Doors and walls: physical barriers and knowledge sharing

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Abstract

The extant literature has demonstrated that physical distance negatively affects knowledge sharing, even within the same building. In addition, the impact of physical barriers, like doors and walls, has been flagged as an important avenue for research. We contribute to 'micro-geography' literature, by unpacking the effects of physical barriers on knowledge sharing and moderators of that relationship. We apply micro-level, single-firm observational data on employees' knowledge-sharing dyads and find that physical barriers are detrimental to knowledge sharing after accounting for distance. Simultaneously, we theorise on and find evidence of several moderators of the detrimental relationship between physical barriers and knowledge sharing at the dyadic and individual levels: strong ties, participation in coordination mechanisms across departments, job autonomy, and location in an office near a printer room. The study has implications for managers deciding on office allocation and the physical layout of offices.

Keywords: knowledge sharing, physical barrier, distance, ties, coordination, autonomy

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Introduction

While knowledge sharing has been widely linked to organisational performance (Donnelly 2019; Oyemomi, Liu, Neage, Alkhuraji, 2016), its determinants in the physical environment are less researched (Oliveira et al., 2019)A seminal study by Allen (1977) showed that physical distance between individuals acts as a deterrent to knowledge sharing in organisations (Kabo, Hwang, Levenstein, and Owen-Smith, 2015; Monge, Rothman, Eisenberg, Miller, and Kirste, 1985)Other researchers have shown that proximity matters for individual knowledge-sharing behaviour (Chown and Liu, 2015; Masket, 2008). Notably, Allen's (1977) work supplemented and inspired other scholarly investigations of how changes in the physical environment affect knowledge sharing (Allen and Gerstberger, 1973; Gullahorn, 1952; Oldham and Brass, 1979).

Physical distance and barriers, like walls and doors, are inherent components of the physical environment. Scholars have studied these factors in the context of change in physical layouts of office spaces (i.e. moving from one office to another) that result in a larger or smaller number of immediate enclosures .(Allen and Gerstberger, 1973; Gullahorn,1952; Oldham and Brass, 1979).

The focus of this stream of research has been on comparing one physical setting to another rather than on the effect of the physical barriers themselves. Nonetheless, scholars have emphasised that the physical barriers 'appear(s) to be the aspect of physical structure in greatest need of future research' (Hatch 1987, 388).

In this paper, our goal is two-fold. First, we aim to demonstrate the importance of physical barriers (e.g. doors and walls) and thereby go beyond the focus on sheer distance. Second, we aim to develop theory and theorize and explore mechanisms that may offset the negative effects of barriers on knowledge sharing at the dyadic and individual levels (i.e. strong ties among dyads, participation in coordination mechanisms across departments, job autonomy, and location in an office next to a printer room).

We use observational data from 796 employee dyads from a single firm located in one building with offices spread across five floors. Doors and walls are the physical barriers on which we focus. We test the effects of these physical barriers and the focal moderators on the frequency of knowledge sharing in the sampled dyads.

Our findings suggest that the negative effects of physical barriers (i.e. doors and walls) on knowledge sharing are present even when distance remains constant. However, these negative effects are alleviated in the presence of strong ties between employees, if employees have substantial job autonomy, if employees are part of work tasks that involve multiple departments, or if employees are located in an office next to a printer room.

The study has implications for managers in charge of office allocation and physical layouts at firms, as well as those implementing tasks forces across departments. It shows the detrimental effects of seat allocation on knowledge sharing. While it may not be possible to completely overcome or alleviate these negative effects of physical barriers, several interventions are possible: fostering social relations through community building, explicitly giving employees job autonomy, introducing mechanisms that cut across departments, and designing the workspace with an equal distribution of social spots, such as printer rooms.

Distance, physical barriers, and knowledge sharing

An important body of research indicates that as physical distance[1] increases, the likelihood of knowledge sharing decreases. Allen (1977) presented seminal results along these lines, and his findings have been supported by subsequent studies, even in cases of relatively short distances and when employees are working in the same building (see, e.g., Fayard and Weeks, 2007; Sailer and Mcculloh, 2012) . For instance, scholars have shown that co-location, or proximity (Khazanchi, Sprinkle, Masterson, and Tong, 2018), matters for voting behaviour and political outcomes (Chown and Liu, 2015; Masket, 2008). Similarly, the cancellation of an academic conference – an opportunity for participants to be temporarily proximate[2] – led to a decrease in the likelihood of scientific collaboration (Campos, Leon, and McQuillin, 2018). Moreover, the literature on knowledge diffusion highlights benefits that accrue to local versus distant actors, such as inventors or firms (Baruffaldi and Raffo, 2017; Feldman and Kogler, 2010; Jaffe, Trajtenberg, and Fogarty, 2000) , although hypotheses on localised knowledge spill-overs have been questioned (Breschi and Lissoni, 2001, 2009).

Proximity promotes spontaneous gatherings and face-to-face interactions (Sole and Edmondson, 2002) . Face-to-face interactions are richer and have higher bandwidth than, for instance, phone conversations, as they allow for 'body-work'(Nardi and Whittaker, 2002) . Distant employees forego the opportunity for random encounters (Hatch, 1987; Waber, Magnolfi, Lindsay, 2014), as there is less scope for serendipitous conversations and spontaneity around the water cooler or other social spots. While proximity effects are established to be

[1] We equate distance with physical distance in this paper. However, we acknowledge the multi-faceted character of distance and research referring to other dimensions of distance (Dolfsma and van der Eijk, 2016) .
2 For more on temporary physical proximity or collocation, see Baruffaldi and Poege, (2020), Chai and Freeman (2019); Lavoratori, Mariotti, and Piscitello (2020), Torre and Rallet (2005).

positive in organizational studies, social ecology studies of interactions in housing context brings in some nuance finding that physical proximity makes not only friends, but also enemies (Ebbesen et al., 1976)

Following Allen's seminal studies (1977), scholars have focused on exploring the effects of adding or removing physical barriers (i.e. exposing the same employees to various types of physical environments at different points in time) by, for instance, moving employees from a traditional closed office to an open-office space or by removing walls that separate employees (Oldham and Brass, 1979) . The first wave of studies associated open space offices with higher rates of informal interaction when compared to traditional closed offices (Allen and Gerstberger, 1973; Brookes and Kaplan, 1972; Szilagyi and Holland, 1980). Other studies found that such moves may decrease the number of interactions because of perceptions of supervisor feedback or the type of interaction (Oldham and Brass, 1979; Sundstrom et al., 1982; Värlander, 2012). Researchers have also studied the effects of increasing transparency in the physical environment, which decreases privacy, and found negative effects on workers' performance (Bernstein, 2012). As such, research on the effect of changes in physical barriers has provided mixed results.

