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The use of rewards in the sharing of research resources

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ABSTRACT

The literature has shown that academics often share intermediate research resources bilaterally and only infrequently deny requests for sharing. This study goes further and investigates how resource sharing is rewarded. We contrast rewarded and non-rewarded sharing, and further differentiate the types of rewards into direct (e.g., coauthorship) and reputational (e.g., acknowledgments). In a survey of 1,204 resource suppliers or recipients in the UK, Germany, and Japan, we find that rewards are commonly used, and that the form of rewarding is associated with the context in which academics work. In particular, we find that suppliers who are commercially active are more likely to agree on direct rewards. Instead, suppliers who make use of open sharing platforms are more likely to agree on reputational rewards and less likely to agree on direct rewards. For both suppliers and recipients we find that those working in larger teams are more likely to agree on direct rewards, and that their interdisciplinarity is positively linked to direct rewards and negatively to reputational rewards. These results suggest that a reward system for intermediate resources is emerging and rewarding practices are evolving with contextual differences.

1. Introduction

Science policy scholars and policymakers have been making efforts in recent years to facilitate openness in science (e.g., Dasgupta and David, 1994; NAS 2003; Nelson, 2004; Schofield et al., 2009). Open sharing is the foundation on which science collectively accelerates its advancement as science is largely a cumulative process ("atop the shoulders of giants") (Merton, 1973), relying not only on previously discovered knowledge but also all types of intermediate resources (or research products) such as data, materials and computer algorithms (Dasgupta and David, 1994; Walsh et al., 2007). While the sharing of discoveries through publication has long been a norm in modern science, sharing intermediate resources is attracting growing policy attention as a means to expedite science (NAS 2003).

The sharing of intermediate resources is relevant in science as it enables replication, increases efficiency and avoids resource redundancy, which expedite research discoveries and progress (Murray and O'Mahony, 2007; Shibayama and Baba, 2011; Walsh et al., 2007). Though academics broadly agree that open sharing is beneficial to science, the degree of openness and means of sharing differ by context and are considerably dependent on the discretion of individual academics (Blume, 1974; Hackett, 1990; Nelson, 2016). While some community guidelines require that intermediate resources should be openly shared (NAS 2003), not every academic perfectly follows such a requirement in practice (Frickel and Moore, 2006; Hackett, 1990; Merton, 1973; Mitroff, 1974). For example, under increasing competition, academics are more likely to refrain from sharing intermediate resources in order to maintain their scientific lead (Dasgupta and David, 1994; Haas and Park, 2010; Haeussler et al., 2014; Merton, 1973). A growing orientation toward commercialization has also occasionally led to resource withholding and secrecy (Haas and Park, 2010; Walsh et al., 2007).

In this policy context, this study aims to understand the underlying incentive mechanism for resource sharing. While the reward system behind the sharing of scientific discoveries – the disclosure of discoveries credited by the community through authorship – has been well studied and established (Merton, 1973), a clear consensus on how intermediate resources should be shared and rewarded has not been reached among academics or among policy scholars.

Unlike the sharing of scientific discoveries, resource sharing is mostly a bilateral transaction between a supplier and a recipient, which allows greater discretion for individual academics (Shibayama and Baba, 2011; Tenopir et al., 2011), such that academics may calculate the

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value of shared resources and decide to share only if the value of expected rewards matches. This subtlety in sharing and rewarding has largely been overlooked in the literature, which has thus far focused on academics' choice between sharing and withholding resources (Walsh et al., 2007), a dichotomy that can be too simplistic and misleading. Therefore, drawing on social exchange theory (Molm et al., 2007; Yamagishi and Cook, 1993), we differentiate between sharing that is rewarded and sharing that is not rewarded. While the former implies reciprocity between exchanging parties, the latter can be seen as an expression of openness. Moreover, we distinguish the types of rewarding, which can range from recognizing the contribution made by suppliers through acknowledgments and citations (*reputational* rewards), to exchanging coauthorship and other costly rewards (*direct* rewards) (Haeussler, 2011; Nelson, 2016; Shibayama et al., 2012). By conceptualizing the heterogeneity in the sharing of intermediate resources, our primary contribution is to provide a more precise understanding of the operation of sharing and to determine how this practice fits into the conventional reward system in science.

Importantly, the practice of sharing and rewarding differs significantly between individuals. As a second contribution we provide an understanding of these differences relating to contemporary trends in the dissemination and production of research. Specifically, we focus on commercialization, open science, and team science (increasing size and interdisciplinarity), which have significantly shaped academic research in the past decades and affected how knowledge is generated and diffused (Etzkowitz, 1998; Nelson, 2016; Tenopir et al., 2011; Walsh et al., 2007; Walsh and Lee, 2015; Wuchty et al., 2007). Despite their importance in modern science, previous literature has been largely silent as to how these trends relate to academics' practices and expectations with regard to sharing of intermediate resources. Further, we investigate supplier and recipient sides in sharing transactions, as they may be influenced, and thus behave, differently. This offers a more comprehensive picture of the flow of intermediate resources and rewards between academics.

Our empirical analysis is based on a survey of 1,708 academics in four disciplines in Germany, Japan, and the UK. Our findings firstly show that sharing of intermediate resources is commonly accompanied by rewards, with more costly resources attracting direct rewards such as coauthorship and future collaboration. Secondly, we find that suppliers who are commercially active are more likely to agree on direct rewards. Suppliers who make use of open sharing platforms, on the other hand, are more likely to agree on reputational rewards and less likely to agree on direct rewards. For both suppliers and recipients we find that those working in larger teams are more likely to agree on direct rewards, and that their interdisciplinarity is positively linked to direct rewards and negatively to reputational rewards. Our findings thus show that the practice of sharing is related to the work context in which individual academics operate. These results are confirmed in a number of econometric models.

The remainder of this paper is structured as follows. The following section outlines the previous literature, we then explain the empirical setting and data, before we present and discuss the results and finally conclude with implications and future directions.

2. Literature review

2.1. Sharing in Science

Sharing of research output

Open conduct of research is one of the core norms of the modern scientific community (Barber, 1952; Merton, 1973). The sociology of science in the tradition of Merton (1973) describes a normative structure in which "communalism" crystalizes the indispensability of openness in science. This norm prescribes that scientific discoveries are owned by the scientific community and that individual academics have the ownership right only to recognition for their discoveries. This norm manifests in the publication of discoveries without delay and without omission, which allows certified and rapid progress of science (Dasgupta and David, 1994; Merton, 1973).

The mechanisms of scientific disclosure have been well studied in the literature. The notion of communalism has been justified by collective benefits, where sharing can be modeled as gift-exchange (Hagstrom, 1965). Here, academics disclose their discoveries in the public space without direct gain from those who use the published findings, while benefitting themselves whenever necessary from previous discoveries of other academics (Merton, 1973). Communalism is also driven by a reward system based on recognition and priority (Bourdieu, 1975; Dasgupta and David, 1994; Merton, 1973), which is a powerful mechanism for increasing the stock of knowledge (Dasgupta and David, 1994). In the publish-or-perish culture, credit is a prerequisite for participation in science. Credit is allocated to authors of published discoveries, which then can be transformed into a number of benefits and resources, such as grants and academic posts, that help produce subsequent discoveries (Latour and Woolgar, 1979: Ch.5).

Sharing of intermediate resources

While scientific research indispensably relies on shared prior discoveries, it also draws on a number of 'intermediate resources', which we define as research resources that are "created along with the published 'result'" (Dasgupta and David, 1994, p.501) or are "required to produce results" (Dasgupta and David, 1994, p.514), such as research materials, experimental equipment, computer code, research protocols, and datasets. Academics produce or purchase these intermediate resources, which can be put into productive use in subsequent research not only by themselves but also by others (Dasgupta and David, 1994). Academics occasionally share research materials and tools (e.g., proteins, chemical compounds) (Blumenthal et al., 1997; Haas and Park, 2010; Walsh et al., 2007), as their preparation requires specific knowledge and infrastructure that only few academics possess (Stephan, 2012). Also, some research facilities and devices are expensive (e.g. NMR), and lack of wider access can deter research (Stephan, 2012). It is therefore not uncommon for their owners to offer access to other academics. Academics also occasionally share raw data, even before publication (Campbell et al., 2000), which has become more feasible with the advance of information technology (Stephan, 2012).

The sharing of intermediate resources is generally considered beneficial, as it allows academics to avert duplicate investment, reproduce previous findings, standardize research methods and equalize distribution of scientific resources, all of which expedite research discoveries and progress (Murray and O'Mahony, 2007; Shibayama and Baba, 2011; Walsh et al., 2007). The sharing of certain types of intermediate resources is often formally required by research communities or the guidelines of academic journals and funding agencies (NAS 2003).

Despite the crucial role of intermediate resources and the push for open sharing, scholarly understanding is limited as to how sharing is incentivized and rewarded. Compared to the sharing of discoveries, i.e. publications, the norm for sharing intermediate resources is far less established, and its practice is far more complex and does not necessarily fit into the conventional reward system of science. Importantly, the ownership or control over intermediate resources can provide academics with an advantage in the 'race for priority', which may be lost if they are shared openly (Dasgupta and David, 1994). Particularly when a recipient is a potential competitor, sharing can significantly hamper the priority race, more so in the case of scarce resources. Dasgupta and David (1994, p.502) thus argued that "if the reward system … cannot sufficiently compensate researchers to induce them to develop research tools that would be useable (by anyone) in subsequent inquiries", this leads to "wastage … as a regrettable necessity".

Academics therefore make cautious calculations when receiving requests for sharing. A possible result of such a calculation is to withhold the resource. By not sharing, academics can maintain the competitive edge and avoid expense. Yet, numerous studies showed that requests for

sharing are only infrequently denied, with 80-95% of requests fulfilled, consistently across different national and disciplinary contexts (Czarnitzki et al., 2015; Haas and Park, 2010; Shibayama and Baba, 2011; Walsh et al., 2007). Hence, withholding actually happens rarely, and recent studies suggest that academics exercise their discretion in subtler ways to control access to resources, such as by negotiating rewards (Haeussler, 2011; Nelson, 2016; Shibayama et al., 2012). The next section discusses the different forms of sharing and rewards described in the literature.

2.2. Forms of Sharing and Rewarding

Generalized exchange

Bilateral transactions between suppliers and recipients play a pivotal role in sharing intermediate resources and by extension in establishing a reward system. We draw on social exchange theory (Ekeh, 1974; Emerson, 1976), which illustrates the mechanisms behind transactions between two or more actors and proposes two contrasting forms of exchange, *generalized* exchange and *direct* exchange (Molm et al., 2007; Yamagishi and Cook, 1993). Generalized exchange is characterized by unilateral giving and indirect reciprocity, where suppliers are not reciprocated directly by the recipients but indirectly by other actors (Bearman, 1997; Yamagishi and Cook, 1993). Generalized exchange is commonly observed in our society; here suppliers are willing to bear the cost of supporting recipients, expecting to be indirectly reciprocated when they are on the recipient side (e.g., blood donation). This is also common in the scientific community. For example, referees of peer-reviewed journals review a manuscript without being rewarded by the author. Similarly, when sharing resources, some suppliers are willing to provide resources without asking for any reward from recipients, which we can consider a form of generalized exchange. This is crystallized as the norm of communalism (Hagstrom, 1965; Merton, 1973) and embodied in some guidelines for open science (NAS 2003).

Despite its common and important role, generalized exchange has a critical weakness – it is vulnerable to free-riders, who receive without giving (Bearman, 1997; Yamagishi and Cook, 1993). If a community involves more than a few free-riders, suppliers become less willing to support others as they cannot expect to be indirectly reciprocated, and thus generalized exchange cannot be sustained.

Direct exchange

This dilemma of non-reciprocity has been well documented in the literature, and a few solutions have been suggested (Takahashi, 2000). A straightforward solution is to adopt direct exchange, the second form of social exchange, where suppliers are directly reciprocated by recipients (Molm, 1994; Molm et al., 2007). Direct reciprocity may be mutually agreed upon or only anticipated by suppliers. Either way, suppliers can control access to their resources and gain rewards. The mitigated risk of non-reciprocity can motivate suppliers to engage in costly transactions, potentially making direct exchange a more efficient mechanism. Direct exchange is also widespread in society, as observed in economic transactions. Authorship as a reward for shared resources also falls into this category.

Direct exchange nevertheless has its own limitations. Importantly, direct exchange fails unless both a supplier and a recipient agree on the conditions of exchange. This is a serious flaw especially when no common currency is available, as is the case in most transactions in academia. Furthermore, if suppliers have strong bargaining power, recipients might need to accept unfair conditions of exchange, such as courtesy authorships, where academics in positions of power obtain authorships without substantial contribution (Bennett and Taylor, 2003; Dance, 2012; Haeussler and Sauermann, 2013). These limitations highlight the advantage of generalized exchange, which does not require direct reciprocity. Indeed, NAS (2003) argues for unconditional sharing (i.e., against direct exchange) on the basis that a "requirement for reciprocity (e.g., coauthorship) can inhibit an academic (i.e., a recipient) from publishing findings that are contrary to the provider's published conclusions."

