' over 'underground' as we noticed during our interviews this better matched our interviewees' vocabulary. After clarifying the key concepts, respondents indicated if they had developed any informal innovation projects in the past three years and how many. If respondents reported more than one underground innovation, they were asked to think of their most recent project to secure a random sample of projects on top of their minds (Malhotra and Birks, 2017). Next, respondents answered questions about the object of their innovation (i.e., product, technology, process, or software), their purposes, collaboration with others, estimated time spent, employed resources, and perceived diffusion.

As the distinction between underground and formal innovation can be blurry, we wanted to avoid respondents presenting data about the wrong type of project. Therefore, the second part of the survey asked about any formal innovation project developed in the past three years—defined as 'projects approved in advance, with a planned budget and timeline and visible within [name of company's innovation portfolio system inserted]'. If required, respondents were asked to think of their most recent project, then answered the same questions (about the innovation object, purposes, etc.)—enabling us to compare directly underground and formal innovation projects to assess the validity of our sample (see hereafter).

4.3. Data

Table 5.2 shows our variables, including descriptive statistics about the sampled underground projects.

Scope. Underground projects are concerned with products (29%), (patented) technologies (26%), software (32%), and processes/ work methods (47%). Multiple objects were possible, as innovations in automotive typically embody various objects. Time spent was added to get a sense of the project volume. Respondents indicated if the underground project, including contributions made by others, had taken hours (15%), days (30%), weeks (29%), months (22%), or years (4%). More precise data were impossible as employees typically develop underground innovations in their slack time.

Table 5.2. Variables (n = 420)

Variable	*Description*	*M*	*SD*
Scope:			
Innovation object	Underground innovation was concerned with a…(multiple answers possible)		
-product	…product or service (0 = no; 1 = yes)	.29	.46
-technology	…technology or patent (0 = no; 1 = yes)	.26	.44
-software	…software (0 = no; 1 = yes)	.32	.47
-process	…process or work method (0 = no; 1 = yes)	.47	.50
Time spent	Estimated time spent on the underground innovation (1 = hours, 2 = days, 3 = weeks, 4 = months, 5 = years)	2.71	1.10
Purpose:			
Change company practice	Average of 4 items* (α = 0.75): I was very persistent at persuading others about this innovation. I would keep working on this innovation, no matter what others think of it. I put in lots of effort to make this innovation pass organizational roadblocks. I have taken lots of effort to propose the innovation to our formal systems.	4.79	1.19
Address work problem/ challenge	Average of 3 items* (α = 0.85): Using this innovation would enable me to do new things or to save a lot of time. This innovation would very much improve our internal processes. The innovation intended to solve problems in a work process.	5.00	1.67
Passion to explore	Average of 3 items* (α = 0.70): I highly enjoyed starting with this innovation; as if it were a personal hobby. This innovation was primarily driven by my passion to explore and invent. I worked on this innovation for fun and personal reasons more than anything else.	5.29	1.15
Involved others:			
Contributors	Number of people who contributed to development or implementation	2.8	3.4
Resources:			
Informal	Average of 3 items* (α = 0.79): To develop this informal innovation… …I often received help from informal contacts within the company. …I was regularly supported by innovation 'buddies' at the company. …Colleagues regularly provided friendly assistance without formal approval.	4.18	1.48
Organizational	Average of 3 items* (α = 0.72): …I strongly expanded my network within the organization to find resources. …I creatively managed to find additional time at work. …I strategically used my knowledge of the decision-making environment to increase the odds of being successful.	4.21	1.38
Personal	Average of 2 items* (α = 0.78): …I regularly worked in my leisure time. …I used personal resources (e.g., income, tools at home).	3.76	1.75
Diffusion:	Diffusion of the informal innovation to… (1 = none, 2 = few, 3 = many, 4 = all)		
Management	…supervisors or managers	1.67	.78
Work team	…colleagues in the work team	2.19	1.03
Beyond work team	…colleagues in other teams, plants or locations	1.79	.83

Notes: M = mean, SD = standard deviation, α = Cronbach's alpha, *rated 1 (totally disagree) to 7 (totally agree).

Purpose. We developed multiple-item measures for the extent to which reported projects aimed to change practices at the company level, address a work-related problem or challenge, or catered to developers' passion for exploring. Since existing measures were unavailable, we developed a list of items based on our interviews, then selected items based on our first (pen-and-paper) survey at the research department (available upon request). Reliability values were acceptable to good (see Table 5.2).

We explored the criterion validity of our purpose measures by correlating them with the innovation's anticipated value to the company. In the first wave, we obtained data on 57 underground projects. Respondents had indicated if their underground was expected to generate value for the company ('*I expected value to the company',* 1 = not at all, 5 = very much). The purpose of changing company practices, obviously, is correlated with the anticipated company value ($r = .49$, $p < .001$), and the purposes of addressing work problems and passion for exploring are not ($r = .14$ and $r = .22$, p = n.s.). This result is in line with our interview findings—i.e., highly missionary projects are done for organizational benefit, while the user and explorer orientations are associated with other intentions.

Involved others. Respondents reported how many people had worked with them to develop the innovation, providing help, knowledge, advice, or resources. Contributions are received from 2.8 others on average.

Resources. We developed multiple-item measures for the extent to which innovation resources were informal, organizational, and personal. Again, since existing measures were lacking in this new area of research, we developed items based on our interviews, then selected items based on the first wave of survey data. Reliability values were acceptable to good (Table 5.2).

Diffusion. Respondents indicated if their innovation had been adopted by managers, colleagues within their work team, and/or other colleagues beyond their work team (1 = none, 2 = few, 3 = many, 4 = all). This question gave us a sense of the extent to which underground innovations diffused and to whom.

Measurement model. Our confirmatory factor analysis shows that the multiple-item measures have acceptable convergent and discriminant validity. All six measures (change company practices, address work problems, passion for exploring; and informal, organizational, and personal resources) were specified as first-order factors indicated by their corresponding items. Factors were allowed to correlate, while error terms of the items were not. The measurement model has acceptable fit ($\chi^2/df = 2.8$; CFI = .92; TLI = .90; RMSEA = .065). Standardized factor loadings are positive and significant ($b > .50$; $p < .001$). For all measures, the square root of the average variance extracted (AVE) exceeds the correlation coefficients with other factors. Also, the model fit is better compared to alternative models, including a model in which all items load on a single factor (χ^2/df = 12.9; CFI = .39; TLI = .31; RMSEA = 0.169) and a two-factor model with all motive items loading on the first, and resource items on the second factor (χ^2/df = 10.5; CFI = .52; TLI = .45; RMSEA = .151).

Quality of sample. We also analyzed if we could be confident that our sample contained truly underground projects. For this purpose, we collected identical survey data on 479 formal, company-approved innovations, then explored the differences between underground and formal projects. See Appendix E. Underground innovations differ from formal projects: they are smaller projects, concerned with objects more eligible for under-the-radar development, associated with motives other than company interests, more often done with personal resources and less with organizational resources, and less adopted by others. By and large, the differences between underground and formal projects are as expected and indicate that our sample contains underground projects.

4.4. Findings

Table 5.3 shows the correlation coefficients between our variables. Common method bias was not expected to be problematic. We alternated the response scales between our survey questions, ensuring that self-reported items were followed by factual questions and vice versa (Podsakoff et al., 2003). Absolute values of the correlation coefficients are mostly < .20, which is smaller than the correlations normally encountered when common method bias is present (Podsakoff et al., 2003). To check, we applied Harman's single-factor test with exploratory principal component analysis. The first factor explained only 22% of the variance. Also, the correlations indicate no multicollinearity concerns. In our regression models hereafter, variance inflation factors do not exceed 1.12. This is well below established thresholds (Cohen et al., 2003).

We estimated a range of regression models to validate and finetune the three orientations. Recalling Table 5.1, where we identified the three orientations after observing that each purpose was associated with particular involvement of others, resources, and diffusion patterns, we estimated if similar associations existed in our survey sample.

Table 5.3. Correlation matrix (n = 420)

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*	*(14)*
2 Technology	.22**													
3 Software	-.22**	-.11^												
4 Process	-.22**	-.34**	.01											
5 Time spent	.06	-.06	.09	.09										
6 Change company practices	.14**	-.02	-.08	.08	.31**									
7 Solve work problem	-.31**	-.42**	.19**	.50**	.18**	.20**								
8 Passion to explore	.07	.04	.10^	-.01	.05	.29**	.13*							
9 Contributors	.15**	.01	-.06	.02	.21**	.23**	.06	-.04						
10 Informal resources	.16**	.06	-.09	.06	.15*	.20**	.09	.02	.29**					
11 Org. resources	.19**	-.08	-.12^	.15**	.32**	.41**	.18**	.10^	.24**	.56**				
12 Personal resources	.07	.02	.10^	.02	.14*	.21**	.07	.31**	-.05	.13*	.20**			
13 Management adoption	.09	-.10^	-.05	.12^	.25**	.31**	.15**	.02	.22**	.21**	.27**	.00		
14 Work team adoption	-.11^	-.22**	.12^	.26**	.17**	.25**	.35**	.04	.19**	.15*	.21**	-.09	.56**	
15 Beyond work team adoption	.05	-.09	.04	.12^	.25**	.24**	.22**	-.03	.20**	.13*	.22**	-.01	.49**	.53**

Notes: two-tailed significance **p < .001; *p < .01, ^p < .05.

In each regression model, the three purposes are the independent variables. The dependent variables are the number of contributors, types of resources, and diffusion variables. We also estimated regression models of the innovation objects and time spent to explore how the three purposes are related. Depending on the level of measurement, we estimated probit, ordered probit, and ordinary least squares models. Each model has a good fit and explains a significant part of the dependent variable's variance. See Table 5.4.

If we read Table 5.4 by its columns, the effect parameters indicate if and how each innovation purpose is associated while controlling for the presence of other purposes.

First, we interpret the results concerning the purpose of changing company practices, which is central to underground projects' missionary orientation. This purpose is positively related to the development of new products ($b = .25$, $p < .001$) and negatively to new software ($b = -.18$, $p < .001$). It is also positively related to time spent ($b = .23$, $p < .001$) and involvement of others ($b = .74$, $p < .001$). All three types of resources are used more. Organizational resources are especially positively related ($b = .46$, $p < .001$), but we witness positive relations also for informal resources ($b = .26$, $p < .001$) and even personal resources ($b = .19$, $p < .05$). Finally, underground projects dedicated to changing company practices have better adoption rates: by managers ($b = .36$, $p < .001$), work team members ($b = .21$, $p < .001$), and employees beyond the innovator's work team ($b = .24$, $p < .001$).