In this paper, we depart from these studies and aim to fill in the gap in our knowledge of physical barriers. Accordingly, we theorise and comparatively study the behaviour of individuals separated by physical barriers and the behaviour of those for whom such barriers are absent, while controlling for physical distance. Notably, we do not study changes in the physical environment, but exploit the fact that employees are exposed to different physical environments to scrutinise the effects of those environments on their knowledge-sharing behaviours. We also explore possible moderators of the effects of physical barriers on knowledge sharing.

Search costs are an important determinant of individual matching processes (Boudreau, Brady, Ganguli, Gaule, Guinan, Hollenberg, and Lakhani, 2017; Catalini, 2018) and have a strong restrictive effect on knowledge sharing (Hansen, Mors, and Løvås, 2005). While both distance and physical barriers give rise to search costs, several mechanisms distinguish the effect of distance from qualitative discontinuities, such as doors and walls.

First, the concept of privacy is closely linked to the physical barriers in the workplace (Khazanchi, Sprinkle, Masterson, and Tong, 2018). Privacy affects knowledge-sharing behaviours in multiple ways (Archea, 1977). First, the privacy conferred by doors and walls is correlated with one's range of visual access. In the first phase of the knowledge-sharing process, an employee initiates a search (Hansen et al., 2005). Visual access is important in this regard, as the employee may simply lean out of his or her workspace or stand up to check whether another colleague in the same office is available. As such 'quick checks' are not possible across doors and walls, the consequence of blocked visual access is that an individual may leave his or her own office only to discover that a colleague is absent or busy, with both alternatives deterring knowledge-search prospects (consistent with Archea's (1977) notion of inflection in gradients).

In addition, given visual access in the same office, an employee may use 'body language' (Nardi and Whittaker, 2002) to communicate with a colleague without engaging in a conversation. Even if the focal colleague is busy, the employee may still get his or her attention and signal a need to talk later at a very low cost. Therefore, visual access in one's own office implies lower search costs than the alternative of walking to another office.

Nevertheless, privacy related to visual access has been considered a paradox – while too much of privacy may be detrimental to collective behaviour, too little privacy (or too much transparency) may have the same effect (Bernstein, 2012)Indeed, in line with the Hawthorne

effect, employees exposed to others' visual fields may adjust their behaviours (Archea, 1977, 121). In other words, 'being seen' by others may prevent employees from engaging in certain types of interactions, such as informal chats. As this fear of 'being seen' is present for reaching out both within one's office and beyond it, we expect its effect on all types of social interactions to be constant.

Second, Ashkanasy, Ayoko and Jehn (2014, 1173) noted that:

> A collective of employees in an open-plan office environment may contribute to employee identification at the group level. For example, the opportunity for team members to work close to each other in an open-plan environment may help to build team identification. (1173)

Social interactions – 'values and norms that may together promote collective or team identification' (Ashkanasy et al., 2014, 1173) – contribute to such identification. These authors also propose that 'the physical environment provides employees who work together (e.g. in collaborative spaces) an opportunity to mark their workspaces with group awards, group certificates, and logos that display the group vision while communicating the group identity' (Ashkanasy, et al., 2014, 2273). Such an identity may drive employees' knowledge-sharing behaviour, with a tendency to favour within-group, rather than between-group, interactions.

In summary, Pfeffer (1982) argued that doors and walls have a significant effect on behaviour, as people do not walk through partitions or talk through walls. Archea (1977) seconded this idea, stating 'doors, walls, corners, and other places in the environment where new information first impinges on a situation will have special behavioural significance' (Archea, 1977, 121). Given the high search costs, lack of visibility, and difficulty of developing a shared

identity associated with physical barriers, we expect them to reduce the frequency of knowledge sharing, regardless of distance. Employees sharing the same office are not separated by doors and walls, but employees located in different offices are. Therefore, we posit:

H1: After controlling for physical distance, employees separated by physical barriers, such as doors and walls, have a lower frequency of knowledge sharing than employees who share an office.

Physical barriers, moderating factors, and knowledge sharing

The effects of doors and walls may impede social interaction in a workplace. Since knowledge sharing is generally a desired element of an organizational space, firms may want to know about ways to counter and possibly alleviate such impediments. Below we identified three different categories of factors that may possibly moderate the negative effects of doors and walls on knowledge sharing: types of tasks and responsibilities an employee has within the organization (individual-level characteristic of the focal employee), type of relationship between a pair of employees (dyadic characteristics) and finally characteristics of the environment (related to the focal employee).We review the three categories of moderators and further explore their interplay with the physical enclosure in the empirical section.

Extant research suggests that the behaviour of employees changes when their supervisors are present, as employees fear monitoring (Lecuona-Torras and Cummings, 2018) . This finding is in line with the fear of 'being seen' by others (Archea, 1977). However, some qualitative characteristics of employees' tasks and roles may confer legitimacy on social interactions, including interactions that involve leaving one's own office. We theorise that two types of job characteristics can circumvent the negative effect of physical barriers. First, being part of a task

force and coordinating across departments provide employees with reasons to reach out to colleagues outside their own departments. This is in line with Fayard and Weeks' (2007) argument on the importance of social designation, which provides 'legitimate rationalisations for people to stay and talk to each other' (625). Therefore, the negative effects of physical barriers may be offset in the case of employees involved in coordination across departments.