Reputation mechanism for generalized exchange

To sustain generalized exchange without relying on direct reciprocity, "reputation" is commonly used (Nowak and Sigmund, 2005; Pollock and Dugatkin, 1992; Simpson et al., 2018; Takahashi, 2000). That is, community members monitor one another and share one another's reputation. Free-riders, if found, are given negative reputation, based on which community members can avoid supporting them further (e.g., ostracism). Compliant members are given positive reputation, based on which members feel safe to continue supporting them. As long as the reputation mechanism functions properly, generalized exchange is sustained among "good" members.

A challenge with this solution is that it costs community members to mutually monitor and share reputation. Community members may be willing to bear the cost, if it is acceptably small, in the belief that it does good to the community and that others also contribute to reputation formation (Yamagishi, 1988).[1] However, if the cost is too high, reputation is not properly built and generalized exchange malfunctions (Nowak, 2006). For example, when a community grows larger, processing reputation information can exceed the cognitive capacity of individual members, which collapses the reputation mechanism and the generalized exchange.

This is a concern in the contemporary, expanded and internationalized scientific community, which requires an efficient mechanism for reputation formation. Acknowledgment is a formalized practice to process and share reputation information (Cronin, 1995; Kassirer and Angell, 1991). Citing suppliers' work (e.g. publications, data and materials) is another way to formally raise suppliers' reputation (Merton, 1973). NAS (2003) in fact recommended that "sharing should be recognized by citing a relevant publication … and in the acknowledgement section of a paper."

These practices in the scientific community can be considered a hybrid of generalized exchange and direct exchange. On the one hand, as recipients do not have to offer more than recognition, the primary benefit of generalized exchange is secured. On the other hand, as recognition that raises reputation for suppliers is given directly by recipients in exchange for shared resources, the reward is secured, qualifying as a form of direct exchange. Coupling the reputation mechanism and the generalized exchange mechanism gives recipients incentives to contribute to reputation, mitigating the non-reciprocity concern for suppliers as well as addressing the cost issue in the reputation mechanism.

2.3. Types of sharing transactions and rewards

In sum, based on social exchange theory, we propose three forms of sharing transactions: (1) "no bilateral rewarding", corresponding to generalized exchange, in which suppliers provide resources to recipients based on the norms of open sharing and communalism; (2) "direct rewarding", corresponding to direct exchange, in which recipients provide scarce rewards in exchange for shared resources that constitute an economic exchange and directly contribute to suppliers' productivity; and (3) "reputational rewarding" at the intersection of generalized and direct exchange, in which recipients contribute mainly to suppliers' reputation in exchange for shared resources. While the latter may help suppliers gain additional benefits, such as promotion and funding, this occurs only after the reputational reward is recognized by other community members.

In actual rewarding practices in science the distinction between direct and reputational rewarding may be ambiguous, as reputation is at

[1] To be precise, the reputation mechanism requires another layer of generalized exchange (Yamagishi, 1986).

the core of the reward system in science (Merton, 1973). For example, sharing in exchange for coauthorship is considered direct rewarding as authorship contributes to suppliers' productivity which can be used to realize other forms of benefits and resources (promotion, grants, etc.) (Latour and Woolgar, 1979; Wilcox, 1998), while simultaneously contributing to suppliers' reputations. Similarly, while the original function of citations is reputational, it may also directly rewards suppliers, especially when received citations are considered as representative of the quality of the work (Hicks, 2012).[2] Acknowledgments are a less ambiguous case, in that suppliers are unlikely to benefit only from receiving more acknowledgments (Giles and Councill, 2004; Latour, 1987). An opportunity of future collaboration is another reported reward for sharing (Haeussler, 2011; Shibayama et al., 2012), which contributes to suppliers' productivity first and is a less ambiguous example of direct rewarding. Here we consider a dichotomy which is confirmed empirically, with coauthorship, collaboration, or reciprocal sharing considered as direct rewards, and acknowledgment or citation as reputational rewards. These direct and reputational rewards may both be agreed on in a single sharing transaction, i.e. are not mutually exclusive.

2.4. Contexts driving rewards

What constitutes a suitable reward and if rewarding is agreed at all will differ significantly between individual academics, as they are influenced by norms and conventions in specific social and technological contexts (Blume, 1974; Frickel and Moore, 2006). In recent decades, the scientific community has experienced a number of major transitions in how research is produced and disseminated. Four dominant developments that have been the focus of scholarship are (1) commercialization and (2) open sharing, which are linked to the dissemination of research; and growing (3) team size and (4) interdisciplinarity, which are linked to the production of research. Individual academics have been shown to be substantially influenced by these developments (Etzkowitz, 1998; Nelson, 2016; Tenopir et al., 2011; Walsh et al., 2007; Walsh and Lee, 2015; Wuchty et al., 2007).

Firstly, concerning the dissemination of research, since at least the 1990s, academics have been explicitly encouraged to contribute to industry and technological development (Etzkowitz, 1998; Slaughter and Rhoades, 1996), incentivized by pecuniary rewards, such as licensing income. A concern was voiced that commercialization contradicts the norm of openness, and indeed, has been shown to deter resource sharing (Haas and Park, 2010; Walsh et al., 2007).

Secondly, to address the side effects of commercialism, as well as to further expedite scientific progress through "open science", intermediate resources are increasingly being pooled in the public space, in repositories, to enable access for all (Nelson, 2016; OECD 2015; Tenopir et al., 2011). This recent shift may directly impact sharing of resources, as it favors unconditional access.

Third and fourth, a generic trend in the production of research in recent decades has been a dramatic increase in team science and interdisciplinarity (Jones et al., 2008; Wuchty et al., 2007). This trend has been associated with higher research quality and as such been incentivized in science policies (Stephan, 2012). The growth in team size and interdisciplinarity is accompanied by greater division of labor and specialization (Walsh and Lee, 2015), which has consequences for how contributions are credited and how the reward system in science operates.

Depending on these contexts, some rewards may be more or less likely to be offered or demanded as the perceived value of resources and rewards may be lower or higher. Sharing and rewarding practices may coevolve with these contexts. We also expect that due to the bilateral nature of sharing transactions, suppliers and recipients can be influenced differently by these contexts. Specifically, suppliers and recipients have different degrees of control over resources and rewards, and their incentives are not necessarily aligned. For example, if a certain context makes academics prioritize their own benefit, suppliers would demand more expensive rewards while recipients would prefer to pay less expensive rewards. In what follows we therefore argue for a difference between suppliers and recipients and hypothesize how the four contexts affect their rewarding practices separately.

Commercialization

In recent decades, science policy has supported the commercialization of academic research and its application (Etzkowitz, 1998; Slaughter and Rhoades, 1996). Here, academics are incentivized to contribute to business or wider society in exchange for economic returns for themselves or their institution. These policies are of interest in the context of sharing, as they may discourage academics from engaging in open research activities and from openly sharing their resources, while engaging in selective economic exchanges. Specifically, an emphasis of commercial incentives can change academics' perceptions of norms, particularly in commercially active communities (Stuart and Ding, 2006), and lead them to act in accordance with economic rationality (Festre, 2010; Gneezy and Rustichini, 2000).

Viewed from the perspective of the suppliers of intermediate resources, secrecy or withholding also implies that academics can reap further pecuniary benefits in the forms of licensing income, industrial funds, or commercial profits, where there is a market for intermediate research resources (Kneller, 2007; Nagaoka et al., 2009; Walsh et al., 2008). Indeed, several studies have found that academics with commercial interests are more likely to withhold material or data when receiving sharing requests (Blumenthal et al., 1997; Blumenthal et al., 2006; Czarnitzki et al., 2015; Haas and Park, 2010; Walsh et al., 2007). Commercially active suppliers may moreover attach conditions, such as rewards, to the sharing of resources. In particular, commercially active academics have opened up routes in which their resources and expertise can be monetized. The opportunity costs of sharing openly, without bilateral rewarding, are thus higher and may discourage them from doing so (Haas and Park, 2010). More specifically, suppliers involved in commercializing their research may likely agree to share in exchange for more costly rewards that justify the potential commercial loss when sharing resources, that is, direct rewards rather than reputational rewards.[3]

Hypothesis 1A (H1A): Suppliers are more likely to receive direct rewards and less likely to receive reputational rewards if they are engaged in commercial activities.[4]

The perspective of the recipient in a sharing exchange is less clear in the previous literature. On the one hand, commercially active academics have shown themselves to be entrepreneurial (Kuratko et al., 2020; Shane, 2000), possibly pursuing favorable conditions for sharing and looking for resources at lower cost. On the other hand, they may approach exchanges with a commercial rather than a purely academic

[2] Publications may be cited for many other reasons (Bornmann and Daniel, 2008).

[3] Recipients may accept or reject such demands for rewards, and often engage in negotiation with the supplier (Walsh et al., 2007). While the commercialization status of the particular resource will impact the terms of sharing, the recipients decision to agree on rewards is less likely to be influenced by the suppliers' commercialization as this is often unobservable, and as rewarding may be an accepted necessity for IP-protected resources, where sharing transaction follows a legal process (Walsh et al., 2007).

[4] The main interest in our hypotheses concerns the likelihood of receiving/giving direct (or reputational) rewards as opposed to not receiving/giving direct (or reputational) rewards. The latter consists of cases of "no bilateral rewarding" and cases of "no direct (or reputational) rewards but with reputational (or direct) rewards." A choice between direct or reputational rewards on condition that sharing is rewarded is also of interest, which will be further analyzed in the empirical section.

mindset, as their 'hybrid' role identities influence their work practices and thought processes (Jain et al., 2009). In our context, this could result in a preference for sharing with rewards over less formal mechanisms. In addition, a previous survey in the US indicated that commercially oriented academics, who are more likely to have a history of withholding intermediate resources (Walsh et al. 2007), are also more likely to have their own requests denied (Campbell et al. 2000). This poor standing could force commercially oriented recipients to accept more costly, i.e. direct, rewards. Overall, theoretical prediction about the association with rewarded sharing is mixed and inconclusive.

Repository use for open sharing

Recent developments in science policy have seen a shift that requires intermediate scientific resources be shared publicly, partially to mitigate the side effects of commercialism and intensified competition and to increase the diffusion of research (OECD, 2015). For example, the National Academies of Science (NAS) states that "[a]n author's obligation is not only to release data and materials to enable others to verify or replicate published findings but also to provide them in a form on which other academics can build with further research" (NAS 2003). Sharing through resource deposits helps overcome restrictions in bilateral sharing transactions and is (usually) unconditional. Furman and Stern (2011) and Piwowar et al. (2007) found that for academics who deposit data in public repositories, this is compensated by increased citations, as credit through recognition by the community are encouraged and accepted. While academics generally agree that open sharing is desirable, the amount of resources shared through such open mechanisms is still limited and the majority of resources are shared in one-to-one transactions (Shibayama and Baba, 2011; Tenopir et al., 2015; Wallis et al., 2013). Nonetheless, we argue that the shift to open mechanisms should affect how resources are shared also in bilateral transactions.[5]

For suppliers of intermediate resources, any experience and knowledge of sharing through repositories may indicate familiarity with reward structures advocated by research funders that are supportive of reputational rewards and reject direct rewards (NAS 2003; Tenopir et al., 2015). As a consequence, asking for direct rewards in exchange for shared resources could be perceived as contradictory to the practice, and suppliers may refrain from doing so, instead preferring reputational rewards. Alternatively, repository use and choice of rewards (reputational as opposed to direct rewarding) could be coevolving, i.e. suppliers who share without direct rewarding may be more likely to utilize public repositories to deposit and disseminate resources. Prior empirical evidence on this issue is lacking, but a descriptive study by Tenopir et al. (2015) is indicative of a negative correlation between public repository use and direct rewards, as they find younger academics to be least likely to share data openly but most likely to require direct rewards such as coauthorship as conditions for sharing.

Hypothesis 2A (H2A): Suppliers are less likely to receive direct rewards and more likely to receive reputational rewards if they make use of public repositories.

The recipient's open sharing orientation also has implications for rewarding practices in one-to-one transactions. As in the case of suppliers, recipients who use public repositories may proactively offer reputational rewards as opposed to direct rewards to suppliers, in line with open sharing conventions (NAS 2003). Users of repositories may also be able to build a reputation of being a generous sharer. Indeed, Enke et al. (2012) reported the potential to increase visibility as a motivation for public repository use. If the supplier knows such a reputation or observes the recipient's use of public repositories, the supplier may be persuaded to agree on reputational rewarding.

Hypothesis 2B (H2B): Recipients are less likely to give direct rewards and more likely to give reputational rewards if they make use of public repositories.