Table 5.4. Regression analyses (n = 420)

Dependent variable	*Model*[2]	*Effect of innovation purpose*[1]: *Change company practices*	*Address work problem*	*Passion to explore*	*Constant(s)*	*Model fit*	*(Pseudo)* R^2
Scope:							
Innovation object							
-product	probit	.25**	-.29**	.06	-.67	χ^2 = 45.1**	.11
-technology	probit	.05	-.35**	.10	.23	χ^2 = 62.2**	.15
-software	probit	-.18*	.18**	.14^	-1.27*	χ^2 = 22.8**	.05
-process	probit	-.02	.56**	-.12	-2.26**	χ^2 = 116.8**	.23
Time spent	oprobit	.23**	.06	-.03	5 cut-offs	χ^2 = 28.2**	.03
Involved others:							
Contributors	OLS	.74**	.05	-.34^	.76	F = 7.4**	.06
Resources:							
Informal	OLS	.26**	.05	-.07	3.03**	F = 6.2**	.05
Organizational	OLS	.46**	.09^	-.03	1.72**	F = 26.4**	.18
Personal	OLS	.19^	.01	.41**	.63	F = 16.3**	.11
Diffusion:							
Management	oprobit	.36**	.08	-.11^	3 cut-offs	χ^2 = 53.8**	.06
Work team	oprobit	.21**	.24**	-.06	3 cut-offs	χ^2 = 67.6**	.07
Beyond work team	oprobit	.24**	.14*	-.12^	3 cut-offs	χ^2 = 42.9**	.05

Notes: [1]Unstandardized effect parameters are shown. [2]oprobit = ordered probit, OLS = ordinary least squares. Two-tailed significance **p < .001, *p < .01, ^p < .05.

Second, we looked at our findings concerning the purpose of addressing work problems or challenges. Such use-oriented projects are less likely concerned with new products (b = -.29, p < .001) and technologies (b = -.35, p < .001), and more likely with software (b = .18, p < .001) and (obviously) processes/work methods (b = .56, p < .001). User orientation is unrelated to time spent or the involvement of others. When it comes to resources, we find a positive relationship with employing new resources from the organization (b = .09, p < .05), but not as strong as we encountered previously for missionary orientation. Finally, user orientation is not related to managerial adoption but positively related to adoption by work team members (b = .24, p < .001) and adoption beyond the work team (b = .14, p < .01).

Third, we interpret Table 5.4 with respect to the extent to which the underground projects are driven by a passion for exploration, i.e., explorer orientation. In general, a passion for exploration is only weakly related to most variables, except for employing personal resources (b = .41, p < .001). Also, it is somewhat positively associated with software development (b = .14, p < .05) and negatively with the involvement of others (b = .34, p < .05). Finally, a passion for exploration is associated with lower diffusion rates: adoption by managers is less (b = -.11, p < .05) and ditto for adoption beyond the work team (b = -.12, p < .05).

To further illustrate our findings, we classified our sample into projects that are primarily mission-, use-, or exploration-oriented based on their most dominant purpose. See Appendix F. This analysis ignores that the three orientations can be simultaneously present (so this analysis cannot be regarded as a main result), but advantageous in presenting a straightforward comparison of the three orientations with descriptive statistics that are easier to interpret.

Altogether, our survey results suggest that the orientations derived from the interviews are also present in a bigger sample. Our regression estimates about innovation objects can be interpreted as evidence for the validity of the three orientations: it makes sense that missionary orientation is associated with new products. In any organization, introducing new product parts or concepts cannot be realized without managerial acceptance and requires persuasive effort. Likewise, according to the user innovation literature, solving work problems is almost by definition related to software and processes/work methods (von Hippel, 2005). Finally, when it comes to a passion for exploration, there is no theoretical reason to expect a relationship with any particular innovation object.

Our findings help us to finetune the three orientations. We find that the purpose of changing company practices, i.e., missionary orientation, is related to higher development effort (time spent, contributors), employment of organizational resources in particular, and better diffusion. Next, user orientation is related to higher adoption, especially by work team colleagues. Moreover, explorer orientation is characterized by using personal resources. Our refined orientations are in Table 5.5.

Table 5.5. Refined orientations of underground innovation projects

	Missionary orientation	*User orientation*	*Explorer orientation*
Purpose of innovation	Change company practices	Address a work problem/challenge	Passion to explore
Associated with:			
Innovation object	New products	New processes, software	Mixed
Time spending	Highest	Lower	Lower
Involved others	Many; company-wide network	Some; local network/team	Fewest; buddies and experts
Distinctive resource (on top of slack)	Organizational, seeks new company resources	None, only informal resources/slack	Personal; leisure time and income
Diffusion effort	Proactive persuasion; high effort and persistence	Passive sharing; low effort or hiding	Showcasing; modest effort
Adoption	Highest; also management	Local; mostly colleagues	Least

5. Discussion

Underground innovation studies, so far, focused on employees developing innovations to benefit the company, with bootlegging and creative deviance as prominent concepts in the literature (e.g., Criscuolo et al., 2013; Globocnik and Salomo, 2015; Mainemelis and Sakellariou, 2023). We started observing insights from the user innovation and open-source literature, where employees innovated underground without having company benefits in mind and where the dissemination of innovations within their organization was not self-evident (e.g., Bitzer and Geishecker, 2010; Hartmann and Hartmann, 2023; Lakhani and Wolf, 2005; Zejnilovic, 2016). To study the nature of underground innovation more deeply, we collected data at the level of underground innovation projects. Underground innovation appears to be a more complex activity that occurs for different purposes, with implications for the development and diffusion of these innovations.

Underground innovations can be characterized by their missionary, user, and explorer orientations. These three orientations can be simultaneously present but also appear in isolation. Missionary orientation is the extent to which employees seek to change company practices to create organizational benefits. These projects often entail major efforts to mobilize resources, involve others, and accomplish organizational acceptance. Missionary orientation resembles most of the kinds of innovation that have been described in bootlegging and creative deviance studies (e.g., Abetti, 1997; Augsdörfer, 2008; Mainemelis, 2010; Mainemelis and Sakellariou, 2023). Next, user orientation is the extent to which employees innovate to address a problem or challenge at work. When underground innovations are exclusively use-oriented, their developers generally lack incentives to disseminate. Diffusion does occur, but mainly locally to colleagues able to observe the innovations in use—indicating that strictly use-oriented projects do have broader use-value. Obviously, such projects overlap with the user innovation literature (von Hippel, 2005; Hartmann and Hartmann, 2023). Finally, underground projects can be exploration-oriented: how much developers are driven by a passion and eagerness to move frontiers. In such projects, even leisure time and personal income are used to innovate. Their developers are willing to showcase the innovations but are not overly active in pushing for organizational acceptance. We observed some resemblance with the kinds of motives (passion, curiosity, enjoyment, or meeting like-minded others) found in open-source studies (e.g., Lakhani and Wolf, 2005). In general, especially when missionary orientation is absent, the broader dissemination of underground innovations within the company does not seem to reach its full potential.

5.1. Implications for theory

For researching underground innovation, our study suggests that collecting data at the level of underground innovation *projects* is merited. Especially in quantitative studies, bootlegging and creative deviance scholars have focused on individual employees and their contextual circumstances, using person-level measures. Examples are bootlegging behavior (e.g., Criscuolo et al., 2013; Globocnik et al., 2015), a bootlegging tendency (Globocnik et al., 2022), and the behavior of creative deviance (Lin et al., 2016). Our project-level approach enabled us to detect three orientations that together explain the 'nuisances' observed in previous literature, where not all underground innovations were developed primarily for the organization's benefit and sometimes did not diffuse.

A lack of project-level data is probably why user and explorer orientation remained largely undetected in previous work. Our interviewees mentioned their mission-oriented projects most spontaneously. Given the purpose of these projects to change company practices, our interviewees were more used to communicating actively about these projects, in particular. Also, they were more confident about the value of highly missionary projects for their organization and perceived lower barriers to revealing them. With regard to exclusively user and exploratory projects, examples often came to mind only after we asked more specifically. If we had asked about person-level underground innovation, the odds are that our findings would be biased toward mission-oriented behaviors.

We remark that in previous studies of bootlegging and creative deviance, the explorer orientation has shown some presence. For example, Augsdörfer (2005) noted that a few bootlegging projects in his database seemed driven by 'love for a technology challenge' and 'fun and interest', and by employees who were 'emotionally connected' (p.6). Nevertheless, researchers so far have not integrally identified various orientations and considered those as a source of variance in the outcome of projects (i.e., their dissemination).

Despite use- and exploration-oriented projects not getting a lot of attention so far, we do not think that existing bootlegging and creative deviance concepts—in which organizational benefits are central—are incomplete. Interviewees did not report any underground projects that violated their organization's interests. User innovation projects enabled employees to work more effectively or efficiently and were indirectly related to company performance. Likewise, employees with highly exploratory projects kept themselves up-to-date with the latest technological developments, which contributed to their organization's absorptive capacity and highly motivated them. We did not observe clandestine innovation activities, such as moonlighting, where employees use organizational resources strictly for private gains

(Masoudnia and Szwejczewski, 2012). Hence, the underground innovations we studied contributed to organizational benefits, although it was not always their developers' primary intention.

Project-level approaches enable a range of studies of theoretical and practical interest to increase our understanding of underground innovation. For example, it contributes to our knowledge of when and why underground innovations remain permanently invisible and why projects are not actively promoted. In our interviews, we also observed many employees involved in multiple projects, with the possibility of serving different purposes. Looking at our three orientations, an obvious next step would be to investigate their interactions and how these influence the odds of successful development and dissemination.

Project-level studies can also theorize new variables not considered here: for example, how an innovation's radicalness or its fit with managerial preferences or organizational objectives influences its outcomes. It is also possible to conduct multilevel studies in which employees' involvement in multiple underground projects is considered of theoretical interest. For example, hypotheses can be developed about interactions between project-level characteristics and previously identified (person-level) antecedents—like risk-taking propensity (Globocnik, 2019) and perceived management support (Lin et al., 2016).