Second, a position with significant job autonomy matters in knowledge sharing behavior too. Job autonomy has been defined as one's discretion to schedule tasks and make decisions on the job (Morgeson & Humphrey, 2006).[3] It has been found to influence knowledge sharing in two ways: indirectly, through factors such as intrinsic motivation or organizational climate (Gagné et al., 2019; Llopis & Foss, 2016; Pee & Lee, 2015) and directly (Nesheim & Gressgård, 2014).[4] Job autonomy may thus drive rates of knowledge sharing higher, even in the presence of physical barriers.

Furthermore, traditionally the literature advanced strong positive spill overs of proximity and social relations so that localised, collocated individuals could form strong ties. Chown & Liu (2015) found that for average peers' location "structures" their access to peers' support, while Masket (2008) documented the existence of peer-effects based on location. Similarly, Lee (2019) found that effects of moving desks closer was the strongest for individuals with no prior ties, corroborating the positive effects of proximity on strong ties. strong ties, such as an ongoing work relationship, may influence patterns of knowledge sharing between individuals in the presence of physical barriers. This phenomenon has been documented by Casciaro and Lobo (2005), who

[3] Some research pointed to managers as individuals with specific knowledge sharing pattern, frequently acting acting as brokers (for a review see, Sergeeva and Andreeva 2016).

[4] Gagné et al. (2019) mentionned however one study" found that looked at job autonomy and knowledge hiding found no relation between them (Černe et al., 2017). Instead, this study found that a combination of job autonomy and a mastery climate decreased the negative effect of hiding on innovative work behavior" (p.787).

found that individuals searching for knowledge are mostly driven by the likeability, not the ability, of potential partners. Similar results were yielded in an empirical study of project outcomes where better results, rather than being attributed to proximity among firms, originated from the strength of ties (Ganesan et al., 2005).

Challenging the work on 'localised knowledge spill-overs', Lissoni and Breschi (2009) demonstrated that networks (i.e. social interactions among inventors) account for a larger part of knowledge diffusion than physical proximity.[5] On a related note, social ecology studies (Ebbesen et al., 1976) found that proximity may also drive disliking because of daily exposure to others' criticisable behaviour, absent in case of distance ties.

Building on this argument and on the importance of likeability in knowledge sharing, we expect strong ties in dyads to alleviate the negative effects of physical barriers on knowledge sharing.

Finally, as mentioned above, the physical context and its social designation play a role in individual behaviour. As Fayard and Weeks pointed out (2007):

> It is to say that only when we include social characteristics – routines concerning who uses what resource when – that shape traffic patterns in the office, for example, norms about social distance and interruption that govern polite behavior, and shared understandings about the behaviors designated as appropriate in the setting – can we understand what behaviors are afforded. (625)

[5] These authors noted that networks of inventors suffer from 'immobility'. In other words, inventors cluster in the same locations.

In Fayard and Weeks' (2007) study, photocopiers were found to 'afford' interactions in the form of individuals helping each other with operating them, negotiating access, or picking up or waiting for printouts – all of which were considered 'legitimate activities' (624). Even passers-by joined in and, as such, Fayard and Weeks (2007) termed the surrounding interactions 'social photocopying'. This is in line with the "passive contacts" and functional distance(Festinger, Schachter, Back, 1950) documented in a housing study. "Passive contacts" are "casual or involuntary meetings" (p.34) that may materialize because of some functional elements of the surroundings. The authors advanced that "factors such as design of a building or the positional relationships among a group of houses are also important determinants of which people will become friends" (p.35) and advanced that functional distance is measured by "the number of passive contacts that position and design encourages" (p.35). In the empirical analysis, the authors found support for an increased number of friendships closed by individuals located in specific part of the building, such as those living by stairways connecting different floors. [6]

In an organizational setting, passive contacts can be made by employees located in proximity of printrooms, we therefore expect that employees' location near a copy room to also alleviate the effects of barriers on individual behaviour. In other words, individuals located within the vicinity of a copy room should be more likely than others to search for knowledge outside of their own office. Such searches may occur randomly because these individuals hear a conversation and simply join in, make "passive contacts" or because the photocopier 'affords' social interactions and makes leaving one's office easier in the first place, as doing so is viewed as legitimate.

[6] The authors documented the well-known detrimental effect of physical distance on the likelihood of friendship formation too. They noted that the relationships between physical and functional distance is complex.

Methods

Research context, case selection, and data collection

The data collected for our main study originated from one firm – a global leader in diesel-engine production. One of the firm's core locations was Copenhagen, the capital of Denmark. We chose this case firm for three reasons. First, knowledge sharing was important for all of the company's employees, who were mostly engineers, as the firm designed, optimised, and serviced engines that were specific to each customer. Many of the services provided to customers were unique in the sense that they required different competences and solutions that were adapted to the specific customer and context, which implied that knowledge sharing across employees and offices was necessary. Second, the employees understood that such knowledge sharing was necessary and legitimate. Third, there were significant variations in distance and in assignments to offices among employees from various departments located in the five-floor building. On each floor, employees were divided into 10 to 15 offices separated by doors and walls. The variation in distance on each floor ranged from 0 to 100 meters. Some offices were located directly by printer rooms, while others were not. Moreover, this study context also had the advantage that some of the other distance dimensions highlighted in the literature, such as geographical and cultural distance, were ruled out by design, as all individuals were in the same location (i.e. the same building) and were only separated by doors, walls, and stairs.