Team size

The amount of research done in teams and the size of teams have continuously increased in the past decades (Jones et al., 2008; Wuchty et al., 2007). The increase in team size has been linked to a number of factors, one of which arises from the advance of the knowledge frontier in some fields requiring longer periods of training and increased specialization in science (Jones, 2009). As more complex research problems are being addressed, single individuals do not possess the required knowledge or skill, making collaborations, sometimes with strict division of labor, vital (Katz and Martin, 1997). Such science teams create the context in which skills and knowledge are shared often between different institutions. Minimizing conflict, and maintaining networks becomes crucial and academics may use rewards to this end, with coauthorship as the fundamental reward mechanism that supports knowledge exchange (Haeussler and Sauermann, 2013; Stokes and Hartley, 1989). These practices of remote collaboration may provide a template for rewards when sharing intermediate resources. With an increase in cross-institutional collaboration one could thus expect team size and rewarding practices to coevolve, such as when authorship is awarded simply for providing data, materials or equipment (Haeussler and Sauermann, 2013; Jabbehdari and Walsh, 2017; Stokes and Hartley, 1989). Jabbehdari and Walsh (2017) indeed showed a positive correlation between team size and such "specialist" contributions.

When considering the viewpoint of resource suppliers, those working in larger teams likely produce more intermediate resources. A resulting abundance means that even valuable resources may not be fully utilized in-house. As large teams are often based on disproportionately large investment, they need to provide evidence of the research these investments support (Birney, 2012). Suppliers may thus need to share unutilized resources with external partners to fully exploit their potential (Wallis et al., 2013). Likely more valuable rewards, i.e., direct rewards rather than reputational rewards, are preferred, as they provide justification for resources spent. In contrast, suppliers working in smaller teams, produce fewer resources, often for specific local purposes. Thus, they would likely only agree to share these resources after they have been fully exploited (Wallis et al., 2013), and are shared for less valuable or no bilateral rewards.

In addition, we need to consider that suppliers' team size may be a result of what they consider fair conditions of exchange. Those working in smaller teams may set higher hurdles for demanding direct rewards. For instance, they may only expect to receive coauthorship when making a significant contribution towards any work. In fact, Tenopir et al. (2015) showed that direct rewards such as coauthorship and collaboration were considered less fair conditions for sharing in subject areas with traditionally small team sizes, such as social sciences and humanities compared to health or chemistry where authors work in larger teams.[6] Therefore, team size and rewarding practices may be coevolving.

Hypothesis 3A (H3A): Suppliers are more likely to receive direct rewards and less likely to receive reputational rewards if they work in larger teams.

Sharing practice is also influenced by the size of the recipient's team. When team size grows, the cost of direct rewarding becomes smaller. This is apparent in the case of coauthorship, where the cost of including more authors is low if authors are listed in order of relative contribution (Maciejovsky et al., 2009). This is not the case for academics working in

[5] We assume that resources shared in one-to-one transactions are not deposited in public repositories on the ground that the role of public repositories in resource sharing is still small. Further, it is plausible that resources in public repositories and resources shared bilaterally have different properties. This selection issue is likely of limited concern due the limited use of public repositories, but may emerge as a factor in the future.

[6] It is not clear if this correlation indicates subject specific norms or is indeed linked to team sizes as argued here.

Table 1
Summary of Hypotheses

	Supplier		Recipient	
	Direct (Coauthor, collaboration, reciprocal sharing)	Reputational (Acknowledgement, citation)	Direct (Coauthor, collaboration, reciprocal sharing)	Reputational (Acknowledgement, citation)
Commercialization (H1A)	+	–	?	?
Public repository use (H2AB)	–	+	–	+
Team size (H3AB)	+	–	+	?
Interdisciplinarity (H4AB)	+	–	+	–
Interdisciplinary transaction (H4C)	?	–	?	–

Note: "?" indicates that no clear prediction is made.

smaller teams, where adding an author dilutes the contribution of existing authors. For example, to recipients routinely working in teams of 10 or more academics, the price of authorship may be negligible compared to those usually working alone or in pairs. Recipients in large teams may therefore more willingly agree or even offer direct rewards compared to those in smaller teams. Haeussler and Sauermann (2020) indeed find evidence that the provision of resources becomes more important as a reason for coauthorship as team size increases. The implication of recipients' team size for reputational rewarding is however unclear, since the personal cost of reputational rewarding is negligible by definition.

Hypothesis 3B (H3B): Recipients are more likely to give direct rewards if they work in larger teams.

Interdisciplinarity. A key driver of increasing team-based science is growing interdisciplinarity. Scientific breakthroughs often happen in emerging fields that span disciplinary boundaries. Here, collaboration is encouraged, as the skills and knowledge of a number of different academics are needed for advancement (Huutoniemi et al., 2010; Stephan, 2012). Academics that find themselves working at such intersections are attuned to the sharing and repurposing of ideas and resources which can open up new opportunities of knowledge exchange, resulting in scientific breakthrough (Bikard et al., 2015). However interdisciplinarity is not without difficulty as it poses substantial challenges due to the need for team coordination and the complexity of research problems being addressed (Hara et al., 2003; Porac et al., 2004). These challenges and expectations can facilitate greater linkages between academics.

Prior empirical research has highlighted that those working at the boundaries or in multiple fields are often specialists whose expertise is valued in interdisciplinary research (Haeussler and Sauermann, 2020; Walsh and Lee, 2015). On the supplier side, specialization in resource provision has in fact been shown to be the most common form of specialization in studies of author contribution (Jabbehdari and Walsh, 2017; Larivière et al., 2016). Direct rewards would then constitute a form of payment for suppliers to reward their specialist skills and knowledge (Shibayama et al., 2012). Further, suppliers that routinely engage in interdisciplinary research can potentially find various routes to exploit their resources, by exploring beyond narrow agendas of a certain discipline. This flexibility could raise the perceived value of their resource, and an expectation for direct rewards when sharing. In contrast, reputational rewards may not be favored, as they could not sufficiently compensate suppliers for their expertise or the value of their resource.

Hypothesis 4A (H4A): Suppliers are more likely to receive direct rewards and less likely to receive reputational rewards if they are engaged in interdisciplinary research.

Recipients engaging in interdisciplinary research are also expected to adopt direct rewarding. They may routinely rely on the expertise of specialists that contribute resources and skills, and thus, may be attuned to offering direct rewards. In addition, the recipient's own interdisciplinarity may be an expression of specialization as described above (Jabbehdari and Walsh, 2017; Larivière et al., 2016). Their inability as a specialist to validate the method or tool of the supplier may encourage the recipient to offer direct rewards in order to secure support for effective use of resources. In both cases we would thus expect recipients to be more likely to offer direct rewards, and less likely to offer reputational rewards.

Hypothesis 4B (H4B): Recipients are more likely to give direct rewards and less likely to receive reputational rewards if they are engaged in interdisciplinary research.

Interdisciplinarity is often associated with cross-disciplinary collaboration rather than the interdisciplinarity of individual academics. Similarly, resources may be shared across disciplinary boundaries, where they are of value to academics in multiple distinct fields. Such sharing transactions have implications for rewarding practices. First, limitation in the reputation mechanism make reputational rewards less valuable in cross-disciplinary transactions (Dodgson, 1993; Porac et al., 2004), compared to academics that share within constrained disciplinary boundaries (Coleman, 1988). The value of reputational rewards (i.e., citations and acknowledgments) is realized when suppliers are recognized by their peers (but not by recipients' peers) (Merton, 1973). This makes it difficult for suppliers and recipients in different communities to agree on reputational rewards. In contrast, direct rewarding can function even across disciplines. Thus, it is plausible that malfunction of reputational rewarding is compensated by more direct rewarding. At the same time, when supplier and recipient operate in different disciplinary fields, they are less exposed to negative competitive effects (Whitley, 2003) and may thus be more willing to share resources without any rewards. Overall, cross-disciplinary transaction should be negatively associated with reputational rewarding, but its association with direct rewarding is ambiguous.

Hypothesis 4C (H4C): Suppliers and recipients are less likely to agree on reputational rewards if they are in different disciplines.

Table 1 summarizes the formulated hypotheses.

3. Methods and data

3.1. Sample

We investigate the practice of resource sharing and rewarding in three countries: Germany, Japan and the UK. Data is drawn from an online survey performed in 2016 which provides detailed information on the sharing experiences of 1,708 research-active academics in the fields of biology, chemistry, engineering and economics/business (corresponding to Thomson Reuter Web of Science (WoS) field classifications).[7]

Academics were sampled via their publications as follows: first, journals listed in the upper half of the 2013 Thomson Reuter journal citation report (JCR) in the selected fields were divided into quartiles of

[7] This expands on prior studies on sharing which have overwhelmingly focused on sharing in the biosciences (Campbell et al., 2000; Haas and Park, 2010; Haeussler et al., 2014).

eigenfactor score. We then drew a random sample of journals within each quartile and field and downloaded all articles that appeared in the selected journals between 2013 and 2015. We then identified all publications with a corresponding author with an address in Germany, Japan or the UK. We retained only those entries with an email or postal address in a university or public research organization, resulting in a sample of 8,499 corresponding authors which were contacted by email in summer 2016.[8] After two waves of email reminders, we received 2,260 at least partially completed responses from our random sample of authors (response rate of 26.6%, or 30.3% after taking into account undeliverable emails). We dropped any responses that were empty on crucial variables and any respondent who no longer resided in one of the three countries of interest or had left academic research altogether. This left us with a sample of 1,708 academics. For these respondents we additionally collected detailed publication profiles from Scopus for the years 2013 to 2016, allowing us to draw inferences on their research activity from a full set of publications.

The survey was tested for response rate and response completion bias. The response rates differ slightly between countries: 36.6% (Japan), 29.9% (Germany), and 24.5% (UK).[9] This difference most likely reflects the degree to which these populations have been surveyed in the past (Franzoni et al., 2012; Haeussler, 2011). The dropout rate, i.e. the share of those starting but not completing the survey, is 5%. Because of the modest response rate we may be concerned about non-response biases. We conducted a non-response analysis which compared respondents and non-respondents on characteristics of the sample article, such as the number of citations received, the number of authors, and the existence of international coauthors, to see if responses are biased with regard to these characteristics. We found that respondents and non-respondents publish in journals of similar quality and have similar author and coauthor characteristics. We observed a slight over-representation of single authored papers, but the differences are small. We also compared early and late survey respondents and found no difference with regard to their experience of sharing. This gives us confidence that our results will not be affected by non-response bias.

Of the 1,708 respondents, 1,204 (70%) made or received at least one request for resource sharing from or to academics outside their institution in the three years prior to the survey (mid-2013-mid-2016).[10] We then asked these respondents to think about the last instance of sharing and provide details on this experience.[11] This approach has several advantages. It enables respondents to answer questions more precisely and avoids recall difficulties as well as problems arising from post-rationalization. It also allows us to ask very detailed questions about the processes linked to this specific sharing experience. A similar question approach focusing on a specific instance of sharing has been used in previous studies (Haeussler, 2011; Walsh et al., 2007). The survey captures experiences of suppliers (approx. 74%) and recipients (26%)[12] alike by allowing respondents to take either role in their description of the latest sharing experience. Of all sharing requests made, 4% were not fulfilled. These cases are excluded in the following analyses.[13]

Table A1 provides the descriptive statistics and correlation matrix of the variables. The Online Supplement provides a list of the survey questions used in this research.

3.2. Measures

Rewarded sharing. The survey inquires whether anything was agreed on for fulfilling the sharing request.[14] Five sharing conditions are concerned with rewards for suppliers: (1) coauthorship on publications resulting from the use of shared resources, (2) opportunity to collaborate on a project, (3) reciprocal sharing of resources, (4) formal acknowledgment in work making use of resources, and (5) formal citation to supplier's work.[15] Respondents can indicate as many rewards as were agreed in one sharing instance. For each of the five reward types, we code a dummy variable 1 if the condition is agreed on and 0 otherwise (*coauthor, collaboration, reciprocal sharing, acknowledgment*, and *citation*). We aggregate these measures and code a dummy variable 1 if at least one of the five conditions is agreed on, and 0 if none of them is agreed on (*rewarded*).

Our respondents shared resources with an agreement of coauthorship (46%), collaboration (47%), reciprocal sharing (21%), acknowledgment (17%), and citation (13%). At least one of these conditions was

[8] A sampling frame based on publications has been used in prior studies of sharing (Haeussler, 2011; Walsh et al., 2007). The goal of our sampling strategy which followed Franzoni et al. (2012) was to create a sample of authors that includes academics publishing across the journal quality spectrum. Initially five journals were drawn in each field quartile, 20 in total for each field. The number of drawn articles was considerably lower in engineering and economics/business and additional journals were drawn, resulting in 40 journals in engineering and 80 in economics/business. Email addresses of corresponding authors were checked for correct formatting and name correspondence and corrected if necessary. If more than one corresponding author was stated, we picked the first. While corresponding authors include academics across all career stages and present the contact point for resource requests, it may underrepresent minor scientists, such as technicians and students, who are likely recipients of resources. The survey was conducted in German, Japanese and English language. The English language questionnaire was also available to respondents in Germany and Japan. The survey collected 129 responses from the field of history for Germany and the UK which are not used in this research. As an incentive, we informed respondents that a summary of the survey results would be published online and shared with respondents (http://www.science-careers.wi.tum.de/).