5.2. Implications for practitioners

In previous studies, management support has been associated with underground innovation by employees who have organizational benefits in mind (e.g., Criscuolo et al., 2013; Globocnik et al., 2022) and also with continued underground innovation behavior, depending on how managers respond when projects are revealed (Lin et al., 2016). Our study adds the insight that, from the perspective of organizations willing to take advantage, managers will not get to see *all* underground innovations. In some projects, it is simply not the developer's intention, and incentives to disseminate or push for organizational acceptance may be missing entirely.

The odds that highly missionary projects will surface are high. In contrast, when underground innovations are only use- and/or exploration-oriented, their developers will not invest (much) effort to reveal, nor will they strive for active dissemination. A clear example we observed was use-oriented software saving the employee over 90% of the time originally needed for a test procedure—a big cost saver that would benefit other employees concerned with similar routines. However, because the employee felt not incentivized to disseminate actively, the software hardly diffused throughout the company. These and similar examples leave the company with unrealized value-creation potential.

A key question is whether managerial and company practices are tailored enough to reveal and leverage underground innovations. For example, idea management systems (IMS) are primarily meant to trigger and facilitate bottom-up innovation to advance company performance (van den Ende et al., 2015). In the default IMS, employees submit ideas for evaluation and may be awarded company resources for the development. It is implicitly assumed that submitters are motivated to work on or contribute to implementation. We expect that the classical IMS will mainly detect mission-oriented projects—if any underground projects are reported at all (Zejnilovic, 2016). (This is also what we observed in our interviews: employees with mission-oriented projects were eager to obtain additional organizational resources, for which interviewees used the company's IMS and other internal challenges.) Our findings suggest that systems should be tailored to trigger sharing and dissemination of projects that were meant to solve work-related problems or that were driven by a passion for exploration.

For strictly use-oriented projects, we expect the classical IMS to be less effective. We find a lack of incentives for employees to actively communicate their user innovations. They sometimes even fear the (potential) negative consequences of revealing. A tailored IMS should explicitly focus on process innovations ('Share your solutions with us! We are looking for fixes worth sharing!'), call on opportunities for altruism and even consider bonuses to trigger developers to report what they have done. The IMS should also diminish the downsides of spending time on dissemination and be as simple as possible (for example, delegate the diffusion effort to a dedicated worker as part of the IMS's service). Also, recall that use-oriented projects diffused mainly to colleagues in the work team. A complementary intervention would be to enable the nomination of underground projects developed by colleagues instead of asking developers to reveal themselves.

Likewise, to detect underground innovations that are mainly exploration-oriented, employees will be more responsive to opportunities to meet experts in their field of interest and to obtain recognition for their achievements. A tailored IMS would focus on developed prototypes and resemble a beauty contest ('We are looking for prototypes beyond the final frontier!'). As part of the contest, exploration-oriented projects should be showcased (e.g., an internal platform, magazine, or award ceremony), with their developers getting expert recognition. Employees with projects of this kind would also appreciate feedback from like-minded others. This would imply that a standard IMS jury is not enough—jury members should be tailored to the submissions at hand.

5.3. Limitations and suggestions

Beyond the implications for research we already discussed, our study has limitations that directly translate into opportunities for continued work.

First, our study was done in a multinational organization concerned with research and product development. An obvious question is whether our results generalize to other contexts. We investigated underground projects of workers with a professional interest in innovation. Given that missionary, user, and explorer orientations explain the nuisances we observed in the literature, we expect our results to generalize. Context may, however, influence the frequency with which missionary, user, and explorer orientations are observed. In non-R&D settings, we would expect relatively fewer exploration-oriented projects—the less innovation is part of employees' daily work, the less we expect underground projects driven by a passion for exploration in innovative domains. In contrast, in organizations with highly standardized work processes, we would expect more use-oriented underground innovations. For example, in Hartmann and Hartmann's (2023) study of the Danish police and military, mainly user innovations were found. This likely has to do with the highly bureaucratic culture of the type of organizations they studied. We recommend replication of our study and expanding it to different contexts.

A second limitation is that we could not collect objective data on the general value of underground innovations. In future research, managerial or company views on the value of these projects are worth including. Such data would enable us to conclude on the optimal dissemination rates of underground projects—we cannot exclude the possibility that high diffusion of mission-oriented projects and lower diffusion of user and explorer projects, as we observed, is actually the optimal outcome.

Third, it remains challenging to investigate how underground innovations can be detected. An important finding was that some underground innovations remain permanently invisible—an observation shared by Hartmann and Hartmann (2023). In this context, Sakhdari and Bidakhavidi (2016) made the first, qualitative inventory of factors that make employees reveal bootlegged projects. The impact of context factors like management support and rewards seems to vary and should probably be tailored to (the) prevailing orientation(s) of underground innovation projects.

In conclusion, underground innovation is a rich, ubiquitous concept. Underground projects can be undertaken for different purposes (mission-, use-, exploration-oriented, or a mix thereof) and do not always aim to create organizational benefits, at least not primarily. Studying underground innovation at the level of projects certainly creates many opportunities for continued research.

Chapter six

Summary and conclusions

Within the scope of this dissertation, I addressed the unexpected sources of innovation. In contrast to the dominant view on innovation, I studied innovation as a distributed phenomenon—recognizing the contributions of citizens who innovate for various (often non-commercial) reasons.

From increased access to information to a shift in production from material to immaterial goods, recent trends enable citizens to become more active agents of change. Both at their homes and workplaces, individual citizens are witnessed to be producers of goods (Ritzer and Jurgenson, 2010), including innovations that enable new functions when compared with the existing goods offered on the (local) market (von Hippel, 2017). These innovations include tangible goods, such as new brewing technologies for making craft beers (Wolf et al., 2020), and intangible goods, like open-source software (Lakhani and Wolf, 2005). Such observations are in stark contrast with our traditional understanding of innovation and open up new challenges for academic research.

In this thesis, first, I took on the challenge of unraveling the process through which citizens manage to produce household sector (HHS) innovations (chapter two). I studied how citizens' income and discretionary time permit them to develop goods at home, conceptualized as do-it-yourself, and subsequently, how these resources allow citizens to be innovative in their efforts. Answering the call for more fundamental studies and in-depth theorizing of HHS innovation by de Jong et al. (2021), the main contributions of this chapter to the literature are the more nuanced conceptualization of HHS innovation—I connect the concept to broader constructs on citizen production behaviors: do-it-yourself and prosumption—and the sophisticated model that theorizes how resources affect citizens' innovation initiatives, allowing also for the explanation of past inconsistent research findings on the role of income in steering HHS innovation (cf. Chen et al., 2020; Praceus and Herstatt, 2017).

Second, I took a helicopter view of the regional factors enabling citizens to develop and diffuse innovations and develop an ecosystem model. Past studies of HHS innovation are weakly correlated concerning the policies they advise (cf. de Jong et al., 2018; von Hippel, 2017). Though the recommendations make sense based on the respective individual studies, the lack of a holistic perspective on HHS innovation has resulted in only a few changes to policymaking in practice (Bengtsson and Edquist, 2022). An ecosystem model explaining how the most significant regional elements may determine the levels of HHS innovation, I argue, can provide a valuable toolbox to scholars and policymakers in suggesting and shaping HHS innovation policies. My model links the suggestions by previous studies, creating an overview of the instruments available to support HHS innovation—and how they complement or weaken each other.

Third, I moved my focus to the interactions between citizens and producer firms in developing and diffusing innovations. Though the growing literature on innovation by citizens has counseled firms to open up their boundaries and facilitate innovation by and absorb knowledge from users of their products (Bogers et al., 2017; West et al., 2014), few theories to date explain variation in users' characteristics and how this might explain their innovation outcomes. I examine quantitatively the case of the Ultimaker 3D printer and the online knowledge-sharing platform founded by Ultimaker: YouMagine. Such platforms allow users to share freely the product improvements or additions they developed. My study offers new insights into the characteristics of users contributing designs well-received by the user community—providing some guidance to firms on which users are likely contributors.

Fourth, I studied how a democratized view of innovation implicates innovation in firms by exploring underground innovation—i.e., the innovations employees initiate and develop without their supervisors or management knowing. Previous studies in the literature on bootlegging (Augsdörfer, 1996; 2005) and creative deviance (Mainemelis, 2010) have reported such cases but did not provide an in-depth account of employees' motivations, while these can have implications for the diffusion, hence the visibility of underground innovations. I contribute such an account and reveal three orientations that characterize employees' projects developed underground.

6.1. Summary of the findings

Chapter two: resources permitting innovation in the household sector. By conceptually embedding HHS innovation in do-it-yourself behavior and constructing a neo-classical model that accounts for this embeddedness, I show that citizens' income and discretionary time positively affect their tendency to produce goods at home but that income negatively affects the likelihood that they are innovative in their efforts. From the theoretical model, I derive that process benefits can be the mechanism explaining these effects. Citizens with higher income more often develop goods for the experience instead of use considerations: process benefits increase with income, explaining why do-it-yourself increases with income. However, as income shifts citizens' focus from use-value to process benefits, the actual function of the good may come at the detriment of income, explaining why the likelihood of innovation can decrease. For the effect of discretionary time, the model cannot show such detailed mechanisms, but the survey data from the United Arab Emirates (n = 2,728) seem to confirm the hypotheses formulated for income and show similar patterns for time. Citizens' tendency to develop goods at home increases with discretionary time, but the likelihood they are innovative in their efforts decreases with discretionary time.

Chapter three: a policy framework for household sector innovation. Based on an extensive literature review of the HHS innovation studies conducted so far and 13 interviews with academic and policy experts on innovation by citizens, I conceptualize an ecosystem model containing eight regional elements enabling the development and diffusion of HHS innovations. I distinguish between factors in the (institutional) environment and more direct facilitators of HHS innovation (diffusion). In the (institutional) environment, I find that (1) rules and regulations, (2) cultural norms and values, and (3) social capital are relevant elements of the ecosystem. As facilitators, I identify (4) human capital, (5) innovation tools, (6) (online) platforms and workshops, (7) general resources and infrastructure, and (8) producers and industry as ecosystem elements. Though the ecosystem model is purely conceptual, I suggest quantitative indicators facilitating future empirical assessments of HHS innovation ecosystems. Furthermore, by connecting the ecosystem elements to policy instruments suggested in previous publications, I find that the elements of cultural norms and values and social capital are not covered so well by these instruments—even though the literature shows a major effect of these elements, especially when it comes to social capital. Moreover, my analysis shows inconsistencies in the policies suggested. A clear example is the suggestion of both open standards (von Hippel, 2017) as promoting technology licensing (de Jong et al., 2018) to facilitate HHS innovation outcomes.