We used a survey instrument – more specifically, a name generator (a common method in the social sciences) – to gather insights into knowledge-sharing behaviours. We also obtained access to detailed plans covering the physical layout of the building, including information on individuals' locations, which enabled us to measure the distance in employee dyads. Employees

were in open offices housing between 5 and 15 employees, and each employee enjoyed some private space. [7]

The different floors in the five-story building were largely allocated to specific functions (e.g. R&D on the fifth floor, engineering on the fourth floor), and employees with the same competences (e.g. IT engineers, quality engineers, or marine engineers) were located together. This non-random seat assignment should generate more knowledge sharing within an office simply because of the interdependence of the conducted tasks. However, a key reason for choosing this firm for our study was that, for most projects, the types of knowledge that were needed were scattered among various offices.

Nevertheless, non-random office assignments may bias our results. We attempted to alleviate this concern in several ways. In our observational study, we added several variables, such as departmental and function dummies, and the number of partners, which should partly control for the non-random office assignment. In addition, we ran several robustness checks, including simultaneous equations (2SLS) with instrumental variables and a model with multiple fixed-effects, in order to alleviate possible endogeneity related to the non-random office assignment.

We pre-tested the survey with various audiences (i.e. academic peers and employees) to ensure that the survey items could be easily understood. The survey was administered over the internet by the firm's representatives. We sent a total of 505 surveys and received 263 answers, giving a response rate of 41%. Due to missing information, we excluded 58 answers, leaving us

[7] The floor plans indicating the location of offices and other facilities on each floor are available upon request.

with a data set of 205 observations. We used dyads of two employees involved in knowledge sharing as our unit of analysis, and we had 796 usable dyads.

Of the 205 respondents, 78% were highly educated males holding a master diploma or higher. 84% of the respondents were in their thirties. With help of the firm's representatives, we compared the demographic characteristics of the non-respondents to those of the respondents. We did not find any significant differences between these two groups. In addition, we did not find differences in the key variables between early and late respondents in t-tests, which suggests that non-response bias is not an issue in our data.

In the survey, respondents were asked to name up to five colleagues located in the same office building with whom they shared knowledge on regular basis (i.e. a name generator). Of the 205 useable responses, 46% listed the maximum of five knowledge-sharing partners, 23% listed four, 15% listed three, 6% listed two, and 10% listed only one. The average number of self-reported partners was 3.88. As such, our dyadic data may not be independent (Broekel, Balland, Burger, van Oort, 2014) , as the same respondents self-reported themselves as part of various dyads. We address this issue in the empirical section (i.e. we add random effects for ego and alter).

Measures

Our dependent variable, *frequency of knowledge sharing,* is a count variable that captures how often an employee shares knowledge with colleagues located in the same office building. Similar measures have been used in other studies on knowledge sharing (Casciaro and Lobo, 2005)(Casciaro and Lobo, 2005). We measured this variable using a nine-point scale ranging from never (= 1) to many times each day (= 9). We obtained data on this frequency for all 796 knowledge-sharing dyads. For 18% of the dyads, knowledge sharing took place several times per

day, while it occurred once per day in 22% of the dyads and several times per week in 28% of the dyads. Knowledge sharing occurred once per month or less in less than 10% of the dyads. The variable indicates good variation in the frequency of knowledge sharing across the dyads.

The independent variable, *distance,* captures the walking distance between the two knowledge-sharing employees in the 796 dyads. This distance was measured as the shortest walking distance (in meters) from chair to chair. The building was designed to ensure that every employee, regardless of location, had a staircase nearby. In total, ten staircases and lifts linked the different floors. Therefore, the shortest walking distances mainly consisted of horizontal distances even when the employees were located on different floors (i.e. employees located in the same area on different floors scored low on distance). However, to separate the effect of different floors, we also controlled for vertical separation. Distance ranged from 0 to 100 meters, with an average of 20.5 meters and a standard deviation of 27.4. As such, the variable indicates good variation in distance across the dyads.

We added a dummy variable to capture whether the two employees in a dyad were in the same office. The variable, *different office*, took a value of 1 if the two employees were in different offices and 0 if they were in the same office (baseline category). In 44% of the dyads, the employees were in the same office.

We computed four additional, moderating variables that each capture a mechanism that may circumvent the negative effects of physical barriers. First, the type of relationship between colleagues in a dyad may affect their knowledge-sharing behaviour (Casciaro and Lobo, 2005) . For instance, friends are more likely to share knowledge, although that knowledge may be largely redundant. We therefore constructed the variable *tie strength* for each dyad to measure perceptions of closeness to the dyad partner rated on a seven-point scale, where 1 denoted

'distant' and 7 denoted 'very close' (Marsden, 1990; Marsden and Lin, 1982). The mean of *tie strength* is 4.1, which suggests a relatively high number of emotionally close dyads.

Second, *job autonomy* captures the extent to which respondents can perform their job-related tasks on their own. The respondents were asked to rate the extent to which they could 'conduct their work tasks on their own' using a scale from 1 (= very little) to 7 (= very much). The mean of 5.5 suggests that most respondents perceived their jobs as rather autonomous in the sense that they had the discretion to conduct tasks in the way they wanted.

Third, we created a construct covering the extent to which an individual was involved in *coordination* activities with other departments. The construct was based on three items capturing whether the individual was involved in 'fixed meetings', 'temporary task forces', or other 'planning activities' across departments (Cronbach's alpha = 0.74). All three items were measured on a seven-point scale ranging from rare (= 1) to very often (= 7), with an average of 3.5 and a high level of variation among the respondents.

Finally, we included a dummy for photocopier, which took a value of 1 for all individuals located in offices next to a printer room. According to Fayard and Weeks (2007), 'social photocopying' is a phenomenon. As such, the vicinity of a *printer room* may affect the employees' behaviour and social interactions. Of the respondents, 56% were located further away from a printer room, while 44% were located next to a printer room.