[9] We report response rates of 'delivered' emails. Response rates for 'completed' responses are: 35.2% (Japan), 28.5% (Germany), and 22.8% (UK).

[10] This is comparable with other similar surveys. For instance, previous surveys in the US and Japan found that 60-75% of life and material scientists made requests for materials at least once in the previous two years (Walsh et al, 2007; Shibayama et al. 2012).

[11] Note that for each transaction we collected detailed information on either the supplier side or the recipient side but not on both sides. Since our sampling strategy applies only to the respondents, the counterpart of sharing transactions may be outside of the above discussed criteria (countries, scientific fields, etc.).

[12] Observing more supplier cases than recipient cases is common in previous studies (Shibayama et al., 2012; Walsh et al., 2007). This is partly because our sampling is biased against low performers, who tend to receive rather than supply.

[13] The low rate of denied cases may be due to desirability bias. The survey inquired into the condition of sharing even if the transaction was denied (denial is more likely when there is 'no bilateral rewarding'). Including denied cases does not affect our main results.

[14] A limitation of this measure is that we do not precisely know whether a supplier demanded a reward or a recipient proposed a reward.

[15] These rewards correspond to questions in Tenopir et al. (2011). We included coauthorship and collaboration as two separate rewards in line with prior surveys. Though coauthorship may be given without substantial joint work and collaboration may occur without sharing authorship, it is difficult to unambiguously distinguish them in the questionnaire especially since academics often use the two terms synonymously. The two items are thus meant to capture either coauthorship or collaboration without overlooking potential borderline cases. The survey item also covers legal conditions of sharing following Tenopir et al. (2015), which are not considered here.

Table 2
Prediction of Rewarded Sharing (vs. No Bilateral Rewarding)

	Model 1 Supplier/Recipient		Model 2 Supplier		Model 3 Recipient	
Share data	.352***	(.093)	.306**	(.106)	.497*	(.206)
Share literature	-.213*	(.091)	-.163	(.103)	-.352†	(.213)
Share equipment	.701***	(.137)	.624***	(.157)	.994***	(.275)
Share software	.173	(.130)	.140	(.148)	.439	(.297)
Share material	.686***	(.120)	.772***	(.136)	.502†	(.267)
Share result	.581***	(.137)	.569***	(.152)	.759*	(.322)
Share protocol	.011	(.103)	.093	(.116)	-.342	(.227)
UK (base)						
Germany	.400***	(.118)	.524***	(.136)	.193	(.264)
Japan	.552***	(.120)	.519***	(.136)	.729**	(.277)
Chemistry (base)						
Biology	-.091	(.121)	-.193	(.140)	.264	(.264)
Economics/Business	-.032	(.170)	-.047	(.195)	-.072	(.367)
Engineering	.017	(.140)	.028	(.154)	-.145	(.305)
Recipient (v. Supplier)	.306**	(.106)				
Cross-country	-.320***	(.092)	-.416***	(.106)	-.052	(.201)
Cross-sector	-.129	(.126)	-.178	(.142)	.008	(.306)
Female	.077	(.123)	-.021	(.140)	.424	(.286)
Ln(#Cite)	.076†	(.039)	.060	(.046)	.126	(.081)
Age	.003	(.004)	.003	(.005)	.003	(.009)
Commercial	.276**	(.093)	.346**	(.108)	.064	(.196)
Public repository use	.068	(.091)	.163	(.104)	-.171	(.206)
Team size	.048	(.114)	.117	(.132)	-.302	(.246)
Interdisciplinarity	-.227	(.287)	-.346	(.326)	.115	(.650)
Interdiscipl. transaction	.028	(.075)	.013	(.088)	.129	(.148)
Chi-squared stat	179.666***		146.193***		61.262***	
Log likelihood	-554.681		-423.455		-118.689	
N	1204		886		318	

Note. Probit regressions. Unstandardized coefficients (robust errors in parentheses). Two-tailed test. †p<0.1, *p<0.05, **p<0.01, ***p<0.001.

met for 72% of the sharing transactions in our sample.[16] Thus, it is common that resource sharing is bilaterally rewarded. While previous studies asked whether these are fair conditions of use (Tenopir et al., 2015), this is the first providing evidence on their use.

We also prepare dummy variables respectively for direct and reputational rewarding. *Direct reward* is coded 1 if at least one of coauthorship, collaboration, or reciprocal sharing is agreed on, and 0 otherwise. Similarly, *reputational reward* is coded 1 if at least one of acknowledgment or citation is agreed on, and 0 otherwise. Note that one transaction can involve both direct and reputational rewards. As discussed above, categorizing reward types, especially coauthorship and citation, is not straightforward. Our categorization is partly based on previous studies and confirmed by our empirical analysis (see Table 4B).

Commercial activities. The survey inquired into commercial activities that respondents undertook in the previous three years, including (1) starting one's own company (4% of respondents), (2) developing a product or process for commercial purposes (9%), (3) licensing patented inventions (11%), and (4) providing consulting to private firms (25%). As measures of commercial activities, we prepare a dummy variable coded 1 if a respondent experienced any of (1)-(4) and 0 otherwise (*commercial*). Together, 38% of academics were engaged in at least one commercial activity.

Public repository use. Since recent policies for openness recommend sharing intermediate resources in public repositories, we attempt to measure academics' propensity to follow policies related to repository use. We consider this as an indicator of whether respondents follow openness policies. A dummy variable is coded 1 if a respondent has used or plans to use public repositories for open sharing and 0 otherwise (*public repository use*). We find that 43% of our respondents have deposited or plan to deposit some of their resources in public repositories for open sharing. This share is similar to the one reported on data depositing in previous survey research (Tenopir et al., 2011). We assume that the focal resources shared by our respondents are not in public repositories in general.[17] Also note that open sharing and commercialization are not incompatible. Academics can be willing to share some resources publicly while restricting access to other resources. In fact, we find only weak correlation between the two measures (*commercial* and *public repository use*).

Team size. We measure the respondent's team size based on their number of coauthors. Drawing on their publications in the period 2013-2016 (the period during which the transaction occurred), we calculate the mean number of coauthors that a respondent had (*team size*). Our respondents are on average in a team of five academics based on coauthor counts.

Interdisciplinarity. We evaluate interdisciplinarity in two measures. First, drawing on the respondents' publications in 2013-2016, we identify the research fields of the journals in which the respondents published. We draw on Scopus All Science Journal Classification Codes (ASJC), which are coded into 24 distinct fields. We then count the number of publications in each field, thereby computing the Herfindahl index for the distribution of the fields (*interdisciplinarity*). Specifically, if a respondent had x_i publications in the i-th field, the interdisciplinarity score is given by $1 - \sum_i (x_i/x)^2$, where $x = \sum_i x_i$ (Simpson, 1949). The

[16] The high rate of rewarded sharing may be caused by a recall bias, where the respondents tend to remember important transactions involving rewards. Since some of the rewarded sharing may be part of continuous collaboration, we are also interested in how often sharing transactions are accompanied with rewards when it is not part of collaboration. Our data do not clearly distinguish such cases, but removing the cases with collaboration as a reward provides a conservative estimate. We find that 48% of the sharing transactions are still rewarded.

[17] When suppliers can choose to share resources either through public repositories or through one-to-one transaction, resources shared through the two routes might have different properties. We assume that this selection effect is limited because the role of public repositories in resource sharing is still small. Future research however needs to further investigate the role of public repositories.

Table 3
Prediction of Direct and Reputational Rewarding

	Model 1				Model 2				Model 3			
	Including non-rewarded cases				Including non-rewarded cases				Including non-rewarded cases			
	Supplier/Recipient				Supplier				Recipient			
	Direct		Reputational		Direct		Reputational		Direct		Reputational	
Share data	.334***	(.088)	.117	(.086)	.343***	(.103)	.082	(.103)	.359*	(.181)	.249	(.172)
Share literature	-.120	(.087)	.097	(.086)	-.058	(.102)	.081	(.101)	-.235	(.186)	.174	(.172)
Share equipment	.730***	(.130)	.112	(.105)	.731***	(.154)	-.002	(.127)	.806**	(.250)	.308	(.197)
Share software	.070	(.123)	.302*	(.123)	.034	(.142)	.384**	(.143)	.260	(.265)	.151	(.243)
Share material	.650***	(.111)	.405***	(.105)	.710***	(.129)	.412***	(.124)	.597**	(.229)	.419*	(.211)
Share result	.520***	(.123)	.266*	(.107)	.479***	(.138)	.281*	(.124)	.769**	(.287)	.267	(.222)
Share protocol	.113	(.099)	.080	(.096)	.154	(.112)	.269*	(.110)	-.067	(.206)	-.474*	(.210)
UK (base)												
Germany	.368**	(.115)	.013	(.123)	.537***	(.135)	.017	(.144)	.001	(.250)	-.036	(.248)
Japan	.512***	(.118)	.191	(.124)	.557***	(.136)	.143	(.145)	.411	(.255)	.275	(.253)
Chemistry (base)												
Biology	-.140	(.113)	.143	(.109)	-.266*	(.132)	.215†	(.129)	.195	(.232)	-.077	(.210)
Economics/Business	.016	(.168)	.260	(.178)	-.163	(.195)	.442*	(.212)	.452	(.342)	-.202	(.359)
Engineering	.147	(.136)	.091	(.135)	.171	(.154)	.139	(.165)	.043	(.278)	-.029	(.253)
Recipient (v. Supplier)	.242*	(.101)	.306***	(.093)								
Cross-country	-.396***	(.089)	.044	(.091)	-.501***	(.104)	.066	(.110)	-.131	(.184)	-.019	(.178)
Cross-sector	-.026	(.119)	.164	(.112)	-.083	(.134)	.153	(.131)	.004	(.275)	.201	(.229)
Female	.175	(.121)	.238*	(.117)	.117	(.141)	.109	(.142)	.262	(.251)	.706**	(.230)
Ln(#Cite)	.055	(.036)	.051	(.036)	.027	(.043)	.054	(.044)	.122†	(.071)	.061	(.065)
Age	.003	(.004)	.000	(.004)	.004	(.005)	.003	(.004)	.001	(.008)	-.005	(.007)
Commercial	.173†	(.091)	.189*	(.090)	.228*	(.106)	.152	(.107)	-.062	(.184)	.355*	(.169)
Public repository use	-.099	(.087)	.230**	(.085)	-.050	(.100)	.282**	(.101)	-.210	(.184)	.117	(.167)
Team size	.168	(.108)	.024	(.114)	.228†	(.127)	.061	(.132)	-.102	(.228)	-.076	(.230)
Interdisciplinarity	.483†	(.285)	-1.155***	(.274)	.209	(.333)	-1.043**	(.323)	1.335*	(.572)	-1.554**	(.549)
Interdiscipl. transaction	.044	(.070)	-.185**	(.071)	.030	(.083)	-.145†	(.088)	.090	(.132)	-.229†	(.120)
Chi-squared stat	304.707***				252.643***				106.569***			
Log likelihood	-1215.339				-868.003				-319.637			
Rho	-.062				-.061				-.166			
N	1204				886				318			
	Model 4				Model 5				Model 6			
	Excluding non-rewarded cases				Excluding non-rewarded cases				Excluding non-rewarded cases			
	Supplier/Recipient				Supplier				Recipient			
	Direct		Reputational		Direct		Reputational		Direct		Reputational	
Share data	.178	(.122)	-.054	(.099)	.247	(.152)	-.007	(.115)	.103	(.225)	.089	(.191)
Share literature	.067	(.121)	.171†	(.096)	.131	(.150)	.138	(.112)	.006	(.211)	.294	(.190)
Share equipment	.549**	(.193)	-.019	(.108)	.735*	(.296)	-.041	(.134)	.351	(.306)	.116	(.199)
Share software	-.068	(.164)	.256†	(.136)	-.303	(.206)	.387*	(.175)	-.280	(.264)	-.025	(.258)
Share material	.409**	(.153)	.248*	(.114)	.311	(.209)	.233†	(.137)	.578*	(.239)	.340	(.229)
Share result	.191	(.155)	.174	(.113)	.046	(.181)	.220†	(.127)	.475	(.325)	.202	(.233)
Share protocol	.207	(.149)	.151	(.104)	.215	(.167)	.252*	(.120)	.288	(.271)	-.344	(.221)
UK (base)												
Germany	.012	(.169)	-.193	(.147)	.168	(.199)	-.142	(.175)	-.736*	(.329)	.018	(.300)
Japan	.074	(.172)	.053	(.149)	.233	(.209)	.050	(.174)	-.635†	(.355)	.209	(.292)
Chemistry (base)												
Biology	-.208	(.157)	.194	(.120)	-.352†	(.198)	.298*	(.139)	-.016	(.278)	-.145	(.221)
Economics/Business	-.010	(.250)	.520*	(.217)	-.421	(.298)	.685**	(.265)	1.240*	(.492)	-.172	(.391)
Engineering	.360†	(.214)	.151	(.148)	.588†	(.301)	.207	(.187)	.102	(.329)	.044	(.274)
Recipient (v. Supplier)	-.048	(.132)	.244*	(.101)								
Cross-country	-.418***	(.126)	.141	(.104)	-.508**	(.163)	.241†	(.129)	-.312	(.222)	.040	(.204)
Cross-sector	.174	(.189)	.174	(.119)	.197	(.252)	.221	(.141)	.304	(.328)	.185	(.254)
Female	.225	(.185)	.207	(.138)	.219	(.210)	.173	(.163)	-.045	(.351)	.661**	(.256)
Ln(#Cite)	-.006	(.050)	.060	(.041)	-.073	(.058)	.041	(.049)	.026	(.094)	.012	(.076)
Age	-.001	(.005)	-.001	(.004)	-.001	(.007)	.005	(.005)	-.004	(.009)	-.005	(.007)
Commercial	-.105	(.129)	.139	(.099)	-.144	(.157)	.034	(.120)	-.239	(.247)	.367†	(.187)
Public repository use	-.365**	(.123)	.195*	(.097)	-.556***	(.153)	.325**	(.114)	-.157	(.239)	.208	(.184)
Team size	.207	(.161)	.006	(.134)	.291	(.200)	-.005	(.159)	.050	(.262)	.047	(.224)
Interdisciplinarity	1.391***	(.384)	-1.255***	(.330)	1.300**	(.464)	-.936*	(.376)	2.821***	(.764)	-1.919**	(.676)
Interdiscipl. transaction	.077	(.091)	-.198*	(.078)	.105	(.121)	-.171†	(.095)	.019	(.173)	-.346*	(.137)
Chi-squared stat	184.018***				157.538***				103.030***			
Log likelihood	-682.522				-445.228				-198.671			
Rho	-.737***				-.773***				-.772***			
N	891				631				260			