Chapter four: firm-hosted user innovation communities. By drawing on survey data gathered among YouMagine users, a social network of their online relations, and data on their status as professionals in 3D printing obtained through a web search, I show significant differences in the adoption of users' add-ons or enhancements to the Ultimaker 3D printer in the user community. It appears that the designs by users with professional experience in the product domain (i.e., 3D printing) diffuse better than the designs by users who lack such experience. However, for this significant difference to show up in the data, users must have a commercial motive to engage with 3D printing and/or hold a central network position, which provides them with superior access to other users' needs and solutions. One of the factors hampering the diffusion of users' innovation is their lack of skills in designing products effortlessly adoptable by others—users' products oftentimes look amateurish (Riggs and von Hippel, 1994; von Hippel, 1994). Professional experience, I argue, equips users with the design and marketing expertise necessary to alleviate these diffusion problems.

Chapter five: underground innovation. Combining the data of qualitative interviews and survey studies conducted at Ford Motor Company, I find that underground innovation projects can be differentiated by three orientations. They can be mission-oriented, use-oriented, or exploration-oriented. Mission-oriented projects are undertaken by employees to bring about change in company practices and to create organizational benefits. These projects, however, may be developed underground for the employees to develop a proof-of-concept before revealing it to the company. Use-oriented projects are developed by employees to address a problem or challenge at work. As employees strictly develop these projects to address their needs, they generally lack incentives to disseminate such innovations. Exploration-oriented projects are driven by employees' passions and eagerness to move (technological) frontiers. These projects likely stay underground as they serve as vehicles for employees to express their interests, but they do not directly address the organization's interests. As I show in detail in chapter five, most importantly, the orientations have implications for the diffusion of underground innovations—affecting the odds that these projects once will become visible to the company or not.

6.2. Conclusions

All the chapters support the premise that innovation has become a distributed phenomenon. Citizens are actively developing and (sometimes) sharing goods that fulfill a function not acquirable on the (local) market. They can do so at their homes, organized in communities online, and at their workplace. Moreover, supporting the argument of complementarity (Gambardella et al., 2017), my thesis shows that citizens can develop add-ons and enhancements to existing products, benefitting both the extent to which users appropriate value from producer firms' products and the firms offering the products, as their offerings increase in consumption value.

My insights, however, also warrant future academic studies to be careful with addressing the emergence of innovations from citizens in the household sector. The innovation process of citizens is complex and rooted in broader production behaviors. Neglecting the embeddedness of HHS innovation in such behaviors, as is often done in correlational studies, likely leads to a failed understanding of the antecedents of citizens' innovations. And, neglecting the diverse ecosystem elements that together enable HHS innovation outcomes likely leads to misalignment of insights.

Furthermore, the results presented in this thesis underline that the diffusion of citizens' innovations is highly intricate and, unfortunately, limited. Thereby, as articulated in detail by de Jong et al. (2015), the impact of these innovations on a grand scale remains below the social optimum. I further explored the role of professional experience and motivation (to share). A lack of any of these makes diffusion more unlikely. On a positive note, these vulnerabilities can be alleviated by strengthening ties between producer firms and citizens. I motivate future studies, policies, and organizational practices to emphasize the complementarity between producer firms and citizens, so that resources are allocated more efficiently in enabling socio-economic progress.

6.3. Contributions to society

The notion of sticky information (von Hippel, 1994) is imperative to understanding the social relevance of innovation by citizens. As (1) citizens have the most accurate information regarding their needs and (2) information is sticky (meaning difficult to transfer from citizen to producer firm), local challenges are unlikely to be overcome unless citizens are empowered to take care of their needs. There are countless examples of well-meant policies failing to address local intricacies or products launched by producer firms failing to satisfy consumer demand. Empowering citizens to innovate through policies that cultivate citizens' innovation resources and offering products that allow for being tweaked according to citizens' needs can bring needs and solutions closer together, enabling society to grow.

Regarding policy, the second and third chapters of this thesis are the most informative. Traditional innovation policies have been targeting the protection of intellectual property and the provision of monetary rewards to incentivize private investments in knowledge and innovation. However, in light of HHS innovation, such policies can be harmful as they hamper need and solution information from diffusing freely between citizens and impose closed innovation models by firms—while society would oftentimes benefit from more open innovation. My thesis contributes to innovation policy that is more inclusive to citizens' initiatives, first, by guiding what citizens to target to increase the effectiveness of policies. The second chapter reveals that these are the resource-deprived citizens in society, as providing more resources to citizens already well-endowed will likely increase their development of goods developed for fun but not contribute as well to the development of innovations. Second, in the third chapter, my thesis provides a framework that can be used by policymakers as a toolbox, as it provides an overview of the regional factors affecting HHS innovation, and can assist the development of future policies while accounting for the complementary or contradicting nature of individual measures and regional intricacies.

For managerial practices, I provide both insights into open innovation practices (chapter four) and in-house innovation management (chapter five).

Chapter four counsels how firms can establish online platforms hosting user innovation communities to make users' product add-ons and enhancements visible. The most important takeaway is that firm-hosted user communities should be designed such they are attractive also for users with professional experience in the product domain and take into account the diverse motivations of users. Some users might be commercially-driven to join a community and feel more inclined to do so when the platform allows market transactions to take place. I note again, however, that online user communities are most likely to flourish when a producer firm actively encourages user innovation also through the design of its products—user innovation is more likely when users can tweak products according to their preferences (as is the case for the Ultimaker 3D printer studied in chapter four).

Finally, for the management of citizen innovation taking place within organizations' boundaries, I suggest how corporate idea management systems can be designed such they account for the diverse motivations that employees' innovations may be oriented to. As I reveal in the fifth chapter, a part of employees' innovations are developed underground, hidden from the radar of supervisors and management. To increase the chances that these innovations are (eventually) reported, corporate idea management systems must be tailored at employees diverse motivations for innovating underground—particularly when creating organizational benefits is not the prime motivator of the innovator.

6.4. Continuing research on the unexpected sources of innovation

As I discussed in the introduction to this thesis, the acceleration of trends propelling innovation by citizens can be traced to the end of World War II. Just as the division of innovation labor between citizens and producer firms has not changed overnight, the paradigm shift in the academic literature addressing innovation will not conclude with this thesis. Throughout my chapters, I have suggested new avenues that future studies can explore to enrich our knowledge of HHS innovation, the interaction between citizens and producer firms, and the process of underground innovation.

For example, future quantitative studies of the ecosystem of HHS innovation can help us to make more sense of the local conditions under which citizens can flourish in developing and disseminating their innovations. Such an approach has recently taken off in the entrepreneurship literature and has proven a powerful tool for policies targeted at raising levels of entrepreneurship (Stam and Spigel, 2016). In chapter three, I propose a set of regional indicators that—with future data collection efforts—could serve as a basis for estimating the relationships between local conditions for HHS innovation and how they explain innovation outcomes.

Many more suggestions for future research on the new innovation paradigm of innovation by citizens can be found in the discussion sections of chapters two to five.

A promising avenue not discussed in detail in my chapters is the relationship between HHS innovation and entrepreneurship. As revealed in chapter three, entrepreneurship is a potential pathway for citizens' innovations to diffuse in society—a dynamic discussed in detail by Shah and Tripsas (2007). However, quantitative assessments of the relationship between citizens' innovative initiatives and the likelihood that these are followed by entrepreneurial activities are rare, making it difficult to judge (statistically) to what extent HHS innovation is a breeding ground for entrepreneurship. I highly encourage future studies to delve deeper into this assessment, as the diffusion of citizens' innovations remains problematic. If we know more about the relationship between HHS innovation and entrepreneurship and the conditions interacting with this relationship, perhaps future policies can be designed such that more citizen innovations diffuse through this pathway and add to societal welfare.

To conclude, I hope the insights I provide in this thesis reinforce the recognition of citizens' innovative initiatives such that—in our future society—challenges can be addressed by those closest to the source and solutions can be scaled through strengthened cooperation between producer firms and citizens.

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Appendices

A1 (chapter two): Analysis of an optimum

Expression (2) displays the reduced-form utility function over labor hours h_m and hours spent on DIY h_{DIY}. To study whether an optimum exists for this utility maximization problem, we compute the first-order and second-order derivatives with respect to h_m and h_{DIY}. See expressions A.1.1-A.1.5 below.

First-order derivatives:

A.1.1 $$U_{h_m} = \frac{\delta w}{\delta w h_m + \varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta}} - \frac{A}{T - h_m - h_{DIY}}$$

A.1.2 $$U_{h_{DIY}} = \frac{\beta\varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta-1}}{\delta w h_m + \varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta}} - \frac{A}{T - h_m - h_{DIY}} + b(w,\theta)$$

Second-order derivatives:

A.1.3 $$U_{h_m h_m} = -\frac{\delta^2 w^2}{\Big(\delta w h_m + \varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta}\Big)^2} - \frac{A}{(T - h_m - h_{DIY})^2}$$

A.1.4 $$U_{h_{DIY} h_{DIY}} = -\frac{\beta\varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta-2}\Big(\varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta} + (1-\beta)\delta w h_m\Big)}{\Big(\delta w h_m + \varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta}\Big)^2} - \frac{A}{(T - h_m - h_{DIY})^2}$$

A.1.5 $$U_{h_{DIY} h_m} = U_{h_m h_{DIY}} = -\frac{\delta w \beta\varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta-1}}{\Big(\delta w h_m + \varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta}\Big)^2} - \frac{A}{(T - h_m - h_{DIY})^2}$$

An optimum exists when all first-order conditions and second-order conditions are satisfied. The first-order conditions are that $U_{h_m} = 0$ and $U_{h_{DIY}} = 0$, giving two implicit functions for h_m and h_{DIY}.