We then added numerous *control variables* to rule out confounding variables stemming from factors related to ability, motivation, and opportunity (Argote, McEvily, and Reagans, 2003; Reinholt, Pedersen, and Foss, 2011). Our controls included both dyad- and individual-level variables. The dyad-level variables reflect relationship-specific factors that may make the sharing

of knowledge more or less likely. They also capture opportunity-related factors. The individual-level variables capture individual-specific aspects of ability and motivation that may affect the propensity to share knowledge. As such, the control variables rule out confounding factors that may explain the frequency of knowledge sharing and the possibility that unobserved heterogeneity biases our results.

We included the standard individual demographic characteristics of age and education. *Age* is an ordinal variable with the following categories: 25 to 34, 35 to 44, 45 to 54, and 55 to 64, with assigned values of 1, 2, 3, and 4, respectively. There were 44 respondents in the first category, 73 in the second, 48 in the third, and 40 in the fourth. Therefore, most of the respondents were in their thirties. *Education* is an ordinal variable reflecting the level of education: high school or below (= 1), middle-range training (= 2), bachelor's degree (= 3), and master's degree or PhD (= 4). Ten respondents were in the first group, 35 in the second, 115 in the third, and 37 in the fourth. As such, most employees were highly educated.

We included the variable *motivation* because employees vary in their willingness and motivation to share knowledge (Gagné, Tian, Soo, Zhang, Ho, and Hosszu, 2019; Gagné and Deci, 2005). Motivation is either extrinsic or intrinsic (Gagné and Deci, 2005). If individuals adopt behavioural regulations or social norms, and if they value compliance with those regulations and norms, they are extrinsically motivated. In contrast, intrinsically motivated individuals engage in collaborative activities, such as knowledge, sharing without any other prerequisites solely because they identify with the social norms (Gagné and Deci, 2005) Both *intrinsic motivation* and *extrinsic motivation* are multi-item measures reflecting respondents' reasons for sharing knowledge, and they use seven-point scales ranging from 'strongly disagree' (= 1) to 'strongly agree' (= 7).

Opportunities to share knowledge have numerous dimensions, including the number of partners and vertical closeness. In this regard, respondents were asked to indicate how many work-related collaborations they had with *internal partners* in the company and *external partners* outside the company. Most respondents indicated that they collaborated with internal colleagues. The mean of internal partners was 16, while the average number of external partners was 7.3. We also controlled for the *vertical separation* of dyads. This count variable, which reflected the number of floors separating the two dyad members, ranged from 0 to 4.

As highlighted above, some dimensions of distance, such as geographical and cultural distance, are ruled out by the study's design. However, other dimensions of distance, such as belonging to different functions and departments (i.e. professional groups), remain. We therefore controlled for *function* – engineering, R&D, sales and marketing, and technical service. The extent of knowledge sharing might vary by function, as some roles (e.g. in R& D) may be required to reach out for knowledge to a greater extent. We also added 46 dummies for each *department* to control for specific effects related to different specialities and professional groups.

The level of interactions, especially face-to-face interactions, is also a function of the extent to which knowledge has been codified in written form so it can be shared in ways other than face-to-face interactions (Carlile, 2004; Tyre and von Hippel, 1997). We therefore measured *codified knowledge* using a seven-point scale denoting the extent to which the shared knowledge was codified and written in the form of reports, manuals, or emails. If the shared knowledge was not codified at all, then it took a value of 1, while it was assigned a value of 7 if it was highly codified.

Finally, we controlled for the gender of the focal individual sharing knowledge, with a *male* dummy taking a value of 1 for all male respondents in the sample (175 of the 205 respondents).

Table 1 provides a correlation matrix and descriptive statistics (including means and standard deviations) for all variables.

Insert Table 1 here

As expected, the independent variables – distance and different office – are both negatively correlated with the dependent variable of frequency of knowledge sharing. The correlation between these variables is positive (0.52), but not perfect, as it picks up different dimensions of the physical separation. Vertical separation is also negatively correlated with knowledge sharing and, as expected, correlated with different offices (0.67). The moderating variables display a common pattern – while they are negatively correlated with distance, the correlation with different office is positive for strength of ties, job autonomy, and coordination. The magnitude of the correlations among these items and with the independent variables is low. Of the moderators, strength of ties exhibits the strongest correlation with the dependent variable.

Self-reported measures have well-known weaknesses, but they remain a widely accepted way of capturing perceptions and behaviours among employees (Howard, 1994; Ng and Feldman, 2012). Nevertheless, we conducted several statistical tests to assess the severity of respondent biases. First, a Harman's one-factor test on the items indicated that common method bias was not an issue. Multiple factors were detected and the variance did not stem from the first factors (Podsakoff and Organ, 1986). The 14 variables included in the model on knowledge sharing form six factors with an eigenvalues greater than 1, and the first two factors capture 18%

and 13% of the total variance, respectively. Second, we ran a partial least squares (PLS) model, including a common method factor with items that encompassed all of the construct's items. Such PLS models provide information on each item's variance as substantively explained by the constructs and the common method factor. The average substantive variances explained by the constructs were all greater than 0.50, while the average method variance was around 0.01 for all items. The ratio of substantive variance to method variance was very high, leading us to believe that the data does not suffer from major respondent biases. While these tests do not eliminate the possibility of respondent biases, they suggest that our results are not predominantly driven by common method variance.

Results

Our data includes multiple dyads with egos (naming others) and alters (named by others), which results in non-independence among the dyads having the same ego or alter. This kind of clustering violates the independence assumption in our models and may reduce the size of the standard errors. To adjust the standard errors for clustering, we introduced a random effect for every ego and alter in our analysis. Furthermore, (two-way) random effects can control for potential unmeasured characteristics of egos and alters that could affect the outcome in terms of knowledge sharing. Therefore, we ran a multilevel – or 'nested' – model with random effects for egos and alters to alleviate the non-independence in our data (Gulati and Nickerson, 2008). We discuss other specifications, including alternative fixed effects (Correia, 2016), in the robustness section.