Note. Bivariate probit regression. Unstandardized coefficients (robust errors in parentheses). Two-tailed test. †p<0.1, *p<0.05, **p<0.01, ***p<0.001. Models 1-3 include transactions with no bilateral rewarding while Models 4-6 exclude such transactions. The latter set of models intends to analyze the effect of contextual factors on the choice of reward types once rewarding is conditioned. Rho indicates the correlation coefficients between the two equations of direct rewarding and reputational rewarding. As suggested by insignificant rho's in Models 1-3, consistent results are obtained by two separate probit regressions. After excluding transactions without bilateral rewarding, Models 4-6 present significantly negative rho's, suggesting that direct rewarding and reputational rewarding are substitutes.

Table 4
Prediction of Rewarded Sharing by Reward Type

(A) Regression analysis

	Model 1 Supplier/Recipient Direct rewards Coauthor		Collaboration		Reciprocal sharing		Reputational rewards Acknowledgement		Citation	
Share data	.417***	(.083)	.214**	(.080)	.010	(.088)	.156†	(.093)	-.002	(.098)
Share literature	-.078	(.082)	.018	(.080)	-.037	(.090)	.035	(.094)	.221*	(.096)
Share equipment	.486***	(.102)	.302**	(.096)	.123	(.108)	.213†	(.111)	-.104	(.123)
Share software	.199†	(.113)	.044	(.118)	.154	(.132)	.132	(.138)	.523***	(.129)
Share material	.536***	(.096)	.383***	(.097)	.469***	(.104)	.596***	(.109)	.123	(.121)
Share result	.488***	(.107)	.316**	(.103)	.343**	(.105)	.273*	(.114)	.388**	(.120)
Share protocol	.145	(.091)	.254**	(.089)	.082	(.098)	.002	(.101)	.151	(.107)
UK (base)										
Germany	.243*	(.116)	.210†	(.114)	.209†	(.126)	.011	(.134)	.151	(.140)
Japan	.455***	(.117)	.209†	(.116)	-.081	(.130)	.117	(.135)	.345*	(.143)
Chemistry (base)										
Biology	-.246*	(.105)	-.209*	(.101)	.183†	(.110)	.225*	(.114)	.132	(.126)
Economics/Business	-.002	(.166)	-.261	(.166)	.240	(.190)	.271	(.203)	.328†	(.191)
Engineering	.163	(.122)	-.066	(.120)	.074	(.138)	.195	(.149)	.033	(.155)
Recipient (v. Supplier)	.356***	(.092)	-.039	(.088)	.121	(.096)	.397***	(.099)	.075	(.108)
Cross-country	-.099	(.087)	-.265**	(.086)	-.182†	(.099)	-.027	(.099)	.133	(.104)
Cross-sector	-.226*	(.110)	.091	(.105)	.367***	(.108)	.143	(.117)	.144	(.126)
Female	.196	(.119)	-.006	(.112)	.186	(.120)	.319*	(.125)	.064	(.135)
Ln(#Cite)	.065†	(.034)	.017	(.033)	-.014	(.035)	.076†	(.039)	.029	(.042)
Age	.007*	(.004)	-.001	(.004)	.002	(.004)	-.001	(.004)	-.000	(.004)
Commercial	.073	(.085)	.201*	(.083)	.097	(.092)	.161†	(.096)	.168†	(.100)
Public repository use	-.178*	(.082)	-.033	(.080)	.101	(.086)	.209*	(.092)	.262**	(.097)
Team size	.396***	(.107)	.132	(.106)	.172	(.118)	.026	(.119)	.079	(.125)
Interdisciplinarity	.050	(.277)	.370	(.280)	.444	(.300)	-1.224***	(.294)	-.891**	(.297)
Interdiscipl. transaction	-.032	(.063)	-.000	(.064)	.072	(.069)	-.156*	(.074)	-.184*	(.081)
Chi-squared stat	625.099***									
Log likelihood	-2803.039									
N	1204									

	Model 2 Supplier Direct rewards Coauthor		Collaboration		Reciprocal sharing		Reputational rewards Acknowledgement		Citation	
Share data	.467***	(.096)	.207*	(.094)	.020	(.103)	.067	(.115)	.046	(.112)
Share literature	-.052	(.094)	.028	(.094)	.071	(.104)	.001	(.113)	.250*	(.112)
Share equipment	.466***	(.117)	.302**	(.116)	.139	(.130)	.099	(.139)	-.168	(.142)
Share software	.195	(.127)	.041	(.139)	.039	(.155)	.239	(.164)	.471**	(.146)
Share material	.590***	(.113)	.431***	(.115)	.497***	(.123)	.739***	(.129)	.131	(.145)
Share result	.471***	(.121)	.282*	(.119)	.403***	(.122)	.335*	(.134)	.346*	(.135)
Share protocol	.182†	(.105)	.240*	(.102)	-.040	(.114)	.144	(.120)	.218†	(.122)
UK (base)										
Germany	.333*	(.133)	.313*	(.131)	.296*	(.145)	.020	(.159)	.104	(.160)
Japan	.454***	(.134)	.262*	(.131)	.050	(.147)	-.012	(.155)	.196	(.161)
Chemistry (base)										
Biology	-.314*	(.125)	-.362**	(.120)	.168	(.131)	.238†	(.138)	.168	(.147)
Economics/Business	-.141	(.196)	-.454*	(.195)	.199	(.229)	.471†	(.242)	.283	(.230)
Engineering	.209	(.143)	-.154	(.142)	.056	(.162)	.248	(.188)	-.050	(.181)
Cross-country	-.185†	(.102)	-.319**	(.102)	-.120	(.116)	-.059	(.120)	.146	(.124)
Cross-sector	-.236†	(.127)	.003	(.121)	.308*	(.125)	.191	(.138)	.082	(.144)
Female	.240†	(.142)	.009	(.131)	.152	(.143)	.177	(.156)	-.025	(.156)
Ln(#Cite)	.054	(.041)	-.010	(.040)	-.045	(.041)	.047	(.048)	.010	(.049)
Age	.008†	(.004)	-.000	(.004)	.003	(.005)	.004	(.005)	.006	(.005)
Commercial	.039	(.102)	.306**	(.100)	.118	(.107)	.058	(.119)	.194†	(.115)
Public repository use	-.198*	(.095)	-.058	(.094)	.269**	(.102)	.274*	(.112)	.275*	(.113)
Team size	.362**	(.127)	.152	(.125)	.337*	(.136)	.120	(.138)	.069	(.148)
Interdisciplinarity	-.086	(.329)	.246	(.325)	.571	(.357)	-1.309***	(.343)	-.457	(.355)
Interdiscipl. transaction	-.050	(.075)	-.028	(.077)	-.078	(.086)	-.126	(.093)	-.169†	(.097)
Chi-squared stat	487.460***									
Log likelihood	-1981.220									
N	886									

	Model 3 Recipient Direct rewards Coauthor		Collaboration		Reciprocal sharing		Reputational rewards Acknowledgement		Citation	
Share data	.270	(.169)	.230	(.164)	-.002	(.182)	.419*	(.170)	-.183	(.212)
Share literature	-.179	(.171)	.023	(.165)	-.333†	(.181)	.290†	(.173)	.317	(.195)
Share equipment	.539**	(.205)	.410*	(.184)	.137	(.208)	.415*	(.198)	.116	(.236)
Share software	.287	(.247)	-.030	(.245)	.393	(.286)	-.189	(.274)	.559*	(.277)
Share material	.438*	(.203)	.373†	(.195)	.365†	(.214)	.414*	(.206)	.128	(.223)

(*continued on next page*)

Table 4 (*continued*)

Share result	.588*	(.229)	.438*	(.212)	.301	(.218)	-.002	(.222)	.482†	(.262)
Share protocol	-.014	(.193)	.282	(.187)	.390*	(.196)	-.473*	(.210)	-.179	(.234)
UK (base)										
Germany	.043	(.254)	.007	(.246)	.142	(.280)	-.007	(.272)	.328	(.283)
Japan	.467†	(.256)	.096	(.255)	-.189	(.285)	.302	(.277)	.686*	(.294)
Chemistry (base)										
Biology	-.062	(.206)	.317	(.199)	.365†	(.218)	.091	(.210)	-.136	(.263)
Economics/Business	.294	(.328)	.427	(.340)	.456	(.385)	-.267	(.391)	.281	(.351)
Engineering	.145	(.246)	.278	(.251)	.067	(.288)	.112	(.262)	.193	(.270)
Cross-country	.188	(.176)	-.011	(.177)	-.283	(.197)	.044	(.188)	.013	(.195)
Cross-sector	-.309	(.241)	.217	(.232)	.641**	(.238)	.109	(.220)	.232	(.265)
Female	-.021	(.238)	-.243	(.223)	.293	(.251)	.693**	(.237)	.311	(.250)
Ln(#Cite)	.089	(.067)	.062	(.063)	.043	(.069)	.148*	(.069)	.056	(.094)
Age	.003	(.006)	-.007	(.007)	-.001	(.007)	-.006	(.007)	-.008	(.008)
Commercial	.114	(.163)	-.158	(.164)	.118	(.186)	.377*	(.169)	.179	(.198)
Public repository use	-.074	(.162)	-.000	(.164)	-.447*	(.183)	.087	(.176)	.211	(.191)
Team size	.441*	(.216)	.110	(.212)	-.225	(.249)	-.170	(.236)	.035	(.262)
Interdisciplinarity	.282	(.536)	.716	(.550)	.282	(.554)	-1.246*	(.576)	-1.922**	(.600)
Interdiscipl. transaction	.016	(.120)	.059	(.120)	.425**	(.133)	-.148	(.124)	-.188	(.153)
Chi-squared stat	334.800***									
Log likelihood	-755.926									
N	318									

(B) Correlation Coefficients between Equations in Multivariate Probit Model

	Coauthor	Collaboration	Recip. Sharing	Acknowledge
Coauthor				
Collaboration	.511 ***			
Recip. Sharing	.167 **	.265 ***		
Acknowledge	-.050	-.058	.096 †	
Citation	.020	-.042	.220 ***	.580 ***

Note. (A) Multivariate probit regression. Unstandardized coefficients (robust errors in parentheses). Two-tailed test. †p<0.1, *p<0.05, **p<0.01, ***p<0.001. (B) The correlation coefficients between the equations of multivariate probit regressions for Model 1. Online Supplement presents the correlation coefficients for Models 2 and 3. †p<0.1, *p<0.05, **p<0.01, ***p<0.001.

measure ranges from 0 (least interdisciplinary) to 1 (most interdisciplinary) with a mean interdisciplinarity score of 0.64.