The second-order conditions are (1) that $U_{h_m h_m} < 0$ and $U_{h_{DIY} h_{DIY}} < 0$ and (2) that $D = U_{h_m h_m} U_{h_{DIY} h_{DIY}} - U_{h_m h_{DIY}}^2 > 0$. The former is satisfied as the function $U(.)$ is concave in both h_m and h_{DIY}—see expressions A.1.3 and A.1.4 above. The latter condition is satisfied if expression A.1.6 below holds. To come to expression A.1.6, for simplicity, we assumed that $T = h_m + h_{DIY}$. Hence, we fix the agent's preference for leisure and isolate the agent's decision on engagement in the labor market h_m versus DIY h_{DIY}. Of course, the reality is more complex, but—as previous studies indicate that the make-or-buy decision (i.e., buy a good on the market or self-provision the good through DIY) is crucial for people's engagement in DIY (Wolf and McQuitty, 2013; Nagel et al., 2018)—we isolate this specific element to come to an interpretable solution.

A.1.6 $$D = \frac{(1-\beta)\delta w h_m + (1-\beta)\varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta}}{\gamma} = \frac{(1-\beta)(c_m + c_{DIY})}{\gamma} > 0$$

In which $\gamma = \frac{\left(\delta w h_m + \varphi((1-\delta)w)^{\alpha} h_{DIY}^{\beta}\right)^4}{\delta^2 w^2 \beta \varphi((1-\delta)w)^{\alpha} h_{DIY}^{\beta-2}}$ and is positive by definition of the model. As $0 < \beta < 1$ (see section 3), expression A.1.6 holds, hence, an optimum exists.

Reference

Nagel, D. M., Cronin Jr, J. J., and Utecht, R. L. (2018). Consumption or prosumption? A question of resources. *Journal of Services Marketing*, *32*(6), 739-754.

A2 (chapter two): Comparative statics analysis—effect of income on DIY

Applying the implicit function theorem in combination with Cramer's rule, we can write down the effect of income on DIY as follows:

A.2.1 $$\frac{\partial h_{DIY}^{*}}{\partial w} = \frac{\begin{vmatrix} U_{h_m h_m} & -U_{h_m w} \\ U_{h_{DIY} h_m} & -U_{h_{DIY} w} \end{vmatrix}}{D}$$

We know from our analysis of the optimum (see section A.1 above) that $D > 0$. Hence, an increase in the agent's wage positively affects engagement in DIY when $\begin{vmatrix} U_{h_m h_m} & -U_{h_m w} \\ U_{h_{DIY} h_m} & -U_{h_{DIY} w} \end{vmatrix} > 0$. That is, when $U_{h_m h_m} \cdot -U_{h_{DIY} w} - U_{h_{DIY} h_m} \cdot -U_{h_m w} > 0$. We first compute the partial derivatives $U_{h_m w}$ and $U_{h_{DIY} w}$—see A.2.2 and A.2.3 below:

A.2.2 $$U_{h_m w} = \frac{(1-\alpha)\delta\varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta}}{\left(\varphi w h_m + \varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta}\right)^2}$$

A.2.3 $$U_{h_{DIY} w} = \frac{(\alpha-1)\delta h_m \beta\varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta-1}}{\left(\varphi w h_m + \varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta}\right)^2} + B_w$$

Next, when assuming that $T = h_m + h_{DIY}$ it can be shown that $\begin{vmatrix} U_{h_m h_m} & -U_{h_m w} \\ U_{h_{DIY} h_m} & -U_{h_{DIY} w} \end{vmatrix} > 0$ if and only if:

A.2.4 $$(\alpha-1)\delta w h_m + B_w \frac{w\left(\delta w h_m + \varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta}\right)^2}{\beta\varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta-1}} > (1-\alpha)\varphi\big((1-\delta)w\big)^{\alpha} h_{DIY}^{\beta}$$

This can be simplified to expression A.2.5 below. In which X simplifies the complex term in the middle of A.2.4 ($X = \frac{w(c_m+c_{DIY})^2}{G_{h_{DIY}}}$), that is, the agent's wage times total consumption squared divided by the first derivative of the agent's DIY production function with respect to h_{DIY} and is positive by definition of the model:

A.2.5 $$(\alpha - 1)c_m + B_w X > (1 - \alpha)c_{DIY}$$

For $h_{DIY} > 0$, the effect of income on DIY engagement becomes:

A.2.6 $$\frac{\partial h_{DIY}^*}{\partial w} = \frac{(\alpha - 1)c_m + B_w X - (1 - \alpha)c_{DIY}}{D}$$

By the definition of D (see expression A.1.6) and X (see expression A.2.4), this can be rewritten so that the effect of income on DIY becomes:

A.2.7 $$\frac{\partial h_{DIY}^*}{\partial w} = \left(\frac{\alpha - 1}{1 - \beta} + \frac{B_w w(c_m + c_{DIY})}{(1 - \beta)G_{h_{DIY}}}\right)\gamma$$

As γ is positive by definition, the direction of the effect of income on hours spent on DIY is determined by the terms within parentheses: $\frac{\alpha-1}{1-\beta} + \frac{B_w w(c_m+c_{DIY})}{(1-\beta)G_{h_{DIY}}}$; or by $\frac{\alpha-1}{1-\beta}$ when process benefits approach zero ($b(w,\theta) \to 0$) such that B_w disappears. The possibility of DIY done for necessity (i.e., $b(w,\theta) \to 0$) stems from empirical observations by Williams (2008)—which also show that this, as in our model, is far more likely when individuals face tight resource constraints.

A3 (chapter two): Comparative statics analysis—effect of discretionary time on DIY

Once again, applying the implicit function theorem in combination with Cramer's rule, we can write down the effect of discretionary time on DIY as follows:

A.3.1 $$\frac{\partial h_{DIY}^*}{\partial T} = \frac{\begin{vmatrix} U_{h_m h_m} & -U_{h_m T} \\ U_{h_{DIY} h_m} & -U_{h_{DIY} T} \end{vmatrix}}{D}$$

The partial derivatives $U_{h_m T}$ and $U_{h_{DIY} T}$ are provided by expression A.3.2 below.

A.3.2 $$U_{h_m T} = U_{h_{DIY} T} = \frac{A}{(T - h_m - h_{DIY})^2}$$

As we now focus on the role of time, we lift the assumption of $T = h_m + h_{DIY}$ and allow the agent's preference for leisure to be variable again. Then, it can be shown that $\begin{vmatrix} U_{h_m h_m} & -U_{h_m T} \\ U_{h_{DIY} h_m} & -U_{h_{DIY} T} \end{vmatrix} > 0$ (hence, an increase in discretionary time available has a positive effect on engagement in DIY) if and only if:

A.3.3 $$\frac{\delta w}{\big((1-\delta)w\big)^{\alpha}} > \beta\varphi h_{DIY}^{\beta-1}$$

B (chapter two): Regression results with weighted data

As a robustness check, we re-estimated our sequential logit regressions with weighted data. In the first weighted model (see Table B.2), we weighted the data to make the sample representative for the combination of gender (male, female), age (18-24, 25-34, 35-44, 45-54, 55+ years), and Emirate (Abu Dhabi, Dubai, Sharjah, Northern Emirates). Our weights were based on a table that specified the percentage of UAE citizens across combinations of gender, age, and Emirate (best estimates obtained from the UAE’s Prime Minister's Office). A similar table was specified for our sample. Weights were the ratio of the corresponding table entries: see Table B.1.

Table B.1. Weighting scheme based on gender, Emirate and age

		Population (N = 7.9mln)		*Sample (n = 2,728)*		*Weight*	
		male	female	male	female	male	female
Dubai	18-24 years	2.7%	1.4%	4.0%	1.2%	0.67	1.12
	25-34 years	10.0%	3.7%	12.6%	3.8%	0.80	0.97
	35-44 years	8.1%	2.7%	6.9%	3.0%	1.16	0.88
	45-54 years	3.8%	1.2%	4.2%	1.2%	0.90	1.06
	55+ years	1.6%	0.6%	2.2%	0.7%	0.72	0.81
Abu Dhabi	18-24 years	2.6%	1.4%	2.5%	1.4%	1.02	1.00
	25-34 years	9.7%	3.5%	9.9%	2.9%	0.98	1.22
	35-44 years	7.8%	2.6%	7.0%	1.7%	1.12	1.54
	45-54 years	3.7%	1.2%	2.5%	0.6%	1.50	2.06
	55+ years	1.6%	0.5%	1.8%	0.2%	0.86	2.47
Sharjah	18-24 years	1.2%	0.6%	2.3%	1.0%	0.51	0.66
	25-34 years	4.5%	1.7%	5.1%	1.9%	0.89	0.85
	35-44 years	3.7%	1.2%	3.0%	1.5%	1.20	0.79
	45-54 years	1.7%	0.6%	1.8%	0.3%	0.94	2.20
	55+ years	0.7%	0.3%	0.7%	0.1%	1.00	2.31
Northern Emirates	18-24 years	1.0%	0.5%	1.2%	0.5%	0.83	1.03
	25-34 years	3.8%	1.4%	3.8%	1.2%	0.99	1.14
	35-44 years	3.0%	1.0%	2.6%	1.0%	1.19	1.02
	45-54 years	1.4%	0.5%	0.6%	0.4%	2.46	1.17
	55+ years	0.6%	0.2%	0.4%	0.1%	1.67	1.45

In the second weighted model (see Table B.2), we weighted the data to make the sample representative for citizens’ nationality/country of origin (Emirati, Arabic, Western, Indian, Pakistan, Philippines, Bangladesh, other Asian, other not-Asian). The weight table was computed based on a similar approach as shown in Table B.1 and available on request.

Next, Table B.2 shows that the significant findings in our models are maintained.

Table B.2. Sequential logit models with weighted data

Weight factor based on:	Unweighted (in paper)	Gender, Age, Emirate (combined)	Nationality
Step 1. dependent variable: DIY output (dy/dx)			
Income	.00244**	.00268**	.00245**
Discretionary time	.00105**	.00112**	.00101**
Female	.0098	.0094	.0112
Age	-.0037	-.0045	-.0008
Collective household	-.0236	-.0228	-.0266
Technical education	.0057	.0032	.0009
Technical work experience	.0484**	.0470**	.0487**
Education level	.0248**	.0250**	.0258**
Step 2. dependent variable: HHS innovator (dy/dx)			
Income	-.00666*	-.00549^	-.00717*
Discretionary time	-.00405*	-.00389*	-.00451**
Female	-.0976	-.1152	-.1183
Age	.0013	-.0099	-.0047
Collective household	-.0381	.0021	-.0229
Technical education	.0281	.0529	-.0081
Technical work experience	-.0334	-.0602	.0215
Education level	.0140	.0152	.0231
Model fit:			
Wald-χ^2 (df)	124.2 (8)**	116.8 (8)**	120.8 (8)**
Observations	2,728	2,728	2,728

Notes: Average marginal effects are shown. Two-tailed significance **p < .01, *p < .05, ^p < .10.