Insert Table 2 here

Table 2 presents the main findings for four models. The first model (M1) is the null model with the variance decomposition. The second model (M2) includes the *distance* variable and all control variables, while and the variable *different office* is added in the third model (M3). The full model (M4) includes all of the variables and the interactions of the moderators with *different office.*

The first model decomposes the variation in the frequency of knowledge sharing into three levels: ego, alter, and dyad. The dyad level is the residual when controlling for the ego and alter levels. The decomposition shows that 61.3% of the variance in knowledge sharing relates to the dyad level, 11.3% relates to the alter level, and 27.4% relates to the ego level. As such, a significant part of the variation in knowledge sharing can be attributed to all three levels. Our hypothesis on the effects of distance, doors, and walls relates mostly to dyad-level variation, which is primarily what we explain in the following.

The second model (M2) includes all control variables and the first independent variable – *distance*. As expected, distance is negative with a highly significant parameter ($\beta = -0.01$, $p = 0.002$), which confirms that increasing distance decreases knowledge sharing. Of the control variables, *codified knowledge* is positively correlated with the frequency of knowledge sharing, while *vertical separation* and *extrinsic motivation* negatively affect knowledge sharing.

In the third model (M3), the other independent variable – *different office* – is added to the equation. In that model, the separation in the dyad is split into two elements: physical distance (*distance*) and physical barriers in terms of walls and doors (*different office*). As expected, being in a different office negatively affects knowledge sharing, even when controlling for distance. Moreover, the significance of distance disappears when location in a different office is added.

This indicates that the negative effects of distance are largely a reflection of separation by doors and walls.

The key element of our results is not that the relationships among knowledge sharing, distance, and separation into different offices are significantly negative. This finding is expected, as employees are located near others with similar competences from the outset. The significance of the results lies in the fact that not only distance, but also physical barriers reduce social interactions. This implies that to promote knowledge sharing, one should focus on physical barriers, like walls and doors, rather than on distance when designing office spaces.

In the final model (M4), the main effects of physical barriers and distance are in line with results from Model 3. This model also includes the four moderators of our main hypothesised relationship (i.e. the mechanisms that moderate the negative effect of physical barriers). The four moderators – *coordination*, *printer room*, *tie strength*, and *job autonomy* – are added as main effects and interact with the *different office* variable (reflecting the physical barriers). Two of these moderators are significant alone *(tie strength, job autonomy)*, while the other two are not. Nevertheless, the coefficients of all interaction terms (moderators with the independent variable *different office*) are significant and have the expected positive signs. When running the model with standardised variables, we find that the positive moderating effect is slightly higher for job autonomy (0.11) and coordination (0.10) than for printer room (0.09) and tie strengths (0.08). However, the total effect on knowledge sharing is most positive for tie strength, as it has a significant, positive main effect.

These results remain consistent when each of the four moderators is added one by one. The results clearly indicate that while physical barriers hinder knowledge sharing, the negative effects can be avoided in cases where the employee: 1) is involved in coordination across

departments; 2) is located in an office next to a printer room; 3) has strong ties within the organisation; or 4) has substantial autonomy in solving the job tasks. Strikingly, the model (M4) explains 41.5% of the variation in knowledge sharing (1.475 - 0.863/1.475 * 100) that can be attributed to the dyad level. This can be further disaggregated in the sense that 16% of the dyad variation in knowledge sharing is related to physical barriers (the increased explanatory power from M2 to M3), while another 16% can be attributed to the four moderating variables (the reduction in residual variance at the dyad level from M3 to M4).

We are aware of the so-called "bad control" issue (Angrist and Pischke 2008). Such issue arises when including a variable that can simultaneously be used either as an outcome (first scenario) or are themselves affected by a variable of interest (second scenario- proxy controls). In particular however, the strength of relationships may be problematic here while we have made robustness tests excluding this moderator. More importantly we cannot entirely rule out that some of the relationships were precisely formed because of lack of physical barriers. Although it is theoretically unlikely that the lack of physical barriers is determining the location of print rooms, communication mechanism between offices and individual job-autonomy we are still conducting robustness checks with all combinations of interactions effects.

Robustness Tests

We ran several tests to ensure that our results are robust. More specifically, we ran the following alternative models: 1) a model with fixed-effects rather than random effects; 2) a model that only included observations for employees located on the same floor; and 3) a model with instrumented variables. These alternative models, which are based on M3 in Table 2, are presented in Table 3 as M5-M7.

Insert Table 3 here

The first model (M5) only included dyads that were located on the same floor (N = 535). This model tests whether our results are conflated by the separation of the dyads across different floors. The results we obtain in M5 are similar to those obtained for M3, including a significantly negative coefficient of *different office*.

The second model (M6) is the fixed effects model (Correia, 2016; Correia, Guimarães, and Zylkin, 2020). We ran the same model (M3) as an OLS model with ego-level and actor-level fixed effects (rather than the random effects in our main model). This excludes many of the explanatory variables that do not vary on the ego and/or actor level. However, our hypothesised variables in this model display same signs. In particular, *different office* is significantly negative.

Finally, we ran a two-stage model (2SLS) with instrument variables (M7). This model controls for the non-random assignment of employee seating. For instance, employees meant to work closely together in teams may be purposely seated in the same office, which will naturally increase their level of interaction and reduce their need to reach out to others. We aimed to rule out endogeneity originating from the non-random office assignment, which might imply that the frequency of knowledge sharing as well as distance and location in different offices are endogenously determined. More specifically, we used instrumental variables in the first-stage equation for all three variables. The instruments, which are indicated in Table 3, Model 7, are structural variables related to: function (4 dummies), department (46 dummies), number of internal and external partners, and the nature of the knowledge exchanged. These instruments satisfy both the relevancy and exclusion restrictions, as they explain a substantial part of the variation in distance (22%) and location in different offices (27%) – confirmed in an F-test (3.19, p=0.0001), but are only marginally related to the frequency of knowledge sharing (4%). In Table