Second, we survey the distance between the research field of the supplier and the recipient in the specific transaction as a three-point scale, 0: same, 1: close, and 2: different (*interdisciplinary transaction*). In our sample we find that about 56% of all sharing transactions were made across disciplines.

Resource types. The survey asked respondents to identify the types of resources that are requested. To allow for resources with differing values for recipients and suppliers, we distinguish between data (47%), literature (48%), equipment (22%), software (15%), tangible research materials (e.g., cell lines, chemical compounds; 44%), research analysis results (20%), and experimental protocols (32%). This is an extension to prior surveys which have largely focused on sharing of materials or data. We prepare dummy variables respectively for the type of shared resource (*share data, literature, equipment, software, material, result,* and *protocol*). More than one type of resource can be shared in one transaction.

Disciplinary and national contexts. As the scientific norms and the practice of resource sharing may differ by political, social, and technological contexts (Blume, 1974; Frickel and Moore, 2006), respondents' scientific fields (*biology* (31%)*, chemistry* (34%)*, engineering* (19%)*,* and *economics/business* (16%)) as well as their national affiliation (*Germany* (31%)*, UK* (23%)*,* and *Japan* (46%)) are controlled for.

Other factors. Because academics in different generations may have different norms and practices, we asked about the age of respondents (*age;* 47 on average) (Tenopir et al., 2015). The gender of respondents is controlled for, coded 0 for male and 1 for female (*female*), with 15% of respondents being women. The sharing decision can also differ by the research performance of the academic (Walsh et al., 2007), which we measure as the natural logarithm of total citation counts received by their articles published in 2013-2016 (*ln(#cite)*). Since the distance between suppliers and recipients can affect the perception of competition and the feasibility of rewarded sharing, we measure two further attributes of sharing transactions. First, we survey the geographical distance and prepare a dummy variable, 0: within a country and 1: across countries (*cross-country*). Second, we also survey the sectoral distance and prepare a dummy variable coded 0 if resources were shared between academic institutions and 1 if the respondent had a transaction with the private sector (*cross-sector*). Note that all respondents in our sample are working in academia. In our survey, 35% of sharing transactions are made across countries and 19% across sectors.

4. Results

To investigate the determinants of rewarded sharing, we draw on regression analyses with three series of dependent variables for rewarding (Tables 2, 3, and 4). Table 2 estimates *rewarded* to examine what drives any rewarding as opposed to 'no bilateral rewarding'.

Note that respondents who did not receive or make requests for sharing cannot be observed with regard to completed transactions and thus are dropped from our analyses. As this could cause selection bias, we estimated a probit regression with sample selection to predict the likelihood of any sharing request in the first stage and the likelihood of rewarded sharing in the second stage (see Online Supplement). After controlling for the selection, the second stage probit regression presents consistent results with a model without accounting for selection (Table 2). The statistically insignificant *rho* further indicates that we do not observe selection bias. This allows us to focus on the second stage (i.e., the prediction of rewarded sharing) in the following analyses without controlling for selection into sharing.

Table 3 distinguishes the two categories of rewarded sharing (direct and reputational) and reports the determinants of each reward type, which serves hypothesis testing. Since a sharing transaction could simultaneously involve both reward types, we draw on multivariate (bivariate) probit regressions to jointly estimate potentially correlated binary dependent variables (Cappellari and Jenkins, 2003). Here, we run two sets of regressions, including transactions with 'no bilateral rewarding' (Models 1-3) and excluding such transactions (Models 4-6). The latter intends to analyze the choice of reward types once rewarding

is conditioned.

Table 4 further distinguishes the five reward types (e.g., coauthorship) to examine what drives a particular reward. We similarly draw on multivariate probit regressions. Likelihood ratio tests show that the error terms of the equations for the five reward types are partly significantly correlated (Table 4B). The correlations suggest two clusters of reward types that are significantly correlated within but not across: (1) *coauthorship, collaboration*, and *reciprocal sharing* and (2) *acknowledgment* and *citation*. This supports our assumption that the former is categorized as direct rewards and the latter as reputational rewards.[18]

The main part of our survey inquired into a particular instance of sharing. As our focal independent variables can influence suppliers and recipients differently, we run regressions for (1) the whole sample, (2) the supplier subsample, and (3) recipient subsample. As suppliers control access to resources (Walsh et al., 2007), we expect effects to be stronger for the supplier case.

4.1. Hypotheses testing

Commercialization. Table 2 predicts the likelihood of rewarded sharing as opposed to non-bilaterally rewarded sharing. Model 1, based on the whole sample, shows that engagement in commercial activities is significantly associated with rewarded sharing (+7.2%, p<.01).[19] Further analyses find a significantly positive association in the supplier subsample (Model 2: +9.4%, p<.01), and only an insignificant result in the recipient subsample (Model 3: p>.1).

We then investigate the effect of commercialization on direct and reputational rewards in Table 3. Analyzing the whole sample, Model 1 suggests positive coefficients of commercial engagement for both direct and for reputational rewards (+4.9%, p<.1 and +5.4%, p<.05). Focusing on the supplier subsample, Model 2 finds a significant positive effect for direct rewards (+6.5%, p<.05), but not for reputational rewards, providing only partial support for H1A. Indeed, Model 5, excluding cases with no bilateral rewarding, finds no significant effect, which suggests that commercially active suppliers receive direct rewards instead of no bilateral rewards, but not that reputational rewards are replaced by direct rewards. Table 4A (Model 2) shows that this result is driven by an expectation for collaboration opportunities (+11%, p<.01). The effect on other direct rewards is also positive but not significant. This suggests that the positive prediction in H1A is only supported for collaboration rewards.

On the other hand, Table 3 (Model 3), analyzing the recipient side, finds a positive association with reputational rewards (+11%, p<.05). Table 4A (Model 3) suggests that this is mainly because commercially active recipients are more likely to agree on acknowledging suppliers (+11%, p<.05). The coefficient for citations is also positive, but insignificant. The association with direct rewards is insignificant in both tables, suggesting that commercially active recipients are not providing more or fewer direct rewards than recipients who are not engaged in commercial activities.

Public repository use. Examining the association between academics' willingness to use public repositories and rewarded sharing in general, Table 2 does not find a significant correlation. Differentiating reward types on the supplier side, Table 3 (Model 2) shows that public repository use is significantly positively associated with reputational rewards (+7.7%, p<.01), but does not confirm a negative link with direct rewards. By excluding cases with no bilateral rewarding, Table 3 (Models 4-6) analyzes the choice of reward type once rewarding is conditioned. Model 5 shows a positive coefficient of public repository use on reputational rewards (+10%, p<.01) and a negative coefficient on direct rewards (-7.3%, p<.001). Together with the insignificant coefficient on any rewarding (Table 2), this result suggests substitution, in that repository users favor reputational rewarding over direct rewarding when they provide their resources for sharing. This is consistent with H2A.

Breaking down the reward types, Table 4A (Model 2) indicates that suppliers who use repositories are more likely to agree on both types of reputational reward: acknowledgment (+5.7%, p<.05) and citation (+5.9%, p<.05). The negative coefficient for direct rewards is driven by coauthorship (-6.4%, p<.05), with suppliers with public repository use less likely to agree this form of reward. Instead, reciprocal sharing, which is also classed as direct rewarding, is more likely agreed (+7.0%, p<.01). This discrepancy could come from reciprocal sharing being considered as encouraging sharing and openness by mitigating the risk of non-reciprocity.

Analyzing the recipient subsample, Table 3 (Models 3 and 6) shows consistently positive coefficients for reputational reward and negative coefficients for direct reward, though only insignificantly. Results thus do not support H2B. Table 4A (Model 3), breaking down different reward types, confirms the positive but insignificant coefficients for reputational rewards. All direct rewards also show a negative sign, but only the correlation with reciprocal sharing is significant, suggesting that recipients using public repositories are less likely to agree to share their own resources in exchange for resource access. This is consistent with H2B.

Team size. Next, we investigate the association between team size and rewarded sharing. Table 2 shows a positive coefficient of team size on the supplier side and a negative coefficient on the recipient side, but only insignificantly. Thus, team size is not clearly associated with rewarded sharing in general. Distinguishing direct and reputational rewards, Table 3 finds that suppliers' team size is weakly positively associated with direct rewarding (Model 2: dy/dx=.08, p<.1)[20], but does not find a significant coefficient of recipients' team size (Model 3: p>.1). Models 4-6, dropping cases of no bilateral rewarding, also find no significant effect, suggesting that team size does not affect the choice between direct and reputational rewards. Further distinguishing the five reward types, Table 4A indicates that team size is significantly associated with rewarding by coauthorship in both supplier and recipient subsamples (Models 2 and 3). It also finds that reciprocal sharing is positively associated with suppliers' team size (Model 2). These results suggest that academics in larger teams are more likely to agree on coauthorship rewards, but the link with overall direct or reputational rewarding is unclear, thus showing only partial support for H3A and H3B.

Interdisciplinarity. Finally, we examine whether interdisciplinarity is associated with rewarding practices. Table 2 shows only insignificant association between respondents' interdisciplinarity or interdisciplinary transactions (transactions across disciplinary boundaries) and rewarded sharing. Again, distinguishing reputational and direct rewards, Table 3 (Model 1) suggests that individuals' interdisciplinarity is positively associated with direct rewarding (dy/dx=.16, p<.1) and negatively associated with reputational rewarding (dy/dx=-.34, p<.001). These results are largely consistent both in the supplier subsample (Model 2) and in the recipient subsample (Model 3). Table 3 (Models 4-6) further drops 'no bilateral rewarding' cases to analyze the choice of reward types when rewarding is conditioned. The result is consistent with Models 1-3 and, together with the insignificant coefficient of interdisciplinarity on any reward (Table 2), suggests that suppliers and

[18] Note that *reciprocal sharing* is also correlated with *citation*, yet, correlations with other direct rewards are overall stronger.

[19] The main text hereafter reports marginal effects to help interpretation. Marginal effects are computed with all independent variables set at observed values except for the focal independent variables, and the sample mean is reported. When a focal independent variable (x) is a dummy variable (e.g., commercial), the marginal effect indicates Pr(*rewarded*=1 | x=1) – Pr(*rewarded*=1 | x=0).

[20] The marginal effect takes the form of a derivative as the focal independent variable is continuous.

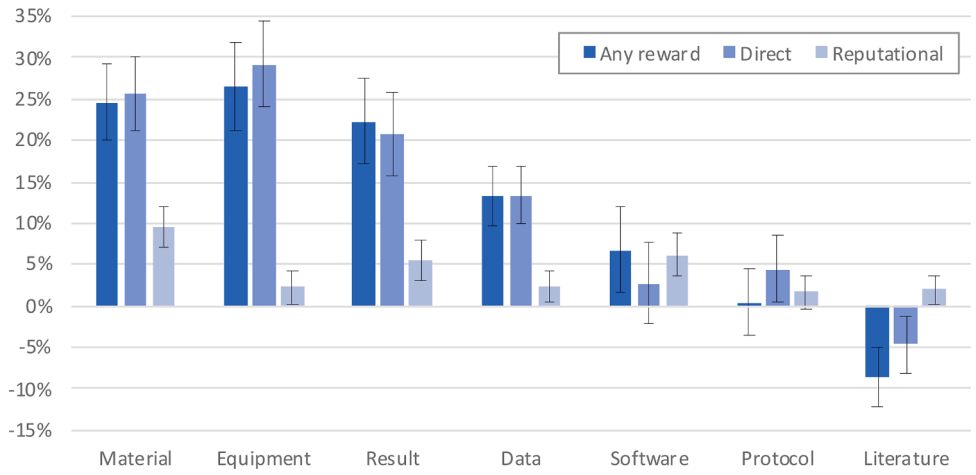

Figure 1. Marginal Effect of Resource Type on Rewarded Sharing
Note. The probability of rewarded sharing is predicted with the regression models: Table 2 (Model 1) for any reward and Table 3 (Model 1) for each reward type. The marginal effect is based on the mean values of all independent variables except for the resource types. The error bars indicate one standard error.

recipients that are highly interdisciplinary in their research profile tend to reject reputational rewarding and favor direct rewarding, which provides evidence of substitution. Further, Table 3 (Model 1) finds that reputational rewarding is less likely in interdisciplinary transactions (-5.3%, p<.01), while no significant effect is found for direct rewarding, which is confirmed for suppliers and recipients across Models 2-6. These results imply a limitation of reputational rewards in the interdisciplinary context and suggest that intellectual recognition is more important in closely connected disciplinary communities, supporting H4A, B and C.