C (chapter three): Complete list of suggested policy measures enabling HHS innovation development and diffusion

Table C.1. Policy measures aimed at supporting the HHS innovation ecosystem

Aggregate dimensions	Ecosystem elements	Proposed policy measures
(Institutional) Environment	Rules and regulation	*Public funding of open standards.[a,x] *Support patients' capability to design and carry out clinical trials independent of producers.[a] *Apply more generative interpretation of the organic statutes governing agencies.[a] *In cost-benefit analyses of regulatory actions, take into account the effect on HHS innovation.[a,y] *Reconsider IPR, as they can hurt HHS innovation[b,y]—e.g., allow for a research exemption to IP-protected products (example can be given by plant breeding rights in the US).[x,y] *Educate citizens about creative commons and alternatives to IPR.[x,y] *Invest in the measurement of HHS innovation, as internationally comparable measures are still scarce and time trends are still invisible.[x,y] *Set up government intermediary agents that can help coordinating HHS innovation communities (e.g., help by pooling resources or granting a common voice when talking to regulators).[z]
	Cultural norms and values	*Promote the Maker culture.[d,k,q] *Promote the entrepreneurial lifestyle.[t]
	Social capital	*Support collaborative innovation so that different personality traits, that support HHS innovation at different stages but do not exist in the same person, complement each other.[c] *Promote HHS innovation communities[e,t,y]—by (1) making organizing network events an evaluation criterium for publicly funded maker spaces[l] and (2) organizing network events for creators without third-party involvement.[l,t]
Facilitators	Human capital	*Invest in and promote technical education[d,u], particularly education in modular design[e,x,y], DIY skills, and sustainable innovation.[z] *Search and support lead users.[e] (To enhance search efficiency, DIY communities can be an interesting pool of lead users. [p]) *Coach HHS innovators in developing entrepreneurial skills: strategy, bootstrapping, business models, etc.[x,y] *Collect and share data on citizens' unmet needs.[a] *Influence and stimulate the need for commercialization of users, e.g., by making them eligible for public innovation challenges that have monetary rewards[x,ab] or by facilitating technological licensing for HHS innovation.[ab]
	Innovation tools	*Subsidize design tools/ mobile production facilities.[d,o,y] *Develop toolkits that channel the personality traits of people into useful factors of production and diffusion. Example: inexpensive CAD software that has a user-friendly interface may enable laypeople to create robust designs more easily and quickly, even if they tend to be high on extraversion and low on conscientiousness.[c] *Invest public funds in gathering data that can be useful for HHS innovators and transfer these data to the knowledge commons (see element below).[f,y,z]
	(Online) platforms and workshops	*Provide public funding for maker spaces and other (public) places where citizens can share innovation-related information.[a,d,k,x,y] *Sponsor online knowledge-sharing platforms.[h,z] *Develop knowledge commons: an (online) place where design information is shared for free.[a,f,y,z]

	*Set up maker spaces as part of education institutes.[o] (For example, as part of universities, like has been done in the University of Pretoria.)
General resources and infrastructure	*Set up agencies that provide public resources for unlicensed use.[a] *Suggested HHS innovation policies will be more effective when targeted to those deprived of resources. This is because increasing the resources of already resource-rich individuals will mostly lead to DIY goods that add little functional novelty.[h,t] *Subsidize access to internet and electricity.[o,x] *Design and support an infrastructure with more local, small-scale production facilities (for public use).[o] *Use democratic crowdfunding mechanisms to publicly fund users who wish to commercialize their innovations.[aa] *Promote crowdfunding marketplaces.[z,aa] *Provide micro-loans.[z]
Producers and industry	*Provide subsidies that help citizens access firms' (mobile) production facilities.[d,o] *Incentivize/require private owners of knowledge to transfer their raw data to knowledge commons (see above).[f,y] *Reconsider R&D subsidies and tax exemptions, as they may induce more closed R&D by firms even when open R&D (inclusive to citizens' initiatives) is more beneficial for social welfare.[d] *Educate producers on the benefits of working with lead users and how to identify them.[x,y] *Analyze and tackle industry characteristics such as concentration as they can constrain HHS innovators to engage in entrepreneurship.[u]

Sources: von Hippel (2017)[a], Shah and Tripsas (2007)[b], Stock et al. (2016)[c], Gambardella et al. (2017)[d], Franke et al. (2006)[e], Potts et al. (2021)[f], Claussen and Halbinger (2021)[g], Mulhuijzen and de Jong (2023)[h], Mauroner (2017)[i], Troxler and Wolf (2017)[j], Browder et al. (2019)[k], Li and Gao (2021)[l], Williams (2008b)[m], Wolf and McQuitty (2013)[n], Fox (2014)[o], Hahn et al. (2016)[p], Collier and Wayment (2018)[q], Williams and Nadin (2010)[r], Grant (2013)[s], Thai and Turkina (2014)[t], Siqueira et al. (2014)[u], Williams et al. (2016)[v], Jeppesen (2021)[w], von Hippel and de Jong (2010)[x], Kuusisto et al. (2013)[y], Nielsen et al. (2016)[z], Brem et al. (2019)[aa], de Jong et al. (2018)[ab].

D.1 (chapter five): Interviewees

	Depart-ment	*Tenure (years)*	*Age (years)*	*Gender*	*Job description*	*Underground innovation**	*Project description*
#1	research	16	43	male	innovation process manager	yes	Powertrain support tool. Software to manage research projects.
#2	prod dev	4	29	male	supervisor internal maker space	yes	Touchscreen integrator. Piece of hardware to attach smartphone to car's touchscreen.
#3	prod dev	10	54	male	global product development manager	yes	Reporting software. Automates weekly progress reports.
#4	prod dev	2	25	female	vehicle concepts researcher	yes	Training program. Facilitates maker space use by electrical engineers.
#5	prod dev	7	38	male	software engineer	yes	Visualization tool. Use VR glasses and headsets to visualize the geometry of designs.
#6	prod dev	8	32	male	vehicle architecture engineer	yes	Crash simulation tool. Software to test effectiveness of new materials.
#7	prod dev	3	36	male	materials engineer	contributor	Steering wheel improvement. Technology enables alignment with car electronics.
#8	prod dev	18	45	male	CAD engineer electrical parts	yes	Breakdown triangle. Self-driving version for autonomous vehicles.
#9	prod dev	7	52	male	buying coordinator	yes	Plastics processing machine. Enables recycling of leftover plastics.
#10	prod dev	14	42	male	senior operator warranty	yes	Innovation board. Work process to assess innovation projects for quality management.
#11	prod dev	5	29	male	mechanical engineer	yes	Multimedia entertainment feature. Integrated in car's multimedia system.
#12	prod dev	20	44	male	CAD engineer	yes	Foldable electric bike. Fits a small car.
#13	prod dev	10	35	male	electrical engineer	yes	E-drive system. Integrated in steering wheel.
#14	prod dev	20	46	male	mechanical engineer	yes	Mobility system. Enables smart use of data that vehicles generate.
#15	prod dev	11	34	female	chassis engineering team leader	no	
#16	prod dev	15	40	male	project planner	yes	Safety belt for children. New buckle system for safety belts
#17	prod dev	8	38	male	engineer brake systems	yes	Brake warning system. Brake system with a sensor indicating overheating of brake pads
#18	prod dev	18	52	male	engineer cooling systems	no	
#19	prod dev	25	58	male	quality coach/advisor	yes	Blinking simulation tool. Software to test dynamic blinking light patterns.
#20	prod dev	20	47	male	powertrain engineer	yes	Integrated catalysator. Simplified design to reduce CO2 emissions
#21	prod dev	6	42	male	engineer upper body electronics	yes	Camera driving monitor. Software to apply driver's smartphone as a dashboard camera.
#22	prod dev	4	28	male	software engineer	no	

	Depart-ment	*Tenure (years)*	*Age (years)*	*Gender*	*Job description*	*Underground innovation**	*Project description*
#23	research	19	45	female	internal coach	yes	Emotional intelligence training program. For engineers and researchers.
#24	research	2	37	male	vehicle systems researcher	no	
#25	research	34	60	female	work council representative	yes	Female engineers panel. Secures female inputs to car design processes.
#26	research	18	40	female	bio-based materials researcher	yes	Material processing technology. Enable degradable materials in body exterior.
#27	research	14	52	male	combustion engine researcher	contributor	Software application for project management. To support research work organization.
#28	research	19	47	male	manager chassis research	no	
#29	research	5	27	male	vehicle systems researcher	yes	Autonomous vehicle parking. System to enable fully automated parking.
#30	research	16	53	male	powertrain systems researcher	contributor	Crankshaft efficiency tool. Enables testing if friction can be reduced.
#31	research	24	48	male	car lighting researcher	no	
#32	research	1	23	male	tooling lab technician	no	
#33	research	4	34	female	hydraulic systems researcher	yes	Simulation tool for power energy requirements. To optimize cars' energy use.
#34	research	13	36	male	manager lightweight materials	yes	Software improvements. To better analyze applications for lightweight springs.
#35	research	10	36	male	chassis researcher	yes	Animation tool. Expands the existing CAD software for chassis design.
#36	research	19	51	female	portfolio planning manager	yes	Internal maker space. Initated and implemented internal maker space facility.
#37	research	18	43	male	vehicle interior researcher	contributor	Artificial intelligence robot. Helps optimize distance and usage of frontdesk buttons.
#38	research	21	50	male	quality control supervisor	no	
#39	research	5	40	male	safety researcher	yes	Material standards. Standardized industry coding system for car materials.

Notes: Eight interviewees reported no underground projects. Four interviewees did not have underground projects, but contributed to others' underground projects.

E (chapter five): Comparison of underground and formal innovation projects

To validate that the projects in our sample (n = 420) were underground innovations, we collected additional data. In the second part of our survey, respondents identified their most recently finished *formal* innovation project (approved in advance; with a planned budget and timeline; and visible within the company innovation portfolio database), then answered exactly the same questions about objects, purposes, involved others, resources, and diffusion. Respondents provided us with details of 479 formal innovation projects. This enabled us to compare underground and formal innovation projects.