3, M7 is the second-stage equation. Our key result of *different office* being significant and negative holds. Furthermore, to test for overidentifying restrictions, we regress the residual from the knowledge sharing equation on the instruments for the model (the Basmann test) and this test also led us to reject the hypothesis of a significant relationship between instruments and residuals ($F = 0.78$, $p = .67$), which is a quite strong result considering the size of our sample, which directly scales the test statistic. In addition, the R-squared value in this regression is very low (.0045), and none of the predictors are statistically significant. We also inspected the bivariate correlations between instruments and residuals, all of which were insignificant and close to 0. In combination, these tests do not provide absolute proof of the absence of endogeneity, but they do suggest that the problem has been addressed in our model.[8]

Discussion and Conclusion

This paper's starting point was that multiple studies, starting with Allen (1977), show that even short distances between individuals hamper knowledge sharing. However, regardless of distance, physical barriers separate employees as well. Consequently, we asked whether these physical barriers matter when controlling for distance. In addition, we explored moderating mechanisms for the hypothesised negative relationship between physical barriers and knowledge sharing.

[8] We also designed a randomized online survey to address the same concern, but we do not cover this aspect in this paper due to space restrictions. When participants were presented with a choice of whom to contact in a knowledge search (i.e. a colleague within or outside one's own office), distance and the other factors remained constant. In an additional check, we included an option to visit a social space outside of the focal office. This represents a first phase in knowledge sharing and does not entirely map on the dependent variable used in the observational study. However, the latter is conditional on the former (for phases in knowledge sharing, see Hansen et al. (2005). The respondents predominantly opted to reach out in their own office, although the choice was moderated by the presence of social spot just outside the office. This offers additional support for our main hypothesis and one of the moderators.

Our study extends the extant literature on distance and knowledge sharing (Kabo, Cotton-Nessler, Hwang, Levenstein, and Owen-Smith, 2014; Monge, Rothman, Eisenberg, Miller, and Kirste, 1985). While the effects of distance have been well documented, this study provides insights into and documents a persistent pattern of decreasing knowledge-sharing behaviour in the presence of physical barriers. In this regard, we contribute to what has been termed 'micro-geography' (Liu and Marx, 2020).

Our observational study indicates that barriers in the form of walls and doors matter, regardless of distance. We found this result to be robust in multiple additional tests, and we corroborated the empirical regularity through the use of a randomised survey. The implication is that in order to understand how the physical environment affects knowledge sharing, it is not enough to focus on distance alone, as other physical barriers seem to be more important. We explored several moderators that alleviate the effects of physical barriers of knowledge sharing: strong ties, job characteristics, and location in an office by a printer room. We believe this exploratory part of the paper is to be taken with caution, but simultaneously we propose that scholars study moderators or physical barriers in detail. In particular the complex relationship between tie strengths and proximity, for instance, the extent to which the proximity may engender disliking and the process itself are fruitful areas of future research. Also, the interaction of job autonomy and knowledge sharing could be interesting, in particular in distributed, virtual teams, context qualitatively different from ours.

The implication of our study for the promotion of knowledge sharing is that one must carefully rethink the organization of physical environments in firms. This is in line with 'situational' learning research (Tyre and von Hippel, 1997), which suggests that the physical setting is an important element in the learning process. To further increase the rate of social

interactions and the frequency of knowledge sharing, managers may consider experimenting with different physical designs involving, for example, glass walls, dividers, or movable and temporary walls. This includes considering solutions that ensure visibility among members of the same team while simultaneously conferring privacy. Strategically located shared areas, such as printer rooms, can enhance knowledge sharing.

Moreover, as noted by Fayard and Weeks (2007), the physical environment should not be considered separately from organisational practices and routines or social designation. Our findings indicate that job autonomy and being part of coordination structures alleviate the effects of barriers. This points to the importance of social designation and the legitimacy of knowledge sharing. Organisations should therefore work to emphasise the legitimacy of knowledge sharing and design spaces that support such behaviour by, for instance, equally distributing lounges, watercoolers, and printer rooms.

We propose several avenues for future research. The question of whether the promotion of social ties through corporate meetings, events, or other interventions (Donnelly, 2019) in managerial discretion and organisational design are substitutes or complements remains open and a potentially interesting extension of our study. As much as proximity and physical space matter for interactions, temporal proximity (Baruffaldi and Poege, 2020; Chai and Freeman, 2019; Lavoratori et al., 2020; Torre and Rallet, 2005)may prove to be a valid substitute, and may be fruitfully considered in knowledge-intensive sectors. Future research could also tackle the types of tools (e.g. regular get-togethers, informal hours) that are most efficient. In addition, we suggest that scholars investigate whether our results are replicable in other contexts, such as less-knowledge-intensive industries or environments with different office designs. Similarly, scholars can compare the search for knowledge in purely professional contexts with the search for

knowledge in other contexts, such as those characterised by friendship ties. Another consideration may be the introduction of flexible work practices, where the concepts of work and home spaces are blurred (Richardson and Mckenna, 2014). Scholars could also use different research designs, such as comparative case studies, to further explore key mechanisms (e.g. employees' in-group biases) as a function of organisational culture. Moreover, although our study focuses on physical barriers, the nature of those barriers and the contingent behavioural effects remain understudied. We therefore suggest that future research should distinguish among different types of barriers (e.g. glass versus traditional brick enclosures or types of doors) to nuance our findings. On a related note, even the structure and design of the printer room itself may matter. Therefore, comparative studies may also address different designs of such spaces.

In addition, personality traits and preferences may drive knowledge sharing. For instance, being more explorative in nature (Mom, van Neerijnen, Reinmoeller, and Verwaal, 2007) may make individuals more likely to search for knowledge outside of their own offices. We suggest future research address the role of such traits.

Finally, our study focuses on dyads in which knowledge sharing materialised. Future comparative research could study the effects of barriers on the extensive margin – that is, the likelihood of knowledge sharing rather than its frequency.