Table 4A (Model 1), breaking down the reward types, indicates negative coefficients of interdisciplinarity on acknowledgements and citation. In the supplier subsample the effect is significant only for acknowledgments, not citations. Table 4A also shows that individual items of direct rewards are associated with respondents' interdisciplinarity mostly positively but only insignificantly. Our hypotheses H4A and H4B are thus not confirmed when differentiating between types of direct rewards. In interdisciplinary transactions, we confirm the significantly negative coefficients for both reputational reward types (Model 1), although they turn largely insignificant in the supplier and recipient subsamples (Models 2 and 3). Recipients in interdisciplinary transactions are also found to be more likely to report reciprocal sharing as a direct reward, while no association is found for suppliers of resources.

4.2. Additional analysis

In all regressions we control for other factors that may impact rewarding, such as resource type and discipline. In addition we investigate if the associations observed above between the independent variables (i.e., commercialization, open sharing, team size and interdisciplinarity) and rewarding practices are moderated by some of these factors, focusing on reward types, national and disciplinary contexts, and generational differences (i.e., age).

Resource type. Academics share many different types of resources, often in combination, with sharing practices crucially dependent on the type of resources being shared. Figure 1 illustrates graphically the marginal effect of each resource type on the rate of reward, based on Table 2 (Model 1) and Table 3 (Model 1). It shows that rewarding in general is more likely when shared resources are costly – materials (+24%, p<.001), equipment (+24%, p<.001), and results (+21%, p<.001) – while the marginal effect is negligible when shared resources are inexpensive – protocol and literature. Distinguishing reward types, Figure 1 also suggests that costly resources are likely to be rewarded by direct rewards rather than reputational rewards. For example, materials are associated with an increase in direct rewards by 25% (p<.001) and reputational rewards by 10% (p<.001). In contrast, less expensive resources (e.g., software, literature) are accompanied by reputational rewards rather than direct rewards. In addition, we analyze in auxiliary regressions whether our hypotheses hold for different resource types. We repeat our models including the interaction terms between the focal contextual factors and resource types. Overall, we find qualitatively similar results across resource types with limited differences, suggesting that our argument is not dependent on the resource being shared. [21]

National context. Second, we also control for national affiliations. Table 2 shows that sharing in the UK is 14% less likely to be rewarded compared to Germany and Japan as reported by suppliers (Model 2, p<.001), and 15% less likely compared to Japan as reported by recipients (Model 3, p<.01). Table 3 (Model 2) further finds that this is particularly noticeable for direct rewards, which are less frequent for suppliers in the UK than in Germany (-16%, p<.001) and Japan (-17%, p<.001). [22] Fig. A2 illustrates the predictions of rewarded sharing by country graphically. We further investigate in auxiliary regressions whether our hypotheses hold for different countries, again making use of interaction terms.[23] While overall results are qualitatively similar, we find that the association between recipients' team size and direct rewarding (H3B) is stronger in Japan.

Country differences in sharing have also been reported in previous studies, with Enke et al. (2012) finding lower levels of open sharing in Germany compared to the US and the EU overall; Tenopir et al. (2015) reporting that a higher share of Asian respondents required permission for data access compared to those in Europe and the US; and Haeussler (2011) finding that UK-based academics are more likely to share information compared to those based in Germany. Our results are consistent with these prior studies and add to these by showing that country differences extend to rewarding practices. Fig. A3 illustrates the predictions of rewarded sharing by country and field graphically.

Disciplinary context. Third, we compare the four disciplinary fields. We find little difference in rewarding in general (Table 2), but we do find some differences when distinguishing reward types. Table 3 (Model 2) suggests, for example, that direct rewards are less common in biology than in chemistry (-7.7%, p<.5) and engineering (-13%, p<.01), and that reputational rewards are more common in economics and business than in chemistry (+12%, p<.05). This suggests some differences in

[21] See Online Supplement.
[22] In unreported results we find low rates of rewards such as coauthorship and collaboration typically for native British respondents (rather than immigrants to the UK), which suggests that these may be attributed to cultural factors.
[23] See Online Supplement.

sharing practices by field as already pointed out by Shibayama et al. (2012). To quantify the influence of scientific fields on rewarding behavior, we also run variance-components model, finding that 7.0%, 10.0%, and 0.7% of variances are explained by the fields respectively for overall rewarded sharing, direct rewarding, and reputational rewarding. Thus, the greatest part of the variances is attributed to the individual level.[24] We also investigate whether our hypotheses hold for different disciplinary fields, finding qualitatively similar results.[25]

Generation difference. The age or seniority of academics plays a critical role in science due to differing norms or practices. While we find little direct effect of respondents' age on sharing practices in our main regressions reported in Tables 2 and 3, we find, in auxiliary regressions including an interaction term, some evidence that public repository use is associated differently with rewarding for senior and junior generations of suppliers (see Fig. A3 for graphical results). That is, in the senior generation, repository users, compared to non-users, are less likely to be rewarded by direct rewards and more by reputational rewards, consistent with H2A. However, in the junior generation, repository users are more likely to be rewarded by direct rewards. Thus, younger academics seem to behave more strategically probably because they are socialized under stronger competitive pressures.

Other control variables. We control for a number of other individual and transaction attributes that could be correlated to rewards. Table 2 shows that there are no significant differences by gender or research performance with regard to rewarded sharing. Differentiating by the type of reward in Table 3 (Model 1), we see that female recipients are more likely to agree on reputational rewards compared to men. Table 2 (Model 2) shows that cross-national transactions – requests made from foreign countries – are less likely to be rewarded (-11%, $p<.001$). Further distinguishing reward types, Table 3 (Model 2) finds that cross-national transactions are less likely to be accompanied by direct rewards (collaboration: -15%, $p<.001$). This is probably because future interaction (i.e., collaboration) across countries is less feasible due to physical distance or because suppliers' perceived competition with recipients is mitigated by distance. Cross-sectoral transactions – requests from industry – are no different from academic transactions in their likelihood to be rewarded. Yet, Table 4 indicates that these transactions are more likely to be associated with reciprocal sharing (+8.4%, $p<.05$) and less with coauthorship (-7.4%, $p<.1$). This is likely because reciprocal sharing is the most feasible rewards for industrial recipients or suppliers who do not necessarily engage in academic publishing.

5. Discussion

Previous surveys on withholding practices found that requests for resources are only refused in 5 - 20% of cases (Campbell et al., 2000; Haas and Park, 2010; Walsh et al., 2007). Our finding suggests that only a small proportion of these exchanges happen without any form of bartering between suppliers and recipients, showing that for 70% of resource sharing a reward is agreed on. Rewards for suppliers range from reputational rewards through acknowledgments and citations, to direct rewards, such as coauthorship and collaboration. The rate of rewarded sharing and the forms of reward depend on various factors such as the value of resources, relationships between suppliers and recipients, and national and disciplinary contexts. For example, valuable resources are likely to be exchanged for direct rewards. This is consistent with survey findings by Tenopir et al. (2015), which showed that a majority of academics consider coauthorship or collaboration a 'fair' condition for sharing data. The result also implies that academics are willing to share under certain conditions and are clearly incentivized to gain benefits for their academic career.

Importantly, our results provide evidence that contemporary science contexts of commercialization, open science, and team science are related to "rewarded" sharing. Amongst these, commercial orientation is known to lead to secrecy and a lower likelihood of fulfilling material requests (Blumenthal et al., 1997; Haeussler et al., 2014; Shibayama et al., 2012). However, we found that the relationship between commercialization and sharing is more complex. Specifically, we showed that suppliers' commercial activity is associated with a higher propensity to agree on direct rewards, specifically future collaborations, providing support for H1A. Thus, when suppliers agree to share, they are more likely to agree a reward that is more costly to the recipient. The commercial orientation of the recipient has occasionally been linked to having access to resources denied (Campbell et al., 2000), suggesting that they could also be disadvantaged in the negotiation of sharing rewards. To the contrary, it is also plausible that commercial, or entrepreneurial, recipients are capable of agreeing on favorable conditions. Our results showed that the commercial activity of recipients is associated with reputational rewarding, specifically acknowledgements, rather than direct rewarding, which seems consistent with the latter argument. The mechanism behind this result, however, requires further investigation.

We further find that about 40% of respondents follow recent openness policies by means of public repository use, at least occasionally. Yet, bilateral sharing is observed for 76% of respondents and thus remains considerably more common (Shibayama and Baba, 2011; Wallis et al., 2013). Suppliers who do not engage in open sharing are significantly more likely to agree direct rewards, specifically coauthorship, which is discouraged by scientific communities (NAS 2003), while those that make use of public repositories are more likely to agree on reputational rewards, such as citations and acknowledgements, as recommended by scientific communities (NAS 2003). This provides support for H2A. Interestingly, and contrary to our expectations, suppliers that use public repositories are also more likely to agree reciprocal sharing of resources, which we classified as a direct reward. This discrepancy could come from reciprocal sharing being considered a form of openness, despite being discouraged as a condition for exchange. For recipients, we cannot confirm the same. We find no support for H2B, likely because suppliers control access to resources. We do however find a negative effect for reciprocal sharing, which stands in stark contrast to the supplier findings. The overall preference for reputational rewards amongst suppliers that use open repositories could be linked to social norms within specific research groups, or because their resources can be shared more easily at a lower cost. As open sharing becomes easier and establishes as a norm we would thus expect less use of direct rewards. This result is somewhat more nuanced when we look at different age groups, with younger academics who are also repository users agreeing more direct rewards in bilateral sharing. Thus, younger academics may deposit selected resources openly while retaining more valuable resources for bargaining. This is in line with conclusions drawn in Tenopir et al. (2015) who found that younger academics are overall less likely to share their resources openly, largely due to their need for credit. Nelson (2016) calls this tactic of sharing some but not all knowledge openly "strategic withholding". The lack of rewards associated with public, unconditional sharing is thus a concern, especially for younger academics (Enke et al., 2012). Given these results, it is probably not realistic or effective to design science policies on the assumption that academics will share all their resources altruistically or for intellectual recognition alone.

Sharing of intermediate resources in science may also relate to the increase in team science that has been observed in the literature and is

[24] We also investigated the contribution of more fine-grained 70 subfields, which presented slightly higher but still limited contribution of the fields (8.8%, 12.4%, and 2.0% respectively). See Online Supplement.

[25] See Online Supplement.

encouraged by policy and funders (Jones et al., 2008; Stephan, 2012; Wuchty et al., 2007). In particular, the way that academics work in teams may guide sharing as sharing 'cultures' are established. We observed academics working in smaller and larger teams and showed that both suppliers and recipients already working in larger teams are more likely to agree on coauthorship in sharing exchanges. This form of reward may therefore relate less to the value of the resource shared but to practices within highly collaborative teams, which are more inclined to demand and provide recognition when sharing resources. This suggests that team size is closely linked to authorship conventions followed by both parties in the exchange. Alternatively, increased team sizes could also be an artifact of resource sharing, as the scientific community becomes more connected. For instance, Haeussler and Sauermann (2020) and Jabbehdari and Walsh (2017) previously found evidence of a link between team size and coauthorship for resource provision alone.

Further, we found that highly discipline-based academics are more likely to agree on reputational rewards and less likely to agree on direct rewards compared to academics that engage in interdisciplinary research. This was confirmed for both suppliers and recipients and provides support to H4A and H4B. Interdisciplinary academics may possibly agree on direct rewards due to greater commitment required in interdisciplinary research, the requirement to specialist contributions, as well as a greater potential of new opportunities for knowledge exchange (Bikard et al., 2015). Transactions that cross disciplinary boundaries, regardless of the disciplinary orientation of the individual academic, are also less likely to involve reputational rewards (supporting H4C), possibly due to limitations of community rewarding mechanisms for boundary crossing works (Dodgson, 1993; Porac et al., 2004). Future research should investigate the bilateral nature of these interactions to shed more light on the mechanisms.

6. Conclusions

This study focused on the sharing of intermediate resources and how this relates to reward structures in science. We illustrated the practices of resource sharing and rewards based on original survey data and evaluated how these are shaped in contemporary science contexts. While the reward system for the disclosure of scientific discoveries is well established (Hagstrom, 1965; Merton, 1973), resource sharing does not follow a clear consensus and may happen at the discretion of individual academics, negotiating ad hoc rewards. The sharing of intermediate resources represents a pivotal form of openness, which enables their productive use by others and expedites research progress and supports rigor in science (Murray and Stern, 2007; Shibayama and Baba, 2011; Walsh et al., 2007). The efforts to facilitate openness in science have followed decades of science policies that emphasized commercialization, which promoted secrecy and withholding (e.g., Dasgupta and David, 1994; Murray and O'Mahony, 2007; Nelson, 2004; Walsh et al., 2007). In this context, we investigated for what 'price' (reward) academics share intermediate resources, drawing on social exchange theory to differentiate between (1) sharing without bilateral rewards, (2) sharing with direct rewarding, and (3) sharing with reputational rewarding.