As an additional validity check, we added a fourth purpose measure to both parts of the survey: to what extent the reported (underground or formal) innovation was done because it was a job requirement. We used Yuan and Woodman's (2010) three-item measure: '*Working on this innovation was perfectly in line with my formal job responsibilities', 'My formal tasks required me to be strongly concerned with this innovation'*, and *'Introducing this innovation was part of my formal, everyday job*' (1 = totally disagree, 7 = totally agree) (Cronbach's α = .75). Underground innovation is less than formal innovation an official job requirement.

Table E.1. Differences between underground and formal innovations

Variable	*Underground (n=420)*	*Formal (n=479)*	*Significance*
Scope:			
Innovation object			
-product	29%	58%	χ^2 = 73.60, df = 1, p < .001
-technology	26%	21%	χ^2 = 3.51, df = 1, p = n.s.
-software	32%	31%	χ^2 = 0.15, df = 1, p = n.s.
-process	47%	42%	χ^2 = 2.66, df = 1, p = n.s.
Time spent (range 1 to 5)	2.71	3.52	t = 10.63, df = 897, p < .001
Purpose (range 1 to 7)*:*			
Change company practices	4.79	4.68	t = 1.46, df = 897, p = n.s.
Address work problem/challenge	5.00	4.35	t = 5.67, df = 897, p < .001
Passion to explore	5.29	4.55	t = 9.15, df = 897, p < .001
Job requirement (additional variable)	4.49	5.35	t = 10.35, df = 897, p < .001
Involved others:			
Contributors (number)	2.8	8.0	t = 7.60, df = 897, p < .001
Resources (range 1 to 7)*:*			
Informal	4.18	4.50	t = 3.49, df = 897, p < .01
Organizational	4.21	4.47	t = 3.09, df = 897, p < .01
Personal	3.76	3.18	t = 5.12, df = 897, p < .001
Diffusion (range 1 to 4)*:*			
Management	1.67	1.97	t = 5.29, df = 897, p < .001
Work team	2.19	2.21	t = 0.33, df = 897, p = n.s.
Beyond work team	1.79	2.10	t = 5.36, df = 897, p < .001

Differences between underground and formal innovation projects are shown in Table E.1 and tested for significance with a χ^2-test or t-test (depending on the level of measurement).

Scope. Underground projects are less concerned with new products (29% vs 58%). This makes sense, as new products in automotive are strictly planned for and nearly impossible to accomplish completely underground. With regard to technologies, software, or processes/ work methods, no significant differences were found.

Underground innovations are smaller projects; the time invested is significantly less. The estimated time spent is in the range of days to weeks (score 2.71) while formal projects took weeks to months (score 3.52).

Purposes. Compared to formal innovations, underground projects do not differ significantly in the purpose of changing the company's practice. This is not entirely surprising, as formal innovations at our research company were usually selected to be implemented in the whole organization. When employees decide to take innovations underground while aiming for company benefits, it is evident that their purpose is similar. Next, addressing work-related problems or challenges is reported as more important for underground innovations ($t = 5.67$, $p < .001$) and likewise for passion to explore ($t = 9.15$, $p < .001$). Also, as we had expected, formal innovation projects are more often done because it was employees' task, i.e. an innovative job requirement ($t = 10.35$, $p < .001$).

Involved others. Underground innovations are developed with fewer others: on average 2.8 persons versus 8.0 persons in formal projects ($t = 7.60$, $p < .001$). Since they are developed under the radar, underground projects are obviously smaller.

Resources. The average underground innovation project relies more on personal resources (leisure time, personal income) than formal projects did ($t = 5.12$, $p < .001$). In contrast, formal projects are associated more with (official) organizational resources ($t = 3.09$, $p < .01$).

An unexpected result is that official company projects use more informal resources (i.e., slack time) than underground projects ($t = 3.49$, $p < .01$). This may have to do with the smaller scale of underground projects, requiring fewer resources, so that also less slack time is required.

Diffusion. Looking at reported adoption rates, underground projects spread as much to work team colleagues as formal innovations do ($t = .33$, $p =$ n.s.). Work team colleagues may be in the best position to observe underground projects and recognize potential benefits. Not surprisingly, managers adopted underground projects less ($t = 5.29$, $p < .001$) and likewise for adoption by colleagues beyond the work team ($t = 5.36$, $p < .001$).

Robustness. We checked the robustness of our analysis, by only comparing respondents who had reported *pairs* of underground and formal projects ($n = 255$). This analysis excludes the possibility that respondents' person-level differences somehow affected our findings. Results are practically the same, and available on request.

Conclusion. Table E.1 confirms that the underground innovations in our sample differ from official, company-approved innovation projects as expected: smaller projects, concerned with objects more eligible for underground development (i.e., less product related), more initiated for reasons other than direct organizational benefits (i.e., addressing work problems, passion to explore), less a formal job requirement, more developed with personal resources, less with organizational resources, and less adopted by others. The only 'violation' we detected in the use of informal resources/slack time, but overall, Table E.1 can be considered evidence that our dataset contained underground innovation projects.

Reference

Yuan, F., and Woodman, R.W. (2010). Innovative behavior in the workplace: The role of performance and image outcome expectations. *Academy of Management Journal*, *53*(2), 323-342.

F (chapter five): Comparison of underground projects across three orientations

For illustration purposes, we divided our sample into underground projects that are primarily mission-oriented (n = 142), use-oriented (n = 149), or exploration-oriented (n = 129), then compared the three groups across our research variables—see Table F.1.

The classification is based on which purpose score was highest (after standardization). It corresponds with the outcomes of a k-means cluster analysis with three predefined groups, where each group has a starting value one standard deviation above the mean score (M + 1*SD) of its corresponding purpose, and starting values at the mean scores (M) on the other purposes. Table F.1 ignores that the three orientations can be related, and discards part of their variance. Although we cannot regard it as a main result, the table enables a more straightforward comparison across the three purposes.

Table F.1 shows in a different way that underground projects that primarily seek to change company practices (i.e., missionary oriented), are associated with new products, more time invested, higher involvement of others, employment of informal and especially organizational resources, and better adoption by managers and colleagues.

Table F.1. Descriptive statistics for underground innovations across three purposes

Variable	*Most important purpose*			*All*
	Change company practices (n = 142)	*Address work problem (n = 149)*	*Passion to explore (n = 129)*	*(n = 420)*
Scope:				
Innovation object				
-product	43%	11%	36%	29%
-technology	30%	13%	36%	26%
-software	23%	40%	32%	32%
-process	37%	67%	36%	47%
Time spent (range 1 to 5)	3.01	2.66	2.46	2.71
Involved others:				
Contributors (number)	3.90	2.30	2.10	2.80
Resources (range 1 to 7)*:*				
Informal	4.34	4.10	4.08	4.18
Organizational	4.58	4.09	3.94	4.21
Personal	3.85	3.30	4.20	3.76
Diffusion (range 1 to 4)*:*				
Management	1.92	1.60	1.48	1.67
Work team	2.33	2.29	1.91	2.19
Beyond work team	1.96	1.87	1.51	1.76

The table also shows that when underground projects primarily address work problems or challenges (i.e., user orientation), they are more likely about new software and processes/work methods, and less about products and technologies. Adoption rates are favorable to colleagues in the same work team and (to a lesser extent) beyond the work team but not to managers.

Finally, projects that are primarily driven by a passion to explore (i.e., explorer orientation) are related to less time spent and involvement of others and have the least favorable adoption rates. On average, such projects employ higher personal resources (leisure time, personal income).

Nederlandse samenvatting

De onverwachte bronnen van innovatie

Sinds de Tweede Wereldoorlog hebben verschillende trends bijgedragen aan het vermogen van individuen om innovaties te ontwikkelen zonder tussenkomst van producerende bedrijven. Betere opleidingen en communicatietechnologieën, een verschuiving van materiële naar immateriële productie en de beschikbaarheid van innovatiehulpmiddelen zoals 3D-printers stellen consumenten in staat om zelf te creëren en innoveren. In de woorden van Eric von Hippel (2005): innovatie democratiseert.

Voorbeelden van de democratisering van innovatie omvatten zowel het materiële als het immateriële spectrum. In het materiële spectrum zien we bijvoorbeeld een toenemend aantal burgers dat op creatieve manieren bier brouwt en daarmee zo nu en dan zelfs nieuwe brouwtechnologieën weet te ontwikkelen (Wolf et al., 2020). In het immateriële spectrum, zoals ook uitgelicht in het vierde hoofdstuk van dit proefschrift, zijn veel voorbeelden gelinkt aan Web 3.0—de algehele benaming voor online bijdragen van burgers waarbij zij hun eigen consumptiewaarde creëren, zoals het creëren en delen van designs die met 3D-printers kunnen worden geprint.

Voor het wetenschappelijk onderzoek, en de aanbevelingen die we aan innovatiemanagers en beleidsmakers kunnen doen, betekent de democratisering van innovatie dat we de bronnen van innovatie moeten heroverwegen. In onze traditionele zienswijze wordt innovatie teweeg gebracht door producerende bedrijven die daarmee concurrentievoordelen behalen (Teece, 1992). Echter, steeds meer innovaties worden ontwikkeld door individuen gedreven door persoonlijke problemen of behoeften die met bestaande goederen niet zijn op te lossen—aangeduid als de *onverwachte bronnen van innovatie*.

In vier studies, gerapporteerd in hoofdstukken twee tot en met vijf, bestudeer ik hoe individuele burgers innovatieve producten, processen en andere applicaties ontwikkelen en verspreiden; welke middelen ze daartoe gebruiken en wat hen motiveert. Daarbij hanteer ik de volgende definitie van innovatie: de ontwikkeling van producten, services en andere applicaties die een nieuwe functie toevoegen in vergelijking met bestaande producten op de (lokale) markt.