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Table 1 Descriptive statistics and correlation matrix, all values > |0.07| are significant at the 5% level

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1) (1) Frequency of knowledge sharing	1.00													
(2) Distance	-0.32	1.00												
(3) Different office	-0.47	0.52	1.00											
4) (4) External partners	0.04	0.10	0.14	1.00										
5) (5) Internal partners	0.01	0.11	0.15	0.39	1.00									
6) (6) Vertical separation	-0.37	0.39	0.67	0.13	0.15	1.00								
7) (7) Codified knowledge	0.01	0.07	0.13	0.25	0.24	0.09	1.00							
8) (8) Intrinsic motivation	0.07	0.06	-0.02	0.10	0.16	-0.01	0.04	1.00						
9) (9) Extrinsic motivation	-0.02	-0.01	-0.03	-0.03	-0.02	-0.07	0.01	-0.11	1.00					
10) (10) Gender	-0.06	-0.01	0.02	0.14	0.03	0.07	0.15	-0.07	0.04	1.00				
11) (11) Coordination	0.06	-0.01	0.05	-0.05	-0.03	-0.01	0.11	0.01	0.06	0.07	1.00			
12) (12) Printer room	0.01	0.05	0.02	0.06	0.09	-0.03	-0.05	0.13	-0.02	-0.09	-0.16	1.00		
13) (13) Tie strength	0.23	-0.08	0.18	0.12	0.18	-0.16	0.16	0.10	0.01	-0.05	0.07	0.03	1.00	
14) (14) Job autonomy	0.05	-0.01	0.04	-0.05	-0.04	-0.03	0.07	-0.02	0.01	0.02	-0.06	0.11	-0.04	1.00
Mean	6.96	20.5	0.44	7.26	16.0	0.56	4.26	5.88	3.44	0.85	3.49	0.44	4.15	5.52
Std. Dev.	156	27.4	0.50	8.77	7.76	0.96	1.56	1.11	1.76	0.36	1.31	0.50	1.45	1.42
Minimum	1	0	0	0	1	0	1	1	1	0	1	0	0	1
Maximum	9	100	1	25	25	4	7	9	9	1	7	1	7	7

Table 2 Frequency of knowledge sharing: nested model, n = 796

Dependent variable Frequency of knowledge sharing	Null model	Hypotheses models		Moderating model
	M1	M2	M3	M4
Intercept	6.990***	8.204***	6.587***	4.354***
	(.08)	(.65)	(.66)	(.82)
Independent variables				
- Distance		-0.010***	-0.002	-0.001
		(.001)	(.002)	(.002)
- Different office			-1.571***	-3.175***
			(.15)	(.50)
Controls				
Relationship level				
- External partners		0.010	0.012	0.013
		(.01)	(.01)	(.01)
- Internal partners		0.003	0.002	-0.012
		(.01)	(.01)	(.01)
- Vertical separation		-0.526***	-0.152*	-0.126*
		(.06)	(.06)	(.06)
- Codified knowledge		0.103*	0.128**	0.065
		(.05)	(.05)	(.04)
- Function (4 dummies)		Yes	Yes	Yes
- Departmental dummies (46 dummies)		Yes	Yes	Yes
Motivation				
- Intrinsic		0.032	0.019	0.067
		(.07)	(.06)	(.06)
- Extrinsic		-0.090*	-0.067	-0.077*
		(.04)	(.04)	(.04)
Individual heterogeneity				
- Age		Yes	Yes	Yes
- Education		Yes	Yes	Yes
- Gender		0.376	0.422*	0.375*
		(.20)	(.21)	(.19)
Moderators variables				
- Coordination				0.006
				(.07)
- Coordination * different office				0.135*
				(.06)
- Printer room				0.025
				(.54)
- Printer room * different office				0.356*
				(.18)
- Tie strengths				0.441***
				(.05)
- Tie strengths * different office				0.112*
				(.05)
- Job autonomy				0.173**
				(.06)
- Job autonomy * different office				0.152**
				(0.06)

Residual variance				
- Ego level	0.659***	0.360***	0.348***	0.316***
	(.11)	(.07)	(.07)	(.06)
- Alter level	0.273***	0.179**	0.158**	0.108*
	(.08)	(.07)	(.06)	(.05)
- Dyad level	1.475***	1.222***	1.029***	0.863***
	(.11)	(.09)	(.08)	(.07)
Model fit				
- 2 Log Likelihood	2853	2605	2503	2359
- AIC	2861	2689	2589	2433

Standard errors in parentheses. *** P < 0.01, ** p < 0.05, * p < 0.1.

Table 3 Robustness tests

Dependent variable Frequency of knowledge sharing	Same-floor model (HLM)	Fixed effects model (OLS)	Instrumental variables model (2SLS)
	M5	M6	M7
Intercept	6.411***	6.134***	7.581***
	(.81)	(.63)	(.41)
Independent variables			
- Distance	0.004	-0.001	-0.011
	(.004)	(.002)	(.007)
- Different office	-1.485***	-2.953***	-0.742**
	(.25)	(.57)	(.33)
Controls			
Relationship level			
- External partners	0.001		Instrument
	(.01)		
- Internal partners	-0.001		Instrument
	(.01)		
- Vertical separation	n.a.	-0.135***	-0.367***
		(.06)	(.05)
- Codified knowledge	0.151**		Instrument
	(.05)		
- Function (4 dummies)	Yes	Yes	Instrument
- Departmental dummies (46 dummies)	Yes	Yes	Instrument
Motivation			
- Intrinsic	0.001		0.094*
	(.07)		(.05)
- Extrinsic	-0.082		-0.051
	(.05)		(.03)
Individual heterogeneity			
- Age	Yes		Yes
- Education	Yes		Yes
- Gender	0.686**		-0.179
	(.24)		(.14)
Model fit			
- 2 Log Likelihood	1640		
- AIC	1720		
- F-value		6.47***	22.90***
- R-squared		0.71	0.25
N			
	535	796	796

Standard errors in parentheses. *** P < 0.01, ** p < 0.05, * p < 0.1.