In terms of theory, this study contributes to the understanding of scientific norms and resource sharing by highlighting the nuanced conflict between communalism and its counter-norm (Frickel and Moore, 2006; Hackett, 1990; Merton, 1973; Mitroff, 1974) or that between openness and commercialism. The literature has treated the normative conflict dichotomously, and as such, previous studies have contrasted sharing with not sharing (Blumenthal et al., 1997; Blumenthal et al., 2006; Czarnitzki et al., 2015; Haas and Park, 2010; Walsh et al., 2007). It is feasible however that academics share a resource while maintaining certain rights over it (Nelson, 2016). This is observed as rewarded sharing, and our data indicate that such rewards are fairly common. Even academics who appear to follow the open science regime (i.e., public repository users) are partly motivated by reputational credit.

The study also contributes towards our understanding of reward systems for resource sharing. Resources are generally more likely to be shared if incentives favor direct reciprocity which mitigates any risk associated with costly transactions for suppliers (producers) (Borgman, 2012). As such direct rewards were shown to be agreed most frequently. Still, heterogeneous modes of sharing have developed within the scientific community, where rewards come in many forms. By conceptualizing the heterogeneity in sharing we are able to determine how this practice fits into the conventional reward system in science. Specifically, while a natural hierarchy exists that recognizes the value of resources and rewards, the contexts in which academics operate can shift the reward expectations in sharing transactions. We demonstrated the association of commercialization, open sharing, team size and interdisciplinarity with different rewards. In doing so we contribute to our understanding of changing science context and reward regimes for resource sharing.

There are several limitations to our study which offer directions for future research. First, while this study considers rewarded sharing and contrasts different types of rewards, the broader implications of commercialization and other work contexts need further examination. For example, commercialization impacts various elements of scientific research and may indeed enable investment in and application of resources. Thus, even if the rewarding practices induced by commercialization cause negative impacts, the production and distribution of sharable resources may have increased overall. Similarly, rewarded sharing could offer new opportunities for the production of and collaboration in science, such as for interdisciplinary research. Future research should address these issues.

Second, although we have rich information on a specific sharing event, we lack some critical information on the bilateral transaction. For one, the value of resources that are shared and the value of rewards that are agreed, are implicitly assumed to shift in different contexts. Analyzing the costs of resources and rewards for different transactions is an avenue for future research, which could also inform open science policies. Further, we do not know if suppliers demand rewards or whether recipients voluntarily offer rewards. We also only have information on one party in the exchange, limiting our ability to understand the relative status of suppliers and recipients. Moreover, in some cases rewarded sharing may occur as part of continuous collaboration while in other cases it may constitute a one-off transaction. Distinguishing between these types could be an avenue to better understand the practice of resource sharing. In asking about a specific sharing event we also are unable to conclusively establish how widespread different types of rewards are. In our survey set-up it is possible that respondents are more likely to recall those exchanges where personal rewards were agreed on. To establish this would require different methodologies to measure sharing. In addition, our paper treats resources as owned and requested by individuals when these are often generated and used by teams. The question of who decides on sharing and who benefits from rewards in team research therefore needs further evaluation and raises additional challenges for empirical analysis and the right unit of observation.

Third, our empirical setting does not allow us to rule out some

alternative explanations. For instance, while those working in teams may be more inclined to share direct rewards, it is also possible that the underlying research problem being investigated requires the input of more specialists, including the supplier. Further, while those following the open sharing norm may reject direct rewards, it is also possible that the proliferation of the norm has made resources more abundant, thus reducing the bargaining for direct rewards. Future research should attempt to unpack and address causality and potential confounding in sharing and reward relationships.

Fourth, we find some differences in the level of rewarded sharing between countries and disciplines. We sent our survey to academics in the UK, Germany and Japan which have all seen a drive towards accountability and changes in how funding is allocated. Our results for instance show that academics in the UK are significantly less likely than academics in Germany and Japan to require rewards. At present we do not clearly know whether these differences are an expression of differences in research culture, differences in policies, or differences in the types of science and hence resources that are being produced. In terms of policy, open access has only received attention very recently in Germany and Japan, while in the UK open data and science have long been advocated on all levels of society and have been made a requirement in publicly funded research (e.g., Jha, 2011). Unlocking these country differences will be of practical use in guiding policymaking.

Creadit auhtor statements

Sotaro Shibayama: Conceptualization, Methodology, Analysis, Writing. **Cornelia Lawson**: Conceptualization, Methodology, Data collection, Writing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.respol.2021.104260.

Appendices

See Figures A1, A2, and Table A1.

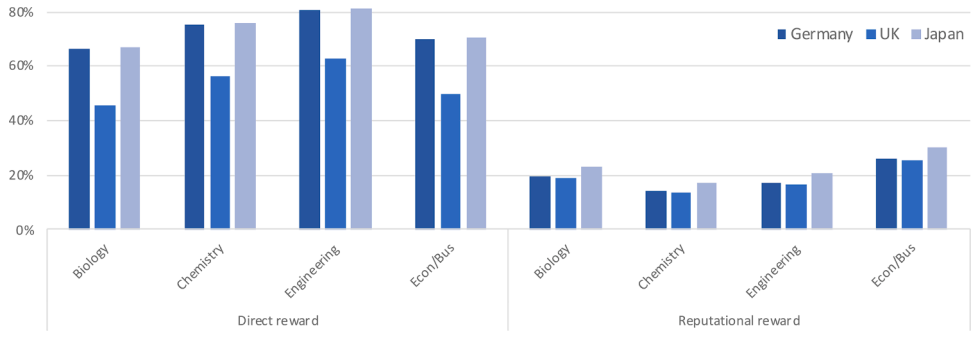

Figure A1. Rewarded Sharing by Suppliers' Country and Scientific Field
Note. The probability of each rewarded sharing is predicted with Table 2 (Model 2) and Table 3 (Model 2) based on the mean values of all independent variables except for the focal independent variables.

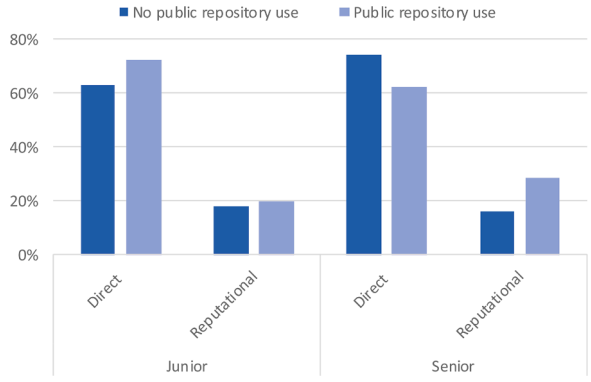

Figure A2. Public Repository Use and Rewarded Sharing by Supplier's Age
Note. The probability of rewarded sharing is estimated based on regression models (online Supplement) with the mean values of all independent variables except for the focal independent variables. The junior and senior generations respectively take 36 and 58 (the mean ± 1 s.d.) of suppliers' age.

Table A1
Descriptive Statistics and Correlation

	Variables	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	Rewarded sharing	0.74	0.44	0.00	1.00																											
2	Direct reward	0.67	0.47	0.00	1.00	0.84																										
3	Reputational reward	0.24	0.43	0.00	1.00	0.33	0.02																									
4	Share data	0.47	0.50	0.00	1.00	0.09	0.08	0.07																								
5	Share literature	0.48	0.50	0.00	1.00	-0.11	-0.08	0.03	0.09																							
6	Share equipment	0.22	0.41	0.00	1.00	0.21	0.25	0.04	-0.02	0.02																						
7	Share software	0.15	0.36	0.00	1.00	-0.03	-0.06	0.04	0.13	0.05	-0.05																					
8	Share material	0.44	0.50	0.00	1.00	0.28	0.29	0.12	-0.13	-0.19	0.10	-0.22																				
9	Share results	0.20	0.40	0.00	1.00	0.18	0.19	0.11	0.21	0.10	0.14	-0.01	0.09																			
10	Share protocol	0.32	0.47	0.00	1.00	0.11	0.15	0.08	0.04	0.10	0.17	-0.08	0.21	0.23																		
11	Germany	0.31	0.46	0.00	1.00	0.04	0.04	-0.04	-0.07	-0.02	0.16	-0.02	-0.05	-0.03	-0.01																	
12	UK	0.23	0.42	0.00	1.00	-0.21	-0.23	-0.01	0.07	0.08	-0.13	0.11	-0.27	0.03	-0.07	-0.37																
13	Japan	0.46	0.50	0.00	1.00	0.14	0.15	0.05	0.01	-0.05	-0.04	-0.08	0.28	0.00	0.07	-0.61	-0.51															
14	Biology	0.31	0.46	0.00	1.00	0.08	0.07	0.07	-0.08	-0.13	-0.06	-0.15	0.40	0.01	0.17	-0.13	-0.14	0.24														
15	Chemistry	0.34	0.47	0.00	1.00	0.10	0.12	-0.05	-0.05	-0.03	0.18	-0.05	0.09	0.02	0.08	0.14	-0.15	0.00	-0.49													
16	Economics/Business	0.16	0.36	0.00	1.00	-0.20	-0.25	0.01	0.10	0.11	-0.21	0.04	-0.37	-0.02	-0.21	-0.01	0.32	-0.26	-0.29	-0.31												
17	Engineering	0.19	0.39	0.00	1.00	-0.03	0.00	-0.03	0.07	0.09	0.05	0.20	-0.24	-0.02	-0.10	0.00	0.04	-0.04	-0.33	-0.35	-0.21											
18	Recipient (v. Supplier)	0.26	0.44	0.00	1.00	0.11	0.09	0.08	0.02	-0.07	0.03	-0.04	0.07	-0.02	-0.07	0.03	-0.06	0.03	0.00	0.02	-0.02	-0.01										
19	Cross-country	0.35	0.48	0.00	1.00	-0.18	-0.22	-0.02	-0.05	-0.02	-0.15	0.08	-0.09	-0.11	-0.05	0.07	0.13	-0.17	-0.01	-0.03	0.08	-0.03	-0.04									
20	Cross-sector	0.19	0.39	0.00	1.00	0.07	0.11	0.08	0.07	0.09	0.11	-0.01	0.12	0.13	0.13	-0.05	-0.11	0.14	-0.02	0.04	-0.11	0.09	-0.08	-0.20								
21	Female	0.15	0.36	0.00	1.00	-0.04	-0.02	0.03	-0.02	0.03	-0.01	-0.03	-0.10	0.00	0.06	0.15	0.12	-0.23	-0.01	-0.04	0.12	-0.06	0.00	-0.01	-0.06							
22	ln(#Cite)	3.60	1.47	0.00	7.73	0.12	0.14	0.00	-0.04	-0.12	0.09	-0.05	0.24	0.01	0.12	0.14	0.01	-0.14	0.03	0.34	-0.32	-0.15	-0.07	0.10	0.00	-0.05						
23	Age	48.06	11.34	26.00	92.00	0.05	0.06	0.03	0.02	0.05	-0.04	-0.11	0.09	0.07	0.06	-0.15	0.02	0.12	0.12	0.01	-0.05	-0.11	0.02	-0.07	0.11	-0.14	0.07					
24	Commercial	0.38	0.49	0.00	1.00	0.11	0.10	0.07	0.03	0.07	0.12	0.00	0.05	0.11	0.09	0.06	0.00	-0.06	-0.06	0.02	-0.05	0.09	-0.05	-0.03	0.25	-0.07	0.08	0.12				
25	Public repository use	0.42	0.49	0.00	1.00	0.03	-0.02	0.08	-0.02	0.00	0.01	-0.03	0.06	0.01	0.09	-0.04	0.07	-0.02	0.13	-0.02	0.00	-0.13	-0.05	0.00	0.05	0.03	0.03	-0.03	0.06			
26	Team size	1.61	0.52	0.00	3.77	0.19	0.24	0.01	-0.07	-0.14	0.19	-0.15	0.36	0.08	0.18	0.06	-0.17	0.09	0.32	0.22	-0.59	-0.10	-0.04	-0.10	0.04	-0.05	0.48	0.04	0.03	0.08		
27	Interdisciplinarity	0.64	0.17	0.00	0.88	0.10	0.18	-0.10	-0.05	-0.04	0.14	-0.04	0.19	0.03	0.15	0.06	-0.14	0.07	0.07	0.24	-0.39	-0.02	-0.04	-0.03	0.08	-0.04	0.40	0.00	0.10	0.04	0.38	
28	Interdiscipl. Transaction	0.64	0.64	0.00	2.00	0.11	0.13	-0.05	-0.10	-0.05	0.10	-0.11	0.22	0.04	0.03	0.05	-0.15	0.08	0.07	0.12	-0.16	-0.09	0.09	-0.06	0.07	0.00	0.11	0.05	0.09	0.12	0.17	0.17

Note. N=1,204.

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