In hoofdstuk twee bekijk ik de rol van inkomen en vrije tijd, en hoe deze middelen van invloed zijn op de mate waarin burgers thuis zelf goederen produceren (doe-het-zelf) en innovaties te creëren (innovatie uit het huishouden). In hoofdstuk drie, beschouw ik het grotere geheel van condities die het ontwikkelen van innovaties door burgers mogelijk maken, en hoe innovatiebeleid zo aangepast kan worden dat het inclusiever wordt naar de initiatieven van burgers. In hoofdstuk vier, bestudeer ik de interacties tussen innoverende burgers en bedrijven. Ik duik in de casus van het bedrijf Ultimaker en haar kennisplatform YouMagine om te onderzoeken welke burgers met productverbeteringen komen die ook door anderen in gebruik worden genomen. In hoofdstuk vijf, treed ik binnen bedrijfsgrenzen om te bestuderen hoe burgers, in hun rol als werknemers, innovaties kunnen ontwikkelen zonder dat hun supervisors of managers daar vanaf weten. Hoofdstukken twee tot en met vijf zijn gebaseerd op individuele studies en kunnen afzonderlijk van elkaar worden gelezen. In de onderstaande paragraven vat ik de belangrijkste inzichten samen.

Hoofdstuk twee: 'The rich or the poor? Personal resources, do-it-yourself, and innovation in the household sector'. Middels een theoretisch model gebaseerd op inzichten uit neoklassieke economische studies (Becker, 1965) kom ik tot de hypothesen (H1a en H1b) dat inkomen en vrije tijd positief zijn gecorreleerd met de neiging van burgers om thuis goederen te produceren, maar (H2) dat inkomen negatief is gecorreleerd met de kans dat thuisproductie leidt tot het creëren van innovaties. Voor vrije tijd staat het theoretische model geen ondubbelzinnige hypothese toe in relatie met innovatie. De theoretische relatie tussen inkomen en innovatie is te verklaren door het nut dat mensen uit het proces van innovatie halen. Studies tonen aan dat, in lagere inkomensgebieden, thuisproductie relatief vaak wordt gedreven door noodzaak, daarbij focussen ontwikkelaars nadrukkelijk op de functie van thuisproductie. In hogere inkomensgebieden, is het proces van thuisproductie ook een belangrijke overweging. Bijvoorbeeld, het plezier dat mensen halen uit het exploreren van nieuwe technologieën (Raasch and von Hippel, 2013b; Williams, 2004; 2008). Doordat thuisproductie attractiever lijkt te zijn naarmate inkomen toeneemt, neemt de tendens van burgers om thuis te produceren toe met inkomen (H1a). Echter, ik veronderstel tevens dat de relatief kleinere rol van de functie van thuisproductie in de overweging van burgers er ook voor zorgt dat inkomen een negatief effect heeft op de kans dat thuisproductie in innovatie resulteert (H2). Met een analyse van data uit de Verenigde Arabische Emiraten (n = 2,728) bevestig ik de hypothesen. Voor vrije tijd vind ik vergelijkbare patronen als voor inkomen: de tendens om thuis te produceren neemt toe met vrije tijd, maar de kans dat thuisproductie in innovatie resulteert neemt af met vrije tijd.

Hoofdstuk drie: 'The household sector innovation ecosystem: A framework and policy implications'. Om tot een kader te komen dat het grotere geheel van condities voor innovatie door burgers samenvat, incorporeer ik inzichten uit de literatuur over innovatie- en ondernemerschap-ecosystemen. Deze literatuur veronderstelt dat een set van regionaal gerelateerde (ecosysteem-)elementen ervoor zorgen dat bepaalde sociaaleconomische uitkomsten mogelijk zijn, zoals ondernemerschap (Stam en Van de Ven, 2021) of innovatie (Lundvall, 1992). Middels een literatuuronderzoek en interviews met vooraanstaande academici en beleidsexperts (n = 13), vind ik dat de relevante condities voor innovatie door burgers onderverdeeld kunnen worden over institutionele elementen en factoren die van directe, faciliterende waarde zijn. Als institutionele elementen onderscheid ik (1) wetgeving en regulering, (2) culturele normen en waarden, en (3) sociaal kapitaal. Als factoren met een directe, faciliterende waarde onderscheid ik (4) menselijk kapitaal, (5) innovatiefaciliteiten, (6) (online) platforms en werkplaatsen, (7) algemene middelen en infrastructuur en (8) producenten en industrie. Elk element interpreteer ik in de specifieke context van innovatie door burgers, waarbij ik uitleg hoe het element innovatie door burgers beïnvloedt en kwantitatieve indicatoren suggereer die in toekomstig onderzoek gebruikt kunnen worden om kwantitatief vast te stellen hoe het ecosysteem van condities voor innovatie door burgers samenhangt. Tot slot, leg ik per element uit hoe innovatiebeleid aangepast kan worden, zodat innovatie door burgers beter tot zijn recht komt.

Hoofdstuk vier: 'The diffusion of user innovations in firm-hosted communities: Contributions by professional versus amateur users'. Voorgaande studies naar innovaties door consumenten tonen aan dat bedrijven hier significante voordelen uit kunnen halen, mits zij deze in kaart kunnen brengen (Gambardella et al., 2017). Bedrijven kunnen dit bijvoorbeeld doen door een online platform op te richten waar gebruikers hun productinnovaties kunnen delen (West and Kuk, 2017). In Nederland is dit onder andere gedaan door het 3D-printer bedrijf Ultimaker. Via Ultimaker's platform YouMagine, kunnen gebruikers hun zelf-ontwikkelde designs voor verbeteringen en toevoegingen aan de 3D-printer delen. Veel van deze designs verspreiden echter niet verder, met nadelige gevolgen voor het nut dat andere gebruikers uit de designs en daarmee de Ultimaker kunnen halen. Met data van 614 designs die de Ultimaker verbeteren of aanvullen vind ik dat het vooral de gebruikers zijn met professionele ervaring in het domein van 3D-printen die designs ontwikkelen welke verspreiden op het YouMagine platform. Dit effect is echter alleen zichtbaar wanneer gebruikers een commercieel motief hebben om deze designs te maken en te delen of wanneer gebruikers zich in een centrale netwerkpositie begeven wat hen toegang geeft tot up-to-date informatie over gebruikersbehoeften met betrekking tot de Ultimaker printer.

Hoofdstuk vijf: 'The nature of underground innovations: Missionary, user, and explorer orientation'. In de laatste studie uit dit proefschrift, waar ik focus op innovatie door burgers in hun rol als werknemers, bestudeer ik de motivaties van werknemers om 'ondergrondse innovaties' te produceren. Dat zijn innovaties waar management en supervisors (initieel) niet vanaf weten, en waar dus ook geen toestemming voor is gegeven. Ondergrondse innovatie, in het bijzonder, is een interessant studieonderwerp, gezien deze innovaties de potentie hebben om waarde aan bedrijven toe te voegen, maar dat niet kan worden gerealiseerd zolang ze volledig onzichtbaar zijn. Middels kwalitatief onderzoek en surveyonderzoek bij Ford Motor Company in Duitsland en het Verenigd Koninkrijk, onderzoek ik de motivaties van werknemers om ondergronds te innoveren, met implicaties voor de wijze waarop bedrijven werknemers kunnen stimuleren om hun innovaties te delen. Ik onderscheid drie motivaties voor ondergrondse innovaties: missie-gedreven innovaties, op gebruik gerichte innovaties en explorerende innovaties. Missie-gedreven projecten worden ondernomen met een bepaalde missie ten goede van het bedrijf, maar worden ondergronds ontwikkeld tot de ontwikkelaar een prototype heeft dat aan het management kan worden voorgelegd. Op gebruik gerichte projecten worden ondernomen om het werk van de ontwikkelaar zelf makkelijker te maken. Deze blijven vaak ondergronds en verspreiden slecht verder, omdat de ontwikkelaar (vooral) richt op eigen gebruik. Explorerende projecten worden ondernomen uit een bepaalde passie van de ontwikkelaar om (technologische) grenzen te verleggen. Ook deze innovaties verspreiden vaak slecht verder, omdat ze weinig directe waarde aan het bedrijf toevoegen. In hoofdstuk vijf, schets ik de implicaties voor managers: hoe kunnen zij ervoor zorgen dat op gebruik gerichte en explorerende projecten toch zichtbaar worden?

Met de bovenstaande onderzoeken naar individuele burgers als *onverwachte bronnen van innovatie* hoop ik bij te dragen aan een samenleving waarin we een breder perspectief ontwikkelen op technologische en sociale vooruitgang. De dominante focus op bedrijven als bewegers tot innovatie heeft geleid tot het uitzetten van beleidsmaatregelen (zoals intellectuele eigendomsrechten) die goed te beargumenteren zijn vanuit innovatie-specifieke marktfalen welke de winstgevendheid van bedrijven in de weg staan, maar tegelijkertijd innovatie door burgers bemoeilijken. Met meer kennis over het innovatieproces van individuele burgers kunnen we innovatiebeleid zo inrichten dat zowel initiatieven binnen als buiten bedrijfsgrenzen worden gesteund.

Curriculum vitae

Max Mulhuijzen was born in Harmelen, the Netherlands, in 1995. There, he was raised in a small family business—a wholesale company in the beverage industry. His roots in an entrepreneurial family inspired Max's deep interest in the dynamics of organizations, their relations to society, and the economics of business and entrepreneurship. He followed a Bachelor's program in Economics and Business Economics at the Utrecht University School of Economics (U.S.E.) and graduated cum laude from the Research Master's in Multidisciplinary Economics at the same institution. In his second year of the Master's program, Max also was a junior researcher at U.S.E.—exploring innovations developed by Ford employees without their managers knowing. Furthermore, as a junior researcher, Max helped to organize the Open and User Innovation Conference 2019 in Utrecht. Following his Master's, Max continued working at U.S.E. as a doctoral candidate. During his doctoral studies, Max explored unexpected sources of innovation. That is, innovations developed by employees under the radar of management (like the Ford employees), but also innovations developed by individual citizens at home. Max's work has been published in academic outlets (such as *Research Policy*), manager-oriented outlets (*MIT Sloan Management Review),* and Dutch newspapers (*Het Financieele Dagblad*). He will continue his academic career as an assistant professor (tenure track) at VU Amsterdam.

Academic experience

2019 - 2023	Doctoral candidate; Utrecht University School of Economics (U.S.E.).
2018 - 2019	Junior researcher; U.S.E.
2017 - 2019	Research Master's (M.Phil.) in Multidisciplinary Economics; U.S.E. (cum laude)
2013 - 2016	Bachelor's in Economics and Business Economics; U.S.E.